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The Economics of Petroleum Refining

Understanding the business of processing crude oil into fuels and other value added products



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Only publicly available information was used in the creation of this report. Canadian Fuels assumes full responsibility for the document's contents.



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About the Canadian Fuels Association

Canadian Fuels is an association of major companies that produce, distribute and market transportation fuels and other petroleum products in Canada.

The sector operates through an infrastructure that employs 100,000 Canadians. This infrastructure includes 18 refineries in eight provinces, and a complex network of 21 primary distribution terminals, 50 regional terminals and some 12,000 retail service stations.

Petroleum fuels supply 95 per cent of Canada's transportation fuel needs.

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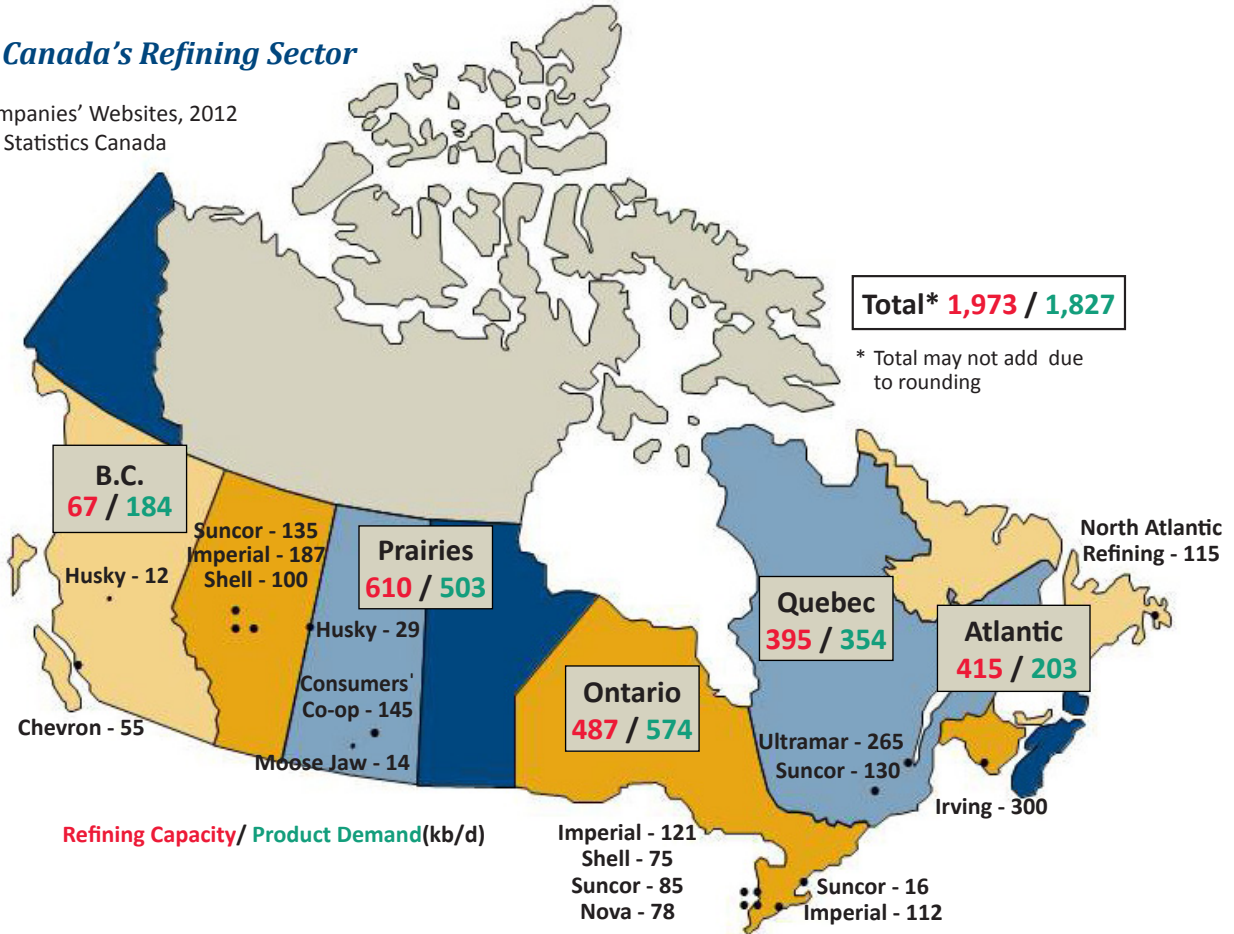
I. Introduction

Fuels refining is an integral component of Canada's oil and gas value chain. Refineries are the crucial manufacturing intermediary between crude oil and refined products. Canada has 18 refineries located in eight provinces with a total

capacity to refine 2 million barrels per day (bpd). They contribute \$2.5 billion in direct GDP and employ 17,500 Canadians. Annual capital investment averaged \$2.8 billionⁱ between 2005 and 2009, with an average rate of return of 11.6 percent over the same period.

Figure 1: Canada's Refining Sector

Source: Companies' Websites, 2012
NRCan and Statistics Canada

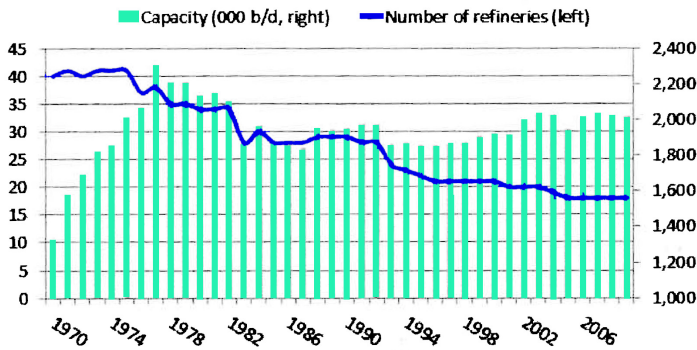


• Number of operating refineries, 2009	18*	• Average rate of return, 2005–09 (per cent)	11.6
• Annual output, 2009 (2002 \$ millions)	2,500	• Average annual investment, 2005–09 (2002 \$ millions)	2,800
• Refining employment, 2009	17,500	• Total production, 2009 (barrels per day, 000s)	1,970
• Gasoline retail employment, 2009	82,000	• Total exports, 2009 (barrels per day, 000s)	420
• Refining industry's share of Canada's manufacturing (per cent)	1.6	<i>Sources: The Conference Board of Canada; Statistics Canada; MJ Ervin & Associates.</i>	

* Plus one asphalt plant.

Figure 2: Number of refineries and Total Capacity, 1970 - 2009

Industry Rationalization Has Not Affected Refining Capacity



The industry has undergone important structural changes in recent years. Since 1970, more than 20 refineries have closed, while others have expanded their capacity to increase efficiency and remain competitive. And while no new refinery has been built in Canada for nearly 30 years* (the last was built in 1984), total Canadian refining capacity has remained at or near 2 million bpd, despite the many refinery closures.

Current Canadian refining capacity exceeds domestic demand. Canada is a net exporter of refined products. Most exports are destined for United States markets.

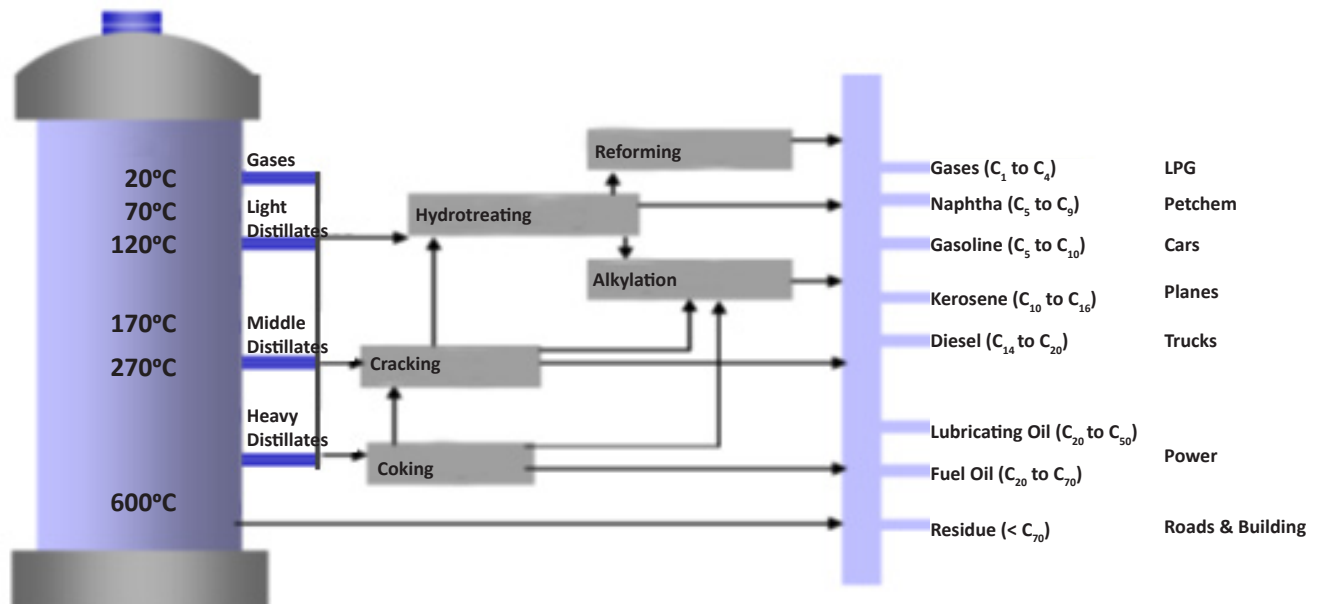
While no two refineries are identical, they all share a number of common features and processes, and use similar state-of-the-art technologies. Refineries process crude oils, which have different types of hydrocarbons with carbon chains of different lengths, into a broad range of refined products. The refining process separates, breaks, reshapes and recombines the molecules of crude oil into value-added products such as gasoline, diesel and aviation fuel.

These essential transportation fuels typically account for 75 percent of output. The remaining 25 percent comprise home heating oil, lubricants, heavy fuel oil, asphalt for roads and feedstocks that the petrochemical industry transforms into hundreds of consumer goods and products that Canadians use and rely on every day—from plastics to textiles to pharmaceutical products.

Refinery processing units perform four functions:

- *separation* of the different types of hydrocarbons contained in the feedstocks;
- *conversion* of separated hydrocarbons into more desirable or higher-value products;
- *treatment* of the products to remove unwanted elements and contaminants such as sulphur, nitrogen and metals; and
- *blending* of various hydrocarbon streams to create specific products that comply with quality standards and regulations.

Figure 3: Typical Refinery Process Flow Chart (Herrmann et al., 2010)



* North West Redwater Partnership broke ground on the first phase, 50,000 bpd, of a 150,000 bpd bitumen refinery near Edmonton in September 2013.

Changing patterns in fuel demand, the trends to processing heavier crudes and increasing refinery complexity, and the growing globalization and trade in refined fuels, have introduced new dynamics to the economics of refining, and have shifted the drivers of refinery profitability.

Within North America, recent demand for refined petroleum products has been flat to declining and is forecast to continue on this path. This is true in virtually all OECD nations. Growing refining overcapacity has resulted in recent refinery closures in eastern Canada and the US Eastern seaboard, as well as in Europe and the Caribbean. At the same time, nearly 1 million bpd of new high complexity refining capacity has been added in the United States Gulf Coast.ⁱⁱ

Meanwhile, Canada's upstream crude oil industry is growing. Surging oil sands production is projected to more than double Canada's crude output between now and 2030.ⁱⁱⁱ Most Canadian crude is landlocked and existing crude pipeline infrastructure is now at or near capacity. New pipeline proposals that would provide market access to Canada's growing crude oil supply are currently the subject of intense debate and scrutiny.

This debate over finding new markets for Canada's growing crude supply carries over into the refining sector. Some Canadians suggest, indeed expect, that with increasing crude production, Canada's refining capacity should also grow. They ask why aren't we refining more of our oil in Canada, and could we not get more value from our petroleum resources from more value added activity – i.e. refining?

The purpose of this document is to contribute to informed answers to these questions; to provide insight into the economics of the refining business; and to describe the factors that influence investment decisions and determine refinery profitability.

II. Basic Refinery Economics

In many businesses, profits or losses result primarily from the difference between the cost of inputs and the price of outputs. In order to have a competitive edge, a business must make higher-value products using lower-cost inputs than competitors. In the oil refining business, the cost of inputs (crude oil) and the price of outputs (refined products) are both highly volatile, influenced by global, regional, and local supply and demand changes. Refineries must find the sweet spot against a backdrop of changing environmental regula-

tion, changing demand patterns and increased global competition among refiners in order to be profitable.

New Builds vs. Upgrades

Oil refining is a capital-intensive business. Planning, designing, permitting and building a new medium-sized refinery is a 5-7 year process, and costs \$7-10 billion, not counting acquiring the land. The cost varies depending on the location (which determines land and construction costs[†]), the type of crude to be processed and the range of outputs (both of the latter affect the configuration and complexity of the refinery), the size of the plant and local environmental regulations. The cost of the now shelved project by Irving Oil to build a second 300,000 bpd refinery in Saint John, NB was estimated at \$8+ billion. The projected cost of the proposed 550,000 bpd Kitimat Clean refinery is \$13 billion. The first 50,000 bpd phase of the new North West Redwater Partnership 150,000 bpd bitumen refinery near Edmonton, AB, Canada's first new refinery in 30 years, has an estimated cost of \$5.7 billion. Adding new capacity or complexity to an existing refinery is also expensive. The recent 45,000 bpd expansion of the Consumers Co-op refinery in Regina, SK cost \$2.7 billion.

After the refinery is built, it is expensive to operate. Fixed costs include personnel, maintenance, insurance, administration and depreciation. Variable costs include crude feedstock, chemicals and additives, catalysts, maintenance, utilities and purchased energy (such as natural gas and electricity). To be economically viable, the refinery must keep operating costs such as energy, labour and maintenance to a minimum. Like most other commodity processors (such as food, lumber and metals), oil refiners are *price takers*: in setting their individual prices, they adapt to market prices.[‡]

This is particularly true for Canadian refineries that operate and compete in an integrated North American market. They "take" wholesale prices that reflect trading activity on markets like the New York Mercantile Exchange (NYMEX). When commodity trading causes US wholesale prices to rise, Canadian wholesale prices rise to ensure the product remains in Canada. Otherwise, US buyers would purchase lower-priced Canadian fuel, leaving Canada in short supply. Conversely, when US wholesale prices decline, so too do Canadian prices. If not, Canadian retailers would buy cheaper, wholesale fuel from the US. Therefore, the prices of the products that are sold in Canada are influenced by the vagaries of the exchange rate and supply and demand in the US.

[†] For example, building a comparable project on the United States Gulf Coast costs less than half of what it does to erect a plant in Alberta according to IHS CERA.

[‡] Persistently low profitability may reduce investment in refineries, which could ultimately constrain domestic/regional capacity and result in higher product prices. Low profitability also puts pressure on refiners to reduce operating and fixed costs while foreign supplies are almost always an actual or feasible option. These realities, however, are also present in other price-taker industries.

Figure 4: Refinery Value Drivers (Source: Lewe et al.)

Input	Crude fungibility <ul style="list-style-type: none"> Local or regional balances Pipeline or imports by ship Multiple asset optimization 	Trading and hedging <ul style="list-style-type: none"> Feedstock Products Currency 	Energy imports <ul style="list-style-type: none"> Electricity Steam 	Blending components <ul style="list-style-type: none"> Gasoline Biofuel Gas to liquids
Asset-related	Scale and technology <ul style="list-style-type: none"> World-scale or sub-scale Distillation and conversion Technology 	Fiscal and regulatory regime <ul style="list-style-type: none"> Tax Regulation Environment 	Supply chain management <ul style="list-style-type: none"> Location Logistics infrastructure Working capital optimization 	Slate flexibility <ul style="list-style-type: none"> Dedication of technology Ability to change baskets Operational flexibility
Output	Fuel and energy <ul style="list-style-type: none"> Merchant only versus retail Export versus local sales 	Specialties <ul style="list-style-type: none"> Specialist markets (marine, aviation, asphalt) with dedicated assets Brand quality 	Petrochemicals <ul style="list-style-type: none"> Which value chain Joint venture or sole ownership Export versus local sales 	Lubricants <ul style="list-style-type: none"> Base oil plant Blending plant and storage

Cost of Inputs vs. Price of Outputs

Since refineries have little or no influence over the price of their input or their output, they must rely on operational efficiency for their competitive edge. Efficiency is measured by the ratio of output to inputs, and increases through constant innovation, upgrading and optimization to produce more outputs from fewer inputs—in other words, the refinery’s capacity to maximize the difference between the cost of the crude oil and the price received for its refined products (the refinery’s gross margin). Examples include:

- selecting appropriate crudes to fulfill anticipated product demand;
- increasing the amount and value of product processed from the crude oil;
- reducing down-time for maintenance, repair and investment;
- developing valuable by-products or production inputs out of materials that are typically discarded;
- operating at a high utilization rate (see Operational Efficiency) when margins are high and, conversely, reducing production and buying product from third parties when margins are low.

Because refining is caught between the volatile market segments of cost and price, it is exposed to significant risks. As Herrman observed, refining is “low return, low growth, capital intensive, politically sensitive and environmentally uncertain.”^{iv} A refinery will close if it cannot sustain its

^v Generally, they move in lockstep over longer periods.

profitability, as they have in Dartmouth, Montreal and Oakville since 2005. Overall, more than 20 refineries have closed in Canada since 1970, a reflection of the shift to larger, more complex refineries and flat to declining demand.

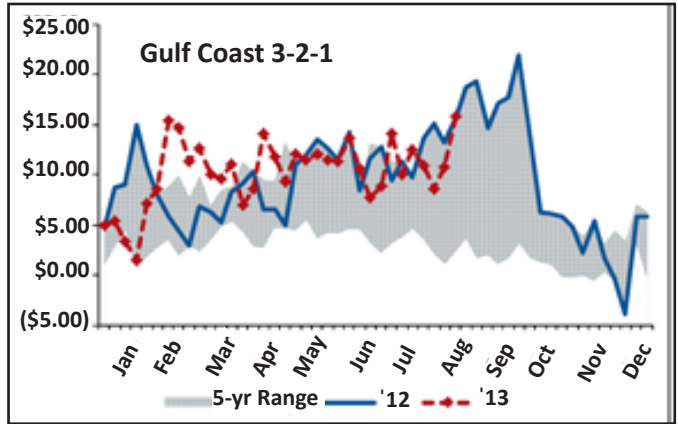
“Crack” Spreads

The term “crack” comes from how a refinery makes money by breaking (or ‘cracking’) the long chain of hydrocarbons that make up crude oil into shorter-chain petroleum products. The crack *spread*, therefore, is the difference between crude oil prices and wholesale petroleum product prices (mostly gasoline and distillate fuels). Like most manufacturers, a refinery straddles the raw materials it buys and the finished products it sells. In the case of oil refining, both prices can fluctuate independently for short periods due to supply, demand, transportation and other factors.^v In 2008, for example, crude oil prices spiked almost 20 percent higher than the price of refined petroleum products. Since then, crude oil prices fell by nearly half, but prices for refined petroleum products are near their 2008 highs. Such short-term volatility puts refiners at considerable risk when the price of one or the other rises or falls, narrowing profit margins and squeezing the crack spread. The crack spread is a good approximation of the margin a refinery earns. Crack spreads are negative if the price of refined products falls below that of crude oil.

A major determinant of a crack spread is the ratio of how much crude oil is processed into different refined petroleum products, because each type of crude more easily yields a

different product, and each product has a different value. Some crude inherently produces more diesel or gasoline due to its composition. These ratios and product combinations vary by region. The most common ratio in the US is three barrels of crude to produce two barrels of gasoline and one barrel of middle distillates (or 3:2:1). In Europe (which includes the Atlantic Basin covering Eastern Canadian refineries), a 6:3:2:1 ratio is the most common (six barrels of crude produce three barrels of gasoline, two of distillates (diesel) and one of residual fuel). As shown below (Figure 5) the 5-year range for the 3-2-1 and 6-3-2-1 crack spreads averaged between \$5 and \$10 per barrel, or approximately five cents per litre, despite wide fluctuations in the price of crude. Although some analysts are quick to point out that spreads can exceed \$20 per barrel, historical data also shows they can be negative under certain market conditions. This demonstrates the level of financial risks that a refiner must be prepared to manage over a long-term horizon.

Figure 5: Historical Crack Spreads



III. The Determinants of Profitability

To the casual observer, all refineries appear to be the same. In reality, each refinery is a unique and complex industrial facility, with some flexibility in the crude oils it can process and the mix of products it can refine. Each refinery constantly weighs a number of factors, including the type and amount of crude oil to process and the conditions under which various conversion units operate. However, there are limits to how flexible a refinery can be. The configuration and complexity of each facility determines the types of crude oil it can process and the products it can produce. Location and transportation infrastructure further limit the degree to which a refinery can access various types of crude and other supplies. These factors impact energy and labour costs, as well as regulatory constraints and compliance costs. As illustrated in Figure 6 below, individual factors can boost or reduce the average crack spread of a refiner by up to \$4 per barrel. Configuration, crude diet and location relative to markets can have the biggest impact. Combined, these factors could change profitability by nearly \$ 10 per barrel.

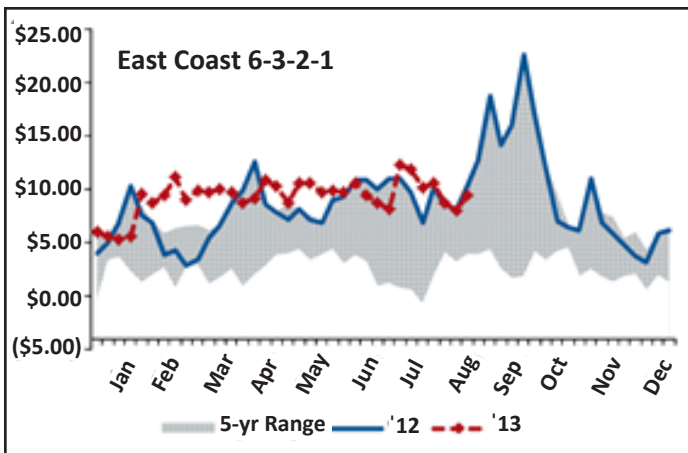
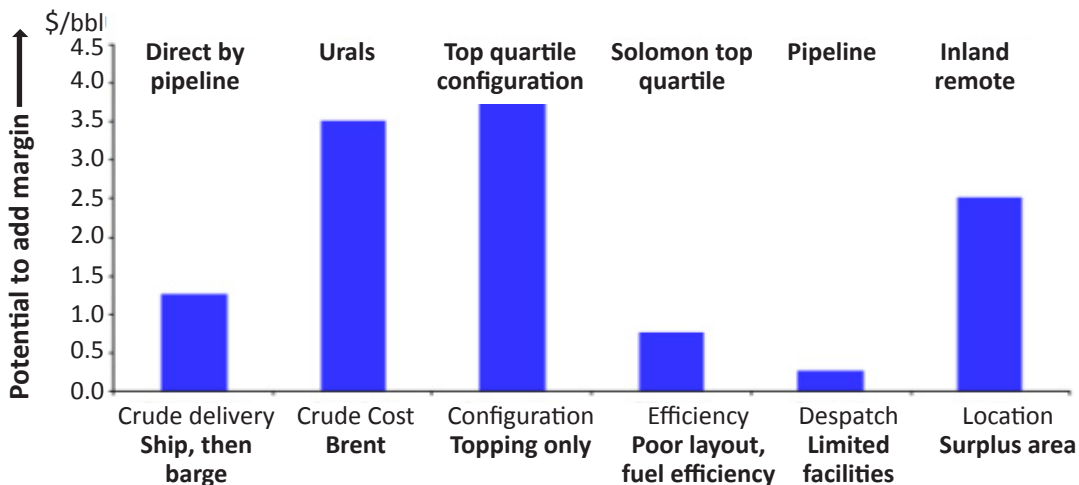


Figure 6: Relative Impact of Factors on a Refiner's Net Margins (Source: Herrmann et al. 2010)



Type of Crude

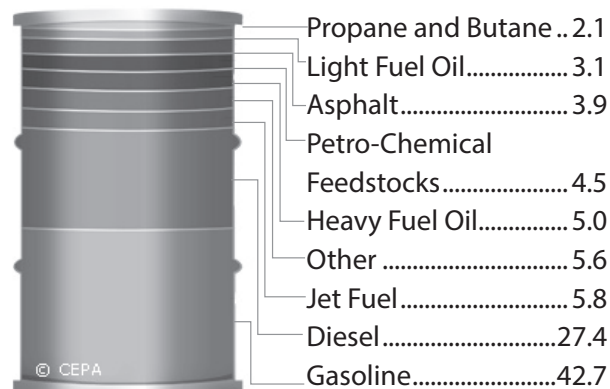
There are more than 150 different types of crude oil in the world. The basic choice of which crude to refine is between lighter and heavier grades. Heavy grades have a higher proportion of heavier hydrocarbons composed of longer carbon chains. Heavy crude oils are cheaper and increasingly plentiful, but more expensive to refine since they require significant investments and have higher processing costs (higher energy inputs and additional processing to meet environmental requirements). Lighter grades require less upgrading at the refinery, but are in decreasing supply. Lighter oils tend to have a lower sulfur content, which makes them ‘sweeter.’ Oils with a higher sulfur content are called ‘sour.’

Crude oil markets have long compensated for the differences in quality between light and heavy crude oils by paying a premium for lighter grades—sometimes significantly more (the “light-heavy price spread”). However, this light-heavy spread does not fully compensate for the lower cost of refining lighter crude. Since the cost of crude oil is a refinery’s largest input cost, processing cheaper heavy crude into higher-value lighter products usually improves profit margins—if the refinery has the configuration to do that.

Cost is not the only reason to choose a particular grade of crude oil. Each grade of crude yields a different array of refined products, each of which has a different price that also varies by region. A “netback” value expresses the worth of each type of crude in terms of the value of the products it makes. Demand from refineries also affects the price differential for different grades of crude. If the crack spread is low, refineries are reluctant to invest in upgrades to process heavier crudes. This dampens demand for heavy crude, and keeps the price difference between light and heavy crude high. On the other hand, if more refineries upgrade to process heavy crude, increasing demand for these oils narrows the light-heavy price spread. Recent growth in heavy oil refining capacity has outstripped available heavy oil feedstock, shrinking the light-heavy price differential.^v Other factors behind the current and longer term outlook for a narrow price differential between light and heavy crudes are the post 2008 recession drop in oil demand and the rapid growth of light sweet crude supply in North America.

Paradoxically, even as the supply of heavy crude has increased, the demand profile for refined petroleum products has shifted to a greater proportion of lighter, higher quality products (from heavy fuel oil, bunker & marine fuels, to diesel and gasoline). This has resulted in the so-called “quality gap” caused by the growing availability of heavier crudes and the inability of older refineries to convert them into lighter products (see Figure 8).

Figure 7: Average Output from a Barrel of Oil (%), Canada (Source: CEPA: Liquids Pipelines)



Source: Statistics Canada

Therefore, every refinery faces a range of choices (and hence, risk and uncertainty). In the short term, they must constantly juggle their choices of inputs (crude diet) and refined outputs (product slate). In the longer term, they have to decide whether to invest in changing their configuration or shutting down.

Canadian refineries utilize a mix of Canadian-sourced and imported crude. While Canada is a net exporter of crude, only about 60 percent of the crude processed by Canadian refineries is sourced from domestic production since refineries in Eastern Canada have only limited access to Western Canadian crude supplies. Proposed pipeline projects (Enbridge Line 9 reversal, TransCanada Energy East project) would enable greater access to Canadian crude for Eastern Canadian refineries. However, Eastern Canadian refineries are generally configured to process light crude oil. Nevertheless, enhanced access to Western Canadian crude would provide Eastern Canadian refineries with additional choice and options to select crude feedstocks based on availability, quality and price.

Figure 8: The Quality Gap (Source: Inkpen and Moffett 2011: 470)



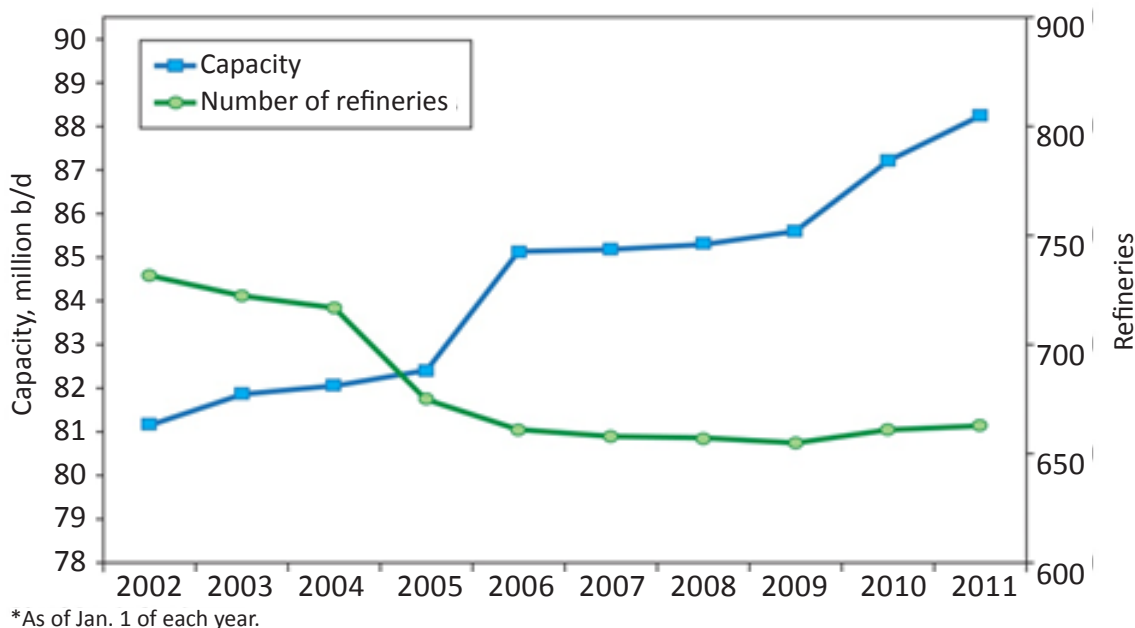
The growing *Quality Gap* between increasing demands for higher product quality and declining crude quality is a growing challenge in global refining.

Refinery Size, Configuration and Complexity

Economies of scale are an important factor in refinery profitability – refinery size does matter. Larger facilities are more efficient, better able to withstand cyclical swings in business

activity and they distribute fixed costs, like those from new regulatory requirements, over a larger number of barrels. As shown below (Figure 9), the global and Canadian trend is to fewer, larger refineries.

Figure 9: Worldwide Refining Consolidation (Source: True and Koottungal, 2010)



Refinery complexity also matters, especially since the trend is to heavier, more sour crudes and lighter products. There are several measures of complexity for refineries. The most publicly used is the Nelson Complexity Index (NCI) developed in the 1960s by Wilbur Nelson in a series of articles for the *Oil and Gas Journal*. The NCI is a pure cost-based index. It provides a relative measure of refinery construction costs based upon the distillation and upgrading capacity a refinery has. The index assigns a complexity factor to each major piece of refinery equipment based on its complexity and compared with simple crude distillation, which is assigned a complexity factor of 1.0. The complexity of each piece of refinery equipment is then calculated by multiplying its complexity factor by its throughput ratio as a percentage of crude distillation capacity. Adding up the complexity values assigned to each piece of equipment, including crude distillation, determines a refinery’s NCI number. The higher the NCI number of a refinery, the more complex it is and costly to build and operate. For example, the Phillips 66 company reports that its American refineries

range from a NCI low of 7.0 for a refinery with a fluid catalytic cracker, alkylation and hydro-treating units to a high of 14.1 for one equipped with a fluid catalytic cracker, alkylation, hydrocracking, reforming and coking units.

Other proprietary, complexity metrics have also been developed and are widely used. Solomon Associates’ complexity metrics, first introduced in the 1980s, and continuously updated, are extensively used in OECD countries to evaluate the relative performance of a refinery.

The increased demand for lighter petroleum products made from heavier crude oil requires more complex refineries. The complexity of a refinery refers to its ability to process crude oil into value-added products. A simple refinery (known as a “topping” refinery) is essentially limited to distilling crude oil; for example, making the raw material for gasoline and heavy fuel oil. A hydro-skimming refinery is also quite simple, with a NCI of about 2, and is mostly limited to processing light sweet crude into gasoline for motorists.

By contrast, a complex refinery has expensive secondary upgrading units such as catalytic crackers, hydro-crackers and fluid cokers. These refineries are configured to have a high capacity to crack and coke crude 'bottoms' into high-value products and to remove sulphur to meet vehicle exhaust system limitations and environmental requirements. Therefore, complex refineries rank higher on the NCI.

Nearly all the new refinery capacity built in the world since 2003 is made up of more complex operations. For example, the Jamnagar refinery belonging to India-based Reliance Industries Limited is now one of the most complex refineries

in the world with a NCI of 14. According to author Robert Maples and *Oil and Gas Journal*, US refineries rank highest in complexity index, averaging 9.5, compared with 8.2 for Canada and 6.5 for Europe.

The increased flexibility of complex refineries enables them to quickly adapt to constant changes in market conditions for both inputs and outputs. This reduces risk and boosts profits. With the closure of older, simpler refineries, complex refineries now represent the vast majority of the world's refining capacity.

Refining Outlook, an OPEC View

The World Oil Outlook^{vi} (WOO 2013), prepared by the Organization of the Petroleum Exporting Countries (OPEC), confirms a challenging environment for North American refiners through 2035, reinforcing the conclusions of other international forecasts. The following points have been excerpted and abbreviated from the report.

- OPEC expects global refining capacity to increase by up to 20 million barrels per day (Mb/d) between 2012 and 2035. Forecast declines in refined product demand in industrialized regions coupled with demand growth in developing regions (Asia-Pacific accounts for 80% of global demand growth) will add to already existing refining capacity surpluses in western countries, contributing to extensive reshaping of oil refining and trade. Penetrating new export markets is seen as an important factor in the continued viability of many North American refineries.
- In China alone, there are currently more than 30 planned projects representing a potential five Mb/d of new refinery capacity. Projects vary between 100 and 400 thousand barrels per day (Kb/d) and are usually structured as a joint venture between a foreign crude exporter and a local company. The focus is on large, efficient facilities with complex conversion capacity capable of processing heavy crudes, either through 'greenfield' sites or expansions/upgrades of existing facilities.
- Globally, there is a strong trend to higher complexity with more upgrading capacity per barrel of crude distillation in new refining projects. Virtually all new major refinery projects comprise complex facilities with high levels of upgrading, desulphurization and related secondary processing able to produce high yields of light, clean products, meeting the most advanced specifications.
- WOO 2013 forecasts global investments of \$650-billion in refinery projects over the period 2012-2035 to align refinery capacity and complexity with future market conditions. This is in addition to routine maintenance and replacement investment.

The advantages of more complex refineries include:

1. **More value from the product slate:** Better yields of high-value products, such as gasoline, and middle distillates, such as diesel fuel and home heating oil reduce the reliance on low-value products, such as heavy fuel oil, asphalt and residues. For example, a topping refinery typically yields 20 percent gasoline, 30 percent middle distillates and 50 percent heavy residuals from Arabian light crude oil. The most complex refineries produce as much as 60 percent gasoline, 35 percent middle distillates and 5 percent heavy residuals.^{vii}
2. **Ability to process a wider range of crude oil types:** Greater flexibility in the choice of crude means refineries can use cheaper heavy crude oils to produce lighter products that are more in demand, and increase profit margins through higher sales volume and greater crack spreads.
3. **Flexibility to adjust to changing markets and local fuel specifications:** This flexibility allows refineries to adapt production to changes in market demand and in fuel specifications (for example, the growing demand for lighter products, diesel rather than gasoline, and reformulated gasoline suitable for ethanol blending).

Since 2003, therefore, the most complex refineries have generated the highest profit margins. However, adding more complexity comes at a cost (see Section I) and some significant business risks. It also entails higher operating costs from additional inputs and greater energy use.

Product Slate and Trade

A refinery's ability to adjust its product slate to meet changes in demand has a huge impact on its profitability. Typically, products like gasoline, diesel, jet fuel and lubricating oils are the most profitable. However, a refinery's flexibility to adjust to market demand is constrained by the types of crude oil available and its own configuration and complexity. Different regional markets have different demand profiles, and these shift over time due to changes in demographics, economic circumstances, regulatory policies and consumer preferences. In addition, seasonal shifts in demand are common, such as increased demand for gasoline during the summer driving season and for heating oil in winter.

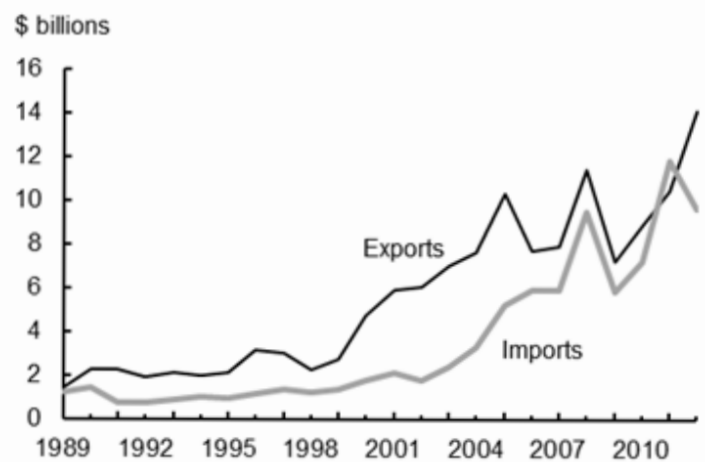
Even so, local refineries often cannot economically meet demand in a given region for a certain refined product: they must import from other regions or countries. For ex-

ample, European demand has gradually shifted due to the large-scale conversion of domestic vehicles from gasoline to diesel. As a result, European refineries have a surplus of gasoline and a shortage of diesel. They have responded by exporting gasoline to North America (primarily the US) and importing diesel from the US. Transportation costs will help determine whether matching production to demand in this way can be profitable in the long term.

Petroleum products flow both ways across the Canada-US border, and increasingly between continents as refiners strive to match production to shifting market demand.

Canada's trade in petroleum products has grown rapidly over the past decade. Exports and imports each were less than \$2 billion a year in the late 1980s, and still under \$3 billion in 1999. However, exports soared to \$14.2 billion in 2012, while imports reached \$9.6 billion, generating a trade surplus of \$4.6 billion for Canada in petroleum products (see Figure 10). Canada's largest export to the US is gasoline, but these exports are now under increasing pressure, as US gasoline demand falls due to weak economic growth, renewable fuel mandates and improving vehicle fuel efficiency. Refineries in Eastern Canada also face increasing competition from larger, more complex refineries located along the US Gulf Coast and elsewhere in the world. While Canada is a net exporter of refined products, it also imports various products to regions of the country where importing is more cost effective than shipping products from other regions of the country, or producing them locally. Product imports have risen at about the same pace as exports.

Figure 10: Trade in Refined Petroleum Products
(Source: Statistics Canada)



The growth of international trade in refined petroleum products is partly due to the trend to build large, complex refineries discussed earlier. These ‘merchant refineries’, like those in Singapore and South Korea, are designed for producing and competing in global markets, not for supplying local markets. This means imports are increasingly used to meet local market needs. As well, Canadian refiners have turned to export markets to close the gap between their increasing capacity to produce and falling domestic demand in the aftermath of the 2008 recession.

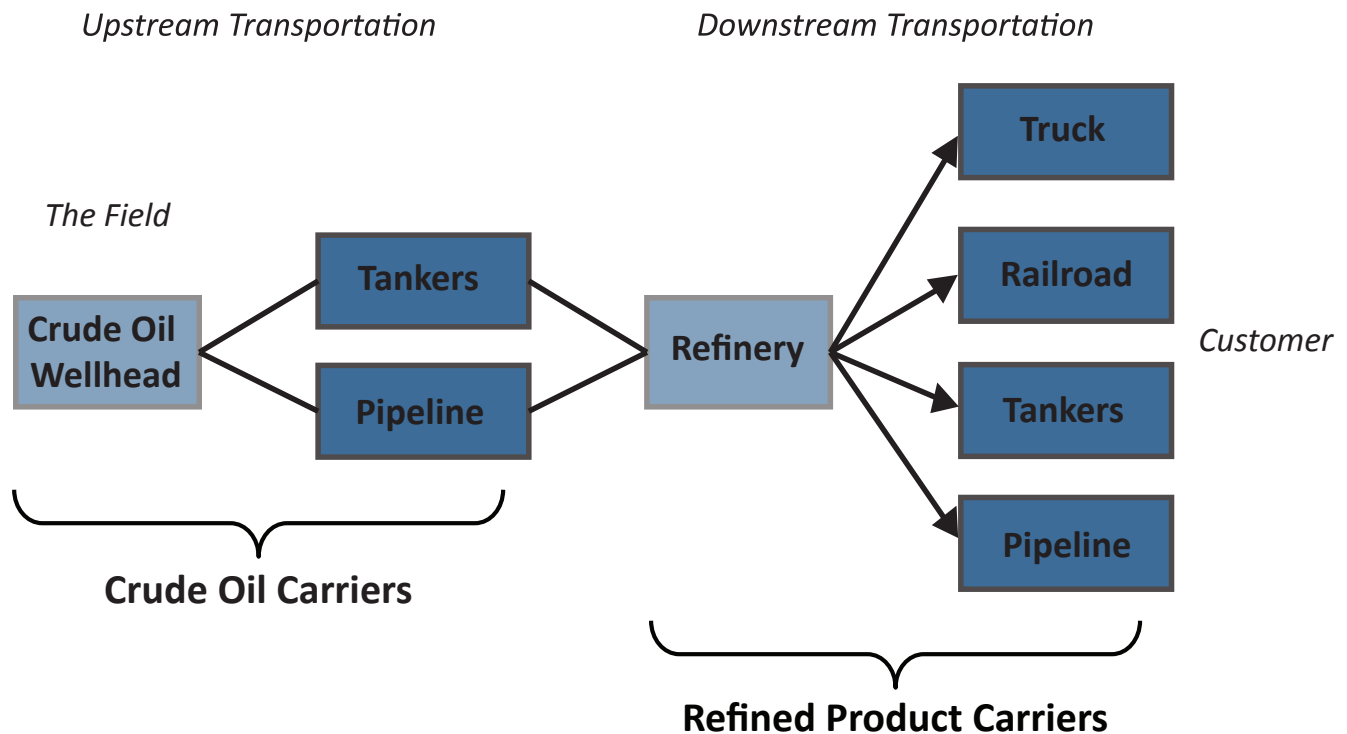
Higher oil prices are another important factor in the shift to globalized trade in petroleum products. Unlike other manufacturing industries, rising energy costs actually increase the incentive to ship both crude oil and refined petroleum products around the world, since the higher value of petroleum reduces the relative importance of transportation

costs, even if higher energy prices raise the latter slightly in absolute terms. In contrast with the boost higher oil prices give to international trade in refined petroleum products, some analysts cite the rising cost of shipping due to higher oil prices as one factor encouraging the return of manufacturing to North America from Asia.

Logistics and Transportation

Refineries receive crude oil via pipelines, ships, and rail cars. Pipeline and marine tankers are the lowest cost and therefore the preferred mode of transporting crude oil to the refinery. There is more flexibility in transporting crude oil than refined petroleum as the latter cannot be exposed to contaminants. Pipeline, ship and rail are the preferred modes to transport products from refineries to terminals located near major markets, from where the fuels are trucked to retail outlets. (Figure 11)

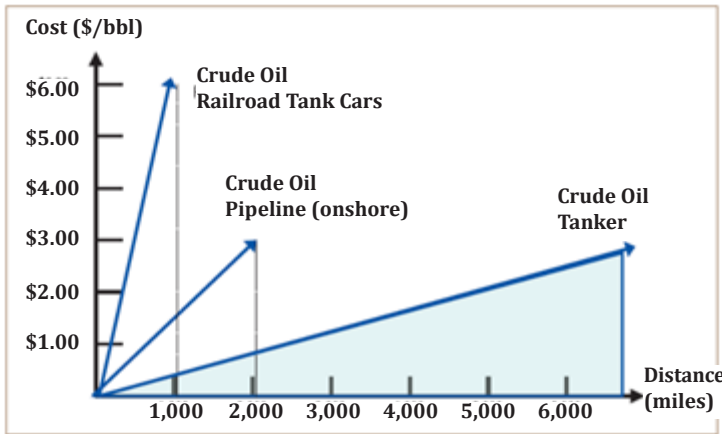
Figure 11: Upstream and Downstream Transportation of Crude Oils and Refined Petroleum Products (Source: Inkpen and Moffett 2011: 394)



A refinery’s location directly affects the cost of bringing crude oil to the facility and then getting the refined product to market. Distance and mode of transport for the crude oil and the refined products are the determining factors for cost. Figure 12 on the next page compares crude transportation costs of rail, pipeline and marine tanker.

Typically, products leaving a refinery cost more to transport than the crude oil coming in, so the refinery’s location needs to balance crude transportation costs and proximity to markets.

Figure 12: Crude Oil Transportation Costs (Approximations) (Source: Inkpen and Moffet, 2011: 398)



Traditionally, proximity to market was the dominant consideration in locating a refinery. For example, refineries often have been co-located with petrochemical complexes in a symbiotic supplier-customer relationship that minimizes transport costs for refined products used as petrochemical feedstocks.

Location dynamics are now more complex. Tidewater locations provide access to low-cost marine shipping. This criterion can trump proximity to market as the dominant consideration. Large, complex refineries located on tidewater have cost advantages that overcome the higher transportation cost of exporting products to distant markets, and are now more common.

Changing preferences for crude types are adding to shifts in refinery location dynamics and a global realignment in crude oil trade patterns – for example, the growing US Gulf Coast refinery demand for Canadian bitumen as a substitute for waterborne crudes from Mexico, Venezuela, and elsewhere. Easy, low cost access to crude can be a locational advantage. However, even though crude may be readily available from a local source, the refinery may not be configured to handle the grade of crude being produced, and the cost of getting the refined product to a suitable market may not support profitable market access. Generally, the farther refineries are from the markets for their product, the more locations near tidewater are preferred because they generally have lower transportation costs than those that are landlocked.

Location is also influenced by:

- technological advances or infrastructure developments that make it more convenient or cheaper to ship inputs and

- outputs. This reduces the cost constraint of supplying more distant markets;
- opportunities to arbitrage significant price differences between two or more markets (arbitrage is discussed in Section 4 of this paper); and
- a refinery’s ability to produce high margin specialty products that generate enough revenue to overcome the disadvantage of higher transportation costs.

The preferred location of refineries changes over time as a result of new sources of crude oil, improved refining and transportation technologies and infrastructure, and shifts in market demand. As noted, shifting market demand creates mismatches with local refining capabilities, which increases the need for inter-regional trade in refined products. This can create real competitiveness challenges for existing refineries, built when locational dynamics were substantially different.

State intervention can also play a significant role in refinery location. For example, in China, the major state owned refiners are adding domestic refining capacity consistent with anticipated growth in domestic demand. The Chinese government has an explicit policy preference for meeting domestic fuel demand from domestic refineries. Chinese refining capacity is expected to grow by 3 million bpd by 2017 to meet forecast demand growth.^{viii}

Operational Efficiency

Operations within a refinery are conducted with mathematical precision. Scheduling refinery production is one of the most complex and tightly controlled operational tasks in all of manufacturing. Every refinery has flexibility in the crude oils it can process and the mix of products it can produce. In order to optimize the combination of inputs and outputs, refiners face a daily challenge of which crude to use, which refinery units to use and under what conditions, and what mix of products to refine. In addition, they must make these decisions while taking scheduled maintenance, inventory levels, and the like into account.

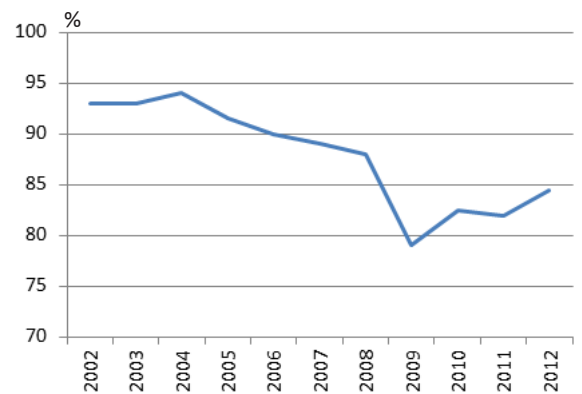
Mathematics is used extensively in operating a refinery. Linear programming models of operations simulate operating unit capacities and yields, product-blending operations, utility consumption, crude-oil pricing and product value. This provides optimal solutions for a broad range of decisions about crude oil selection, short- and long-term operations planning, new process technologies, capital investment, maintenance and inventory control.

Minimizing unscheduled downtime—whether from mechanical breakdowns, utility disruptions, natural disasters, or other causes—is important to maintaining an optimal utilization rate. Since operating a refinery entails high fixed costs, utilization rates are a major factor influencing profitability. Typically, a sustained 95 percent utilization rate is considered optimal. Above that, costs rise due to process bottlenecks. A rate below 90 percent suggests either that some units are down for scheduled or unscheduled maintenance or that production was reduced due to a drop in demand or in profit margins.

Worldwide, refinery utilization rate averaged 90 percent before the 2008 economic slowdown, and has remained below that since then. This current low rate indicates a global surplus of refining capacity. In Canada, the rate fell from near 96 percent in 2004, to below 80 percent in the 2008 recession (see Figure 13). Since then, it has risen to near 85 percent, following a refinery closure in Montreal. In the US, refinery utilization levels are slightly higher, climbing from a low of 83 percent in 2009 to between 86 percent and 89 percent over the 2010-2012 time period.^{ix} European refinery utilization is down from high of 88 percent in 2005 to about 80 percent in 2012.^x

Global refining capacity has been shifting to emerging markets, especially Asia, where demand is growing the fastest. The world's largest refinery, designed to export globally, with the advantage of lower labour, capital and environmental compliance costs, is in Janmagar, India. The refining capacity of this one complex – 1.2 million bpd – is equal to over half of all the refining capacity currently available in Canada. Clearly, oil refining is entering its own era of globalization.

Figure 13: Capacity Utilization Rate of Petroleum Refineries in Canada (Source: Natural Resources Canada, Fuel Focus, May 18, 2012)



Refining Economic Value

One expert view of the issue of refining challenges in Canada is highlighted and abridged here from the IHS CERA report - **Extracting Economic value from the Canadian Oil Sands: Upgrading and Refining in Alberta (Or Not)?**

At one time, oil sands developers upgraded their heavy crude into light products before shipping them to market. Today most operators send their heavy crude directly to markets. This new circumstance has spurred a debate about value added upgrading and refining. The following comments focus on three key issues raised in the IHS CERA report and that have direct relevance to the refining economics discussion:

- **Alberta greenfield upgrading economics are challenged by an outlook for a narrow price difference between light and heavy crudes and high construction costs.** Both factors discourage investment in upgrading equipment or building new refineries not only in Alberta.
- **Instead of building new upgraders or refineries, modifying existing refinery capacity to process oil sands is the most economic way to add processing capacity.** Modifying an existing refinery is more economic than building a new refinery. However, refinery conversions face challenging market conditions in North America. With ample supplies of light crude, refiners have little motivation to undertake substantial investments to convert refineries to consume heavy crudes.
- **For a greenfield refinery focused on oil sands, the strongest investment return is in Asia, where demand is growing. Although the potential is not as strong as in Asia, under the right conditions the economics of new refinery projects in Alberta and British Columbia could work.** Asia's advantage is primarily the result of lower project costs (at least 30 percent less than in North America). Assuming a new refinery project in Alberta or B.C. consumes bitumen, manages to keep capital costs to a minimum, maximizes diesel production, and does not oversupply its market – the economics could work.

Regulatory Environment

Depending on the specific requirement, the capital investment and operating costs of complying with government regulatory requirements can be considerable. For example, the costs imposed by Canada's regulations for sulphur in gasoline and diesel fuel that came into force over the last decade are estimated at \$5 billion in capital spending alone. The cumulative costs of complying with environmental regulations imposed on refineries by all levels of government over the same period is significantly higher.

A July 2012 study by Baker and O'Brien^{xi} highlighted the potential impact on refineries of anticipated new regulatory initiatives in Canada. Baker and O'Brien observed that, when refineries face higher regulatory compliance costs than competitor refineries in other jurisdictions, their economic viability is threatened. The unintended consequences of regulatory policies that impose more stringent requirements than those in competing jurisdictions are impaired profitability, the erosion of the investment environment, and the possible closure of refineries. Baker & O'Brien concluded that five of nine refineries in Eastern Canada (representing 47 percent of overall Canadian refinery capacity) were vulnerable to closure as a result of the cumulative costs of anticipated environmental regulation scenarios.

IV. How Oil Markets Work

Crude oil and refined products are commodities that trade on global commodity markets, such as those in London, New York and Singapore. Arguably, crude oil is the most actively traded and watched commodity in the world. Refined products, such as gasoline and diesel, do not receive the same public profile, but are actively traded nevertheless.

The market prices for crude oil and refined products at any time are a function of current and future supply and demand conditions, and are assessed on a variety of scenarios. For crude oil, these include overall economic conditions, natural disasters and geopolitical or military events, especially in major oil-producing regions. The price of crude oil affects the price of refined product, but the underlying balance of supply and demand for specific refined products (e.g. gasoline, diesel) is often far more important in influencing trading decisions, and determining the wholesale price of these commodities. Refinery outages, inclement weather, temporary surges or declines in demand – all have the potential to impact the supply and demand balance, and the resulting

wholesale commodity price. As a result, wholesale (and consequently retail) gasoline prices can be increasing even when crude prices are decreasing, and vice versa.

Benchmarks

Because there are so many different varieties and grades of crude oil, buyers and sellers have established a number of “benchmark” crude oils. Other crudes are priced at a discount or premium relative to these benchmark prices, based on their quality.

According to the International Petroleum Exchange, the price of Brent crude oil is used to price two-thirds of the world's internationally traded crude oils. Brent is a light blend of four key crude oils from the North Sea, and is generally accepted to be the world benchmark for oil, although sales volumes of Brent itself are far below those of some Saudi Arabian crudes. If no other information is given, reference to an oil price likely cites the Brent price. In the US, the predominant benchmark is West Texas Intermediate (WTI), a high-quality light crude oil blend from several US-based sources. In Canada, the Western Canada Select (WCS) benchmark price is a blend of several heavy conventional and bitumen crude oils.

Markets and Contracts

Over the decades, markets and contracts have evolved towards greater transparency and liquidity. This takes various forms. Trading activity occurs for a spot, forward or futures contract. These types of contracts, especially futures, are another tool that refiners use to reduce risk and uncertainty. In particular, futures contracts allow refineries to lock in the price of their crude oil inputs, preventing sudden spikes in prices from impairing their profitability. This is the same as homeowners locking in the price of their heating fuel by signing a long-term contract with a supplier. Similarly, refiners can sell their refined product at a guaranteed price for future months or even years to protect against a sudden drop in prices. Of course, these strategies do not allow refiners to benefit from a sudden drop in crude oil prices or a surge in the price of petroleum products, so risk and uncertainty remain. Futures contracts are a useful tool for managing risk, not eliminating it altogether.

Trading activity encompasses two “markets”—the physical market, which results in the actual exchange of the commodity, and the paper market, where financial instruments underpinned by a commodity are exchanged. Among the

most common forms of financial instruments are:

- **Spot contracts:** Buying and selling at current market rates to deliver a specific quantity at a given location. They are short-term trades of generally 10-25 days. Commercial traders (producers and refiners) use the spot market to balance supply or demand. Other market participants also use it to take advantage of price differences among different crude oils in global markets. A number of regional spot markets have developed around the world (Rotterdam for Northwest Europe, New York for the US Northeast, Chicago for the US Midwest and Singapore for South Asia) in locations with abundant physical supplies, many buyers and sellers, storage facilities and transportation options.
- **Forward contracts:** Private, bilateral agreements between buyers and sellers with customized delivery (future date, volume and location). Forward market contracts are not standardized, and have only a few participants on over-the-counter (OTC) trading. Forward contracts are mostly used by hedgers who want to eliminate the volatility of an asset's price, and delivery of the asset or cash settlement does usually take place (in contrast to futures contracts, see below).
- **Futures contracts:** Futures contracts are financial instruments that carry with them legally binding obligations. The buyer and seller have the obligation to take delivery of an underlying instrument at a specific settlement date in the future. Oil futures are part of the "derivative" family of financial products as their value "derives" from the underlying instrument. These contracts are standardized in terms of quality (e.g. Brent), quantity (1,000 barrels= 1 contract), and settlement dates. Futures contracts can be for several months or even years ahead. However, the bulk of futures trading activity for oil is typically for delivery in the next three months. Because speculators who bet on the direction of crude oil prices will frequently use futures contracts, they are usually closed out before they mature, and delivery rarely happens.

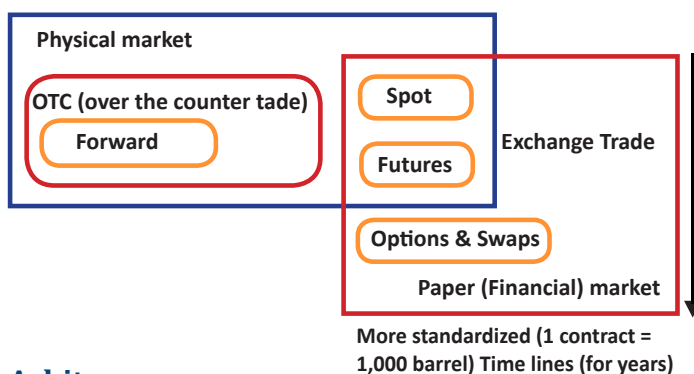
Traders of crude oil and refined products are typically divided into two groups.

- **Commercial traders:** Primarily, oil companies and refineries that use the market to guarantee the selling/buying price in the future to hedge price volatility/financial risks. These traders deal in physical deliveries of crude oils.
- **Non-commercial traders:** Investment banks, hedge funds and other types of investment institutions and speculators, who use the market to profit from price fluctuations, such as buying contracts low and selling them at

higher prices. In general, their interest in crude oil and/or refined product contracts is to diversify their portfolios, and they have no interest in taking delivery of actual commodities. They are considered "paper" trades.

These transactions are conducted around the clock, around the world, through digital platforms. Transparency and liquidity are necessary for these markets to function efficiently. As shown by Figure 14, physical and paper markets are interdependent. As such, significant paper positions taken by traders can influence the spot physical market.

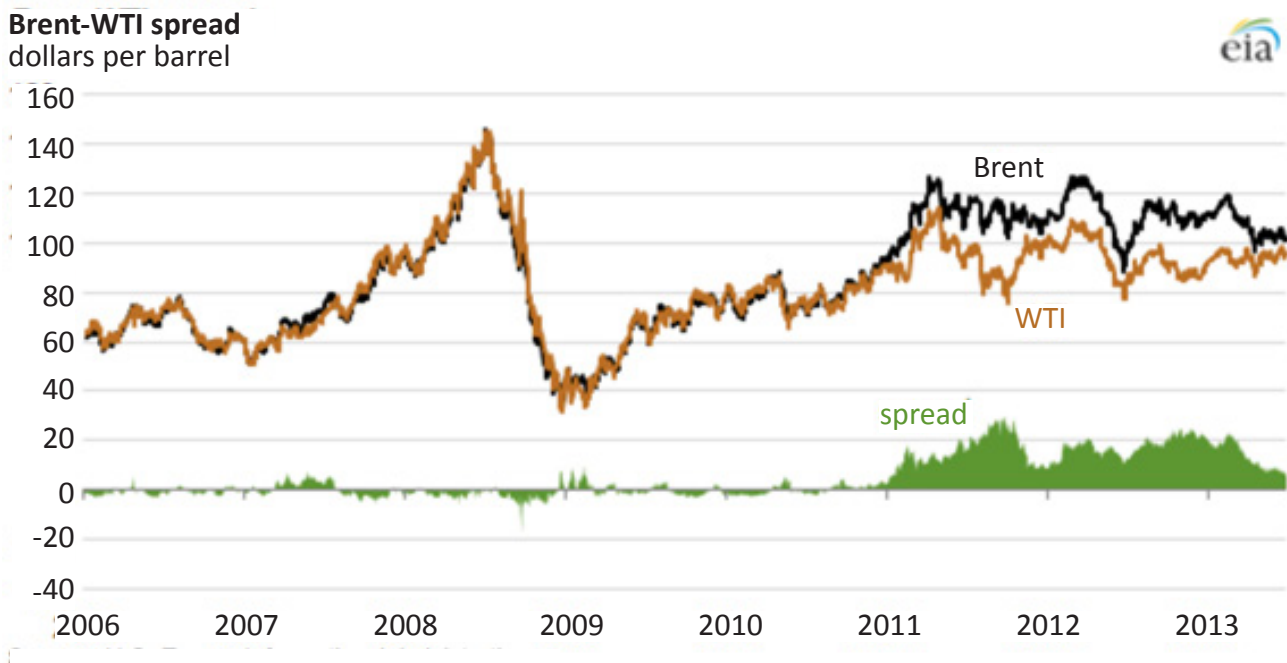
Figure 14: Main Contracts and Markets for Crude Oil (Source: Adapted and modified from Favennec 2003: 99)



Arbitrage

Arbitrage refers to a price differential occurring for the same product in different markets anywhere in the world. A textbook example was the significant price differential that opened up in 2011 and 2012 between the trade prices of Brent and WTI crudes. Normally, prices for these two benchmark products (which have similar quality attributes) move together quite closely, but they began to diverge in 2011 when turmoil in Libya squeezed supplies and raised prices for Brent just as a surge in oil supplies and transportation bottlenecks in North America dampened prices for WTI (see Figure 15). Markets and refineries reacted to this unprecedented differential by moving crude oil supplies from landlocked parts of North America via various modes to access additional markets. For refiners, the Brent – WTI arbitrage opportunity made it economically possible to use more expensive modes of transport to gain access to lower priced WTI benchmarked crude. By mid-2013, the increased shipment of North American oil by pipeline, rail and even barge, coupled with difficult economic conditions in Europe impacting Brent price, had erased most of the Brent-WTI differential. This situation reinforces the importance of long term business and investment perspectives for refiners, that balance decisions and actions that take advantage of short term arbitrage opportunities.

Figure 15: Brent – WTI Price Differential (Source: U.S. Energy Information Administration)



V. Conclusion

The economics of the refining business are complex. As a capital intensive manufacturing industry operating between the two related but independent markets for crude oil and finished petroleum products, refining is a challenging business. Profitable operations that deliver adequate returns on investment are a function of a complex set of variables underpinned by basic supply and demand dynamics, and shaped by competition that is increasingly global in nature.

Refiners must strive to maximize their margins by optimizing a number of variables including: the type of crude feedstocks and products; energy requirements; plant complexity and efficiency; and logistics and transportation, all the while responding to an increasingly stringent regulatory agenda. They operate in a business environment that is dynamic, and that comes with varying levels of commercial, technical, regulatory and economic risks.

Declining demand and excess refining capacity create challenging market conditions for refiners in North America, and especially Canada. Canadian refineries are small by international standards and don't enjoy the same economies of scale as established competitors in the US and emerging competitors in Asia. Most lack the complexity required to

refine heavy crudes and bitumen. Overall capacity utilization is currently below optimal. Eastern Canadian refineries are particularly vulnerable due to weak Atlantic Basin refining margins. Recent studies by the Conference Board of Canada and Baker & O'Brien demonstrate that, overall, Canadian refineries are already in a tough fight to remain competitive and economically viable.

Fuel demand is growing in Asia, and represents a potential new market for Canada – a market that theoretically could be supplied by refining Canadian bitumen. Supplying this product demand from Canada would first require substantial investment in new heavy conversion refining capacity. Any decision to invest in new Canadian refinery capacity must pass a number of critical hurdles to demonstrate real ability to achieve an adequate return on investment. The stakes are high, with a payback period that is 20 to 30 years long, or more.

The bottom line question for prospective investors is whether new Canadian refinery capacity can profitably access and penetrate this market over a period of 30 years or more. Can the complex variables of crude inputs, refinery configuration, product slate, logistics and transportation, and regulatory regime be harnessed with adequate certainty to overcome or sufficiently mitigate the commercial, technical, regulatory and economic risks?

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