ASSESSMENT OF THE EUROPEAN REFINING SECTOR'S CAPABILITY TO PROCESS UNCONVENTIONAL, HEAVY CRUDE OILS

Prepared for

FRIENDS OF THE EARTH EUROPE

AND

EUROPEAN FEDERATION FOR TRANSPORT AND ENVIRONMENT

IN COOPERATION WITH

THE HEINRICH BÖLL STIFTUNG E.V

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INTRODUCTION AND EXECUTIVE SUMMARY

Recently, cargoes of unconventional heavy crude oils produced from Canadian oil sands have reached some European refineries. These cargoes may presage wider use of such crudes by the European refining sector (which we define here as comprising the refineries in the twenty eight countries of the European Union plus those in Norway and Switzerland.) However, it is unclear how much unconventional heavy crude oil the European refining sector could handle in sustained commercial operations. Not all European refineries are capable of processing unconventional heavy crude oils with their existing facilities. Moreover, logistics and location considerations affect the economic incentives for using such crude oils.

Friends of the Earth Europe and the European Federation for Transport and Environment retained MathPro Inc. to survey the European refining sector and identify the European refineries that could process, on a continuing commercial basis, unconventional heavy crude oils – specifically those produced from Canadian oil sands – based on the refineries' processing capabilities, as reported in the open literature. This report is the primary work product of this engagement.

Focus is on Unconventional Heavy Crude Oils Derived from Canadian Oil Sands

The Canadian oil sands are located in the Western Canadian provinces of Alberta (primarily) and Saskatchewan. These formations contain a form of crude oil called *bitumen*. As-produced bitumen is a heavy, viscous hydrocarbon that cannot be transported or refined without first being processed into other forms of crude oil or diluted with lighter hydrocarbons. The derived crude oils supplied to the market from the Canadian oil sands include:

- *Synthetic Crude Oil (SCO)*: light, low-sulfur crude oil containing no vacuum residuum (the heaviest crude oil fraction, with an initial boiling point > than 1000°F), produced by field processing that destroys the heaviest fraction of the bitumen, thereby converting it into a lighter crude oil.

- *Dilbit (diluted bitumen)*: heavy, high-sulfur crude oil containing a large fraction of vacuum resid, produced by diluting bitumen with lighter hydrocarbons to permit transport.

- *Synbit (SCO-diluted bitumen)*: a mixture of bitumen and SCO.

- *Western Canadian Select (WCS)*: a heavy, high-sulfur dilbit that is a mixture of bitumen, a conventional heavy Canadian crude oil, and a diluent, blended to meet certain specifications on the properties of the finished blend. WCS is Canada's benchmark unconventional heavy crude oil.

The Canadian Association of Petroleum Producers' (CAPP) latest forecast shows total Canadian unconventional heavy crude production increasing from about 3 million barrels per day (MM b/d) in 2015 to about 5 MM b/d in 2030. Virtually all of the forecast growth is in dilbit, and WCS in particular.

Oil shale – as distinct from *oil sands* – contains a hydrocarbon resource called *kerogen*, which is a crude oil precursor. Kerogen is not a crude oil and is unsuitable for *direct* processing in a refinery. Oil shale containing kerogen can be processed to yield a material that resembles SCO and that can be refined. Kerogen-sourced SCO comprises mainly middle distillates and some higher boiling range material. The prospective volumes of kerogen-sourced SCO are likely to be small, given the high costs associated with the extraction and conversion of oil shale kerogen. Hence, we did not consider oil shale kerogen in this study.

SCO and Dilbit/WCS Have Significantly Different Properties

SCO and dilbit/WCS have substantially different physical and chemical properties and different distributions of light vs. heavy product yields than those of conventional crude oils (even heavy crude oils), including those processed by European refineries. Moreover, SCO and dilbit/WCS have yield distributions that differ markedly from each other.

- SCO has little or no residuum[1] (because it is destroyed in the upgrading processes used by Canadian producers), very high yields of vacuum gas oil (VGO) and distillate fractions, and very low sulfur content (because the upgrading process includes hydrotreating to remove sulfur).

- Dilbit/WCS has more residuum, about 30%, and less of the lighter crude fractions – naphthas, kerosene, and diesel – than any of the conventional crudes.

These characteristics are key determinants of the refinery configurations and capabilities required for sustained processing of SCO and/or dilbit/WCS, and hence of any given refinery's capability for sustained processing of such crudes with its existing facilities.

Processing SCO and Dilbit/WCS Calls for Specific Refining Processes and Capabilities

Many European refineries could run small volumes of *SCO* temporarily with little, if any, process additions or modifications. A smaller number of European refineries could run small volumes of *dilbit/WCS* temporarily. But permanent replacement of a significant share of a refinery's conventional crude slate with SCO or dilbit/WCS would require that the refinery have certain key process units and capabilities, as summarized in the table below.

[1] *Residuum* is the heaviest crude oil fraction. It is also called *vacuum resid*, *resid*, or *residual oil*. In this report, we use these terms interchangeably.

Threshhold Processing Capability	Canadian Oil Sands Crude	
	SCO	Dilbit/WCS
Vacuum Gas Oil Processing Catalytic cracking (FCC) Gas oil hydrocracking	●	●
Vacuum Resid Processing Coking Resid hydrocracking Solvent desasphalting		●

Refineries having at least some of these processes are called *conversion* refineries.

These processes (described briefly in Section 3 of the report) are minimum, or threshold, processing capabilities for running significant volumes of SCO or dilbit/WCS in sustained commercial operations. Other technical and economic factors, many not discernable from publically available information, can determine whether or not a European refinery has the existing or prospective capability to switch a significant fraction of its crude slate to SCO or dilbit/WCS in continuing commercial operations.

European Refineries That Could Process SCO or Dilbit/WCS

To identify candidate refineries for processing *SCO*, we established these criteria:

1. The refinery's vacuum gas oil conversion capacity is $\geq$ 30% of its distillation capacity (a somewhat arbitrary cutoff), because such refineries are the most likely to have some excess conversion capacity to handle SCO vacuum gas oil.

2. The refinery is located in Western Europe, with easy access to waterborne imported oil and relatively less access to imports from Eastern suppliers (primarily Russia, Azerbaijan, and Kazakhstan).

Exhibit 14 (pages 32 and 33) shows all the European refineries that have vacuum gas oil conversion capacity. On the first page of Exhibit 14, the refineries designated **Most Likely** are those that meet both criteria; the refineries designated **Less Likely** are those that meet the second criterion (location) but not the first. The remaining European conversion refineries are designated **Unlikely** because they do not meet the second criterion (location); regardless of whether they meet the first criterion.

To identify candidate refineries for processing *Dilbit/WCS*, we established these criteria:

1. The refinery has either coking or severe resid hydrocracking capacity *and* FCC or gas oil hydrocracking capacity.

2. The refinery has other vacuum resid processing capacity or another disposition for vacuum resid, such as an asphalt plant, a nearby power plant, or an on-site co-gen plant, as well as FCC or gas oil hydrocracking capacity.

3. The refinery is identified in an authoritative public source as capable of processing heavy crude oils.

4. The refinery has been reported to or has announced that it is processing unconventional Canadian heavy crude on a sustained basis.

Exhibit 15 (pages 34 and 35) shows all European conversion refineries that meet at least one of those criteria. The refineries designated **Most Likely** are those whose resid processing capacity is > 20% of crude distillation capacity and are favorably located (i.e., in Western Europe); the refineries designated **Less Likely** are those whose resid processing capacity is < 20% of crude distillation capacity but are favorably located. The remaining refineries are designated **Unlikely** by virtue of location and crude oil access, though some of them have resid processing capacity > 20% of crude distillation capacity.

The potential volume of SCO that could be processed on a sustained basis by European refineries likely would be small because (i) the forecast increase in the supply of Canadian SCO is small; (ii) the increase is likely to be absorbed by refineries in North America; and (iii) certain properties of SCO fractions make it a problematic feedstock for European refineries.

The potential volume of dilbit/WCS that could be processed on a sustained basis maybe larger than for SCO, because the forecast increase in dilbit/WCS production is considerably larger. However, relatively few European refineries – only those having the necessary vacuum resid processing facilities and ready access to waterborne crude oil imports – are candidates for processing dilbit/WCS.

1. Background

The European refining sector faces continuing overcapacity; high operating costs; declining supplies of North Sea crudes; declining domestic demand for refined products in general and gasoline in particular; and shrinking export markets. Exports of gasoline to the U.S. East Coast have largely been displaced by domestic supplies. In other export markets, European refineries face intense competition from low-cost export refineries in the U.S. Gulf Coast, the Middle East, and elsewhere. These factors have reduced the call for gasoline from European refineries. Hence, some European refineries may have an incentive to introduce into their crude slates some heavy crude oils, having lower gasoline yields and lower acquisition costs than the crudes they currently process.

At the same time, Canadian production of unconventional oil sands crudes is expected to continue growing. Thus far, most of Canada's exports of oil sands crudes have gone to U.S. refineries in the Midwest and Gulf Coast refining regions. As these markets approach saturation, Canadian producers are seeking new markets outside of North America. Currently, these overseas markets can be reached by moving the crude by pipeline or rail to the Gulf Coast and then by marine transport to the export destination. A number of projects are in train to construct pipelines to western and eastern Canadian ports to facilitate exports to Asia and Europe. In particular, the proposed Energy East pipeline, running from Alberta to New Brunswick and scheduled to open in 2019, would add substantial export capacity and provide a more direct route to European markets. And, late in 2014 the European Union's Fuel Quality Directive was revised so as not to preclude imports of Canadian crude oils on the basis of carbon intensity.[2]

In combination, these factors could induce some European refineries to consider processing oil sands crudes. And indeed, within the past year, a number of cargoes of unconventional heavy crude oils produced from Canadian oil sands have been processed in European refineries.[3] These cargoes – the first deliveries of Canadian oil sands crudes to Europe – have raised concerns that they may presage wider use of such crudes by the European refining sector. The concern exists because unconventional heavy crudes derived from oil sands have higher life-cycle GHG emissions than all but a handful of conventional crude oils.

However, it is unclear how much unconventional heavy crude oil the European refining sector could handle in sustained commercial operations. Not all refineries are capable of processing unconventional heavy crude oils with their existing facilities. Moreover, logistics considerations could affect the economic incentives for using such crude oils.

[2] *Council Directive (EU) 2015/652 of 20 April 2015 laying down calculation methods….*; http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0652&qid=1441129630384&from=EN

[3] *Crude Oil, Forecasts, Markets & Transportation*; June 2015; Canadian Association of Petroleum Producers (CAPP Report), pg. 22; and *Oil Sands Crude Reaching Europe, Asia*; The Globe and Mail, Nov.2, 2014.

2. Supply of Canadian Oil Sands Crudes

The Canadian oil sands are located in the Western Canadian provinces of Alberta (primarily) and Saskatchewan.[4] These formations contain a form of crude oil called *bitumen*. Bitumen is "a highly viscous mixture of hydrocarbons heavier than pentanes.

> In its natural state, bitumen is not usually recoverable at a commercial rate through a well because it is too thick to flow."[5] Rather, it is produced by surface mining from shallow formations and by *in situ* processes from deeper formations. The most widely used *in situ* processes are steam assisted gravity drive (SAGD) and cyclic steam stimulation (CSS).

As-produced bitumen cannot be transported or refined without first being transformed, by processing or blending with a diluent, into other crude oil forms. The unconventional crude oils supplied to the market from the Canadian oil sands include:

- *Synthetic Crude Oil (SCO)*: a light, low-sulfur crude oil containing no vacuum residuum (the heaviest crude oil fraction, with an initial boiling point greater than 1000°F).

  Most bitumen produced by surface mining is upgraded to SCO via large, expensive upgrading facilities that convert the heavy, viscous bitumen into a lighter hydrocarbon material. The most common conversion technology is coking, but some projects use hydrocracking. Both processes destroy the vacuum resid, partially converting it into lighter hydrocarbons. The upgraded bitumen is then hydrotreated to substantially reduce its sulfur content.

- *Dilbit (diluted bitumen)*: a heavy, high-sulfur crude oil with a large fraction of vacuum resid.

  Bitumen produced by *in situ* processes is less viscous than bitumen produced by surface mining. This bitumen is mixed directly with various diluents (condensate, natural gasoline, and also SCO) to reduce its viscosity enough to enable pipeline transport.

  (The term *dilbit* is used to denote not only a specific unconventional crude oil – bitumen diluted with light hydrocarbon to permit pipeline transport – but also a class of unconventional crude oils produced by diluting bitumen with lighter hydrocarbons to permit transport.)

- *Synbit*: a mixture of *in situ*–produced bitumen diluted with SCO.

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[4] Large oil sands deposits exist not only in Canada but also in the U.S., Venezuela, Russia, Kazakhstan, Madagascar, and elsewhere.

[5] *Bitumen* is "a highly viscous mixture of hydrocarbons heavier than pentanes. In its natural state, bitumen is not usually recoverable at a commercial rate through a well because it is too thick to flow." *Canada's Energy Future 2013 - Energy Supply and Demand Projections to 2035 – An Energy Market Assessment*; National Energy Board of Canada, 2013; Glossary.)

- *Western Canadian Select (WCS)*: a heavy, high-sulfur crude oil that is a mixture of *in-situ* bitumen, a heavy conventional Canadian crude, and diluents (light hydrocarbons or SCO).

  WCS is produced by blending these constituents in the field so as to meet certain specifications on the properties of the finished blend, including API gravity, sulfur content, carbon residue, and total acid number. WCS is Canada's benchmark heavy crude oil.

The Canadian Association of Petroleum Producers (CAPP) annually produces a report that provides, among other things, historical information on Canadian crude oil production (both conventional and unconventional) and forecasts of future oil production based on a comprehensive survey of Canadian oil producers. The 2015 report forecasts significantly lower oil production post-2020 than the 2014 report, because the current low oil price regime has caused most Canadian oil producers to delay or cancel planned projects.

The 2015 CAPP report shows historical and forecast volumes of (i) conventional crude oil production, (ii) raw bitumen production, (iii) post-upgrading volumes of bitumen/synthetic crude, and (iv) blended market supply of conventional crude oil, synthetic crude oil, and heavy unconventional crudes.[6] The report also breaks out, for the first time, forecast production from projects already operating and under construction versus planned new projects.

Exhibit 1 (page 8) shows historical (through 2014) and forecast supply (blended market volumes) of conventional light and medium crude, conventional heavy crude, SCO, and unconventional heavy crude (including all forms of diluents) for western Canada (small volumes of eastern Canada's supply of light and medium crudes are not included).[7]

The CAPP forecast sees Western Canada's SCO production increasing by about 200 thousand barrels per day (K b/d) by 2020 and by an additional 100 K b/d by 2030. Unconventional heavy crude (dilbit) is forecast to increase by about one million b/d by 2020, and by another million b/d by 2030. The increase in dilbit production to 2020 is from existing (operating and under construction) projects. New *in situ* projects begin to come on line only as of 2020; new surface mining projects as of 2028.[8] The supply of conventional crude oil from western Canada is forecast to decline slightly, by about 70 K b/d, by 2020, and by about a further 20 K b/d, by 2030.

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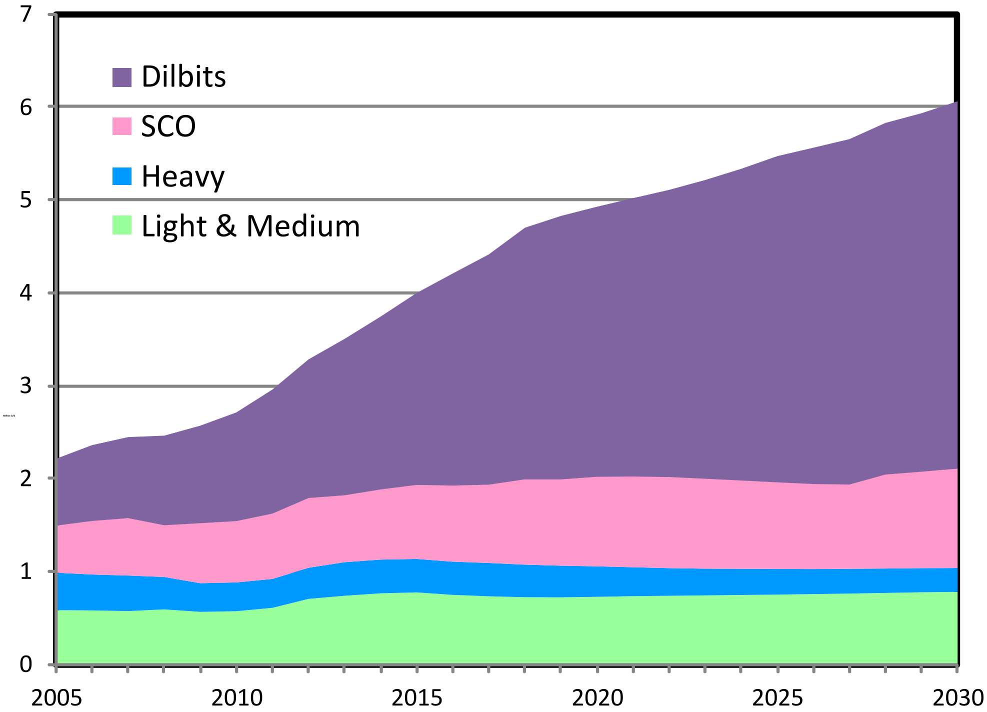
[6] Heavy unconventional crudes include (i) *dilbit* – bitumen mixed with condensate as diluent; (ii) *synbit* – bitumen mixed with synthetic crude oil (SCO) as diluent; (iii) *dilsynbit* – bitumen mixed with a combination of diluents that include SCO; and (iv) *railbit* – bitumen mixed with a lower proportion of condensate than dilbit, to yield a higher viscosity crude that can be transported by rail but not by pipeline.

[7] We allocated the forecast *supply* (blended market volumes) of unconventional crudes to existing versus new projects based on CAPP's forecast of *production* for existing and new projects.

[8] CAPP does not make crude oil price projections. Rather, CAPP forecasts implicitly represent the price forecasts that underlie the responses from individual Canadian producers participating in the survey. The announced delays in developing new projects suggest that Canadian producers expect the current low oil price regime to persist for some time.

Exhibit 1: Historical and Projected Supply of Western Canadian Crude Oil



Year	Conventional Crude		Unconventional Crude						All Western Canadian Crude
			Synthetic Crude Oil			Dilbits/WCS			
	Light & Medium	Heavy	Existing Projects	New Projects	Total	Existing Projects	New Projects	Total	
2005	0.58	0.40	0.51		0.51	0.72		0.72	2.53
2010	0.57	0.31	0.66		0.66	1.17		1.17	2.99
2014	0.76	0.36	0.76		0.76	1.86		1.86	3.96
2015	0.77	0.36	0.80		0.80	2.07		2.07	4.21
2020	0.73	0.33	0.96		0.96	2.88	0.03	2.91	5.18
2025	0.75	0.28	0.93		0.93	2.79	0.72	3.51	5.64
2030	0.78	0.26	0.96	0.11	1.07	2.58	1.37	3.95	6.15

Source: Derived from CAPP Website,*Canadian Crude Oil Production and Supply Forecasts.*

Exhibit 2 (page 9) shows the disposition of Western Canadian supply of crude oil by market area in 2014, along with forecast increases in supply to the various markets by 2020. The primary export market for Western Canadian crudes, especially heavy crudes, is the U.S. Midwest. The CAPP forecast suggests that increases in Western Canadian unconventional crude oil supply of about 1 MM b/d can be absorbed in existing markets in Canada and the U.S. without recourse to exports to Asia or Europe. The U.S. Gulf Coast is the most prospective export market for additional supplies of Canadian heavy crude, because most of the Gulf Coast's refining capacity is oriented towards processing heavy crude oil.

Disposition of the forecast increases in crude supply after 2020 may be more problematic. By then, Canadian markets and most U.S. markets, except for the Gulf Coast, essentially would be saturated with Canadian crude oil, leaving little room for absorbing additional volumes.[9] The Gulf Coast currently imports almost 2 MM b/d of non-Canadian heavy crudes. If transportation infrastructure is in place (pipeline and/or rail), the Gulf Coast refining sector could absorb all of Canada's forecast increase in supply out to 2030. Just as the increase in U.S. domestic production of light crudes has displaced imported light crudes, the Western Canadian crudes likely would displace imported heavy crudes from the Middle East and South America.

Exhibit 2: Supply of Western Canadian Crude Oil, by Market Area
(K b/d)

Country	Region	Reported 2014	Forecast Increase by 2020
Canada	Eastern	470	240
	Western	580	100
U. S.	East Coast	170	-40
	Midwest	1,900	290
	Gulf Coast	240	230
	Mountain	250	40
	West Coast	170	140
Total		**3,800**	**1,000**

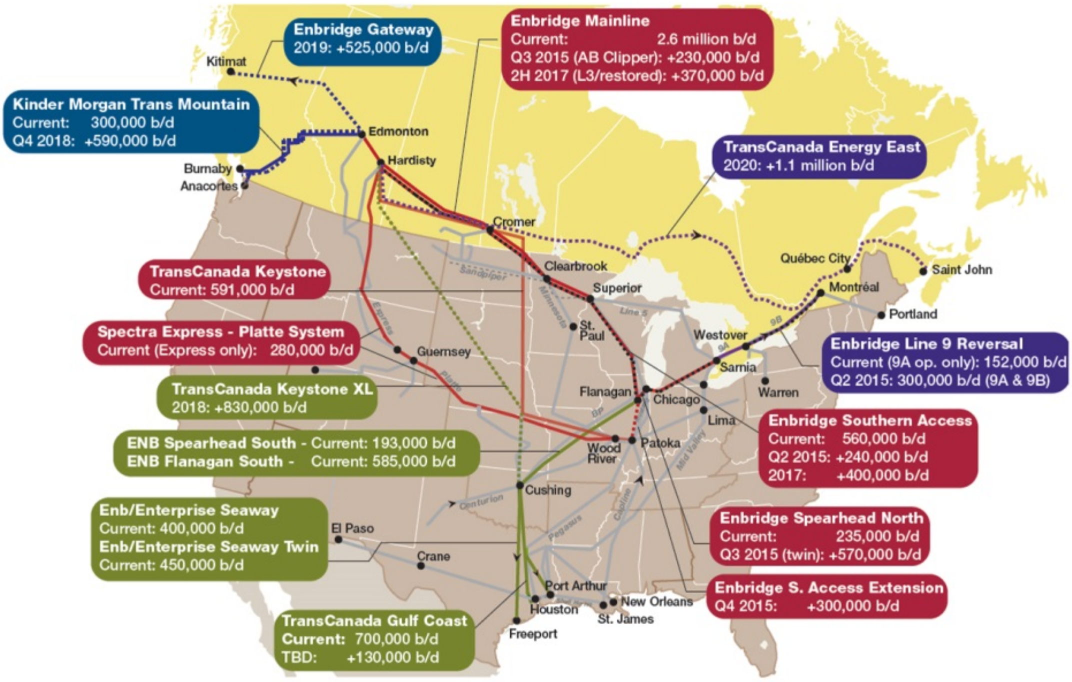
Source: *Crude Oil Forecast, Markets & Transportation*, CAPP, June 2015, pp. 11-21.

However, Canadian producers are seeking to expand export markets for their crude oil beyond the U.S., particularly to Asia, but also to Europe. Diversification of export markets would allow Canadian producers to maximize the value of their oil sands resources. Doing so would require Canadian producers to have low-cost access to harbors that can handle ocean-going tankers. Hence, in addition to the controversial Keystone XL pipeline to the U.S. Gulf Coast, pipeline

[9] California, which imports substantial volumes of crude oil, could be an outlet for large volumes of western Canadian crude. However, no existing or planned pipelines support movement of western Canadian crude oil to California. In addition, California's efforts to control carbon emissions could adversely affect the economics of unconventional Canadian crude oil in California refineries.

operators are seeking to construct (or expand) pipelines to the west and east coasts of Canada, as shown in **Exhibit 3**.[10]

Exhibit 3: Existing and Proposed Pipelines for Transporting Western Canadian Crudes



Source: *Crude Oil Forecast, Markets & Transportation*, CAPP, June 2015, p. iv.

Two pipeline projects have been proposed from Alberta to the west coast of Canada: Enbridge Northern Gateway to Kitimat, British Columbia, and Kinder Morgan Trans Mountain Expansion to Burnaby, British Columbia. The former would be a new pipeline with an initial capacity of 525 K b/d; the latter would expand an existing pipeline system by 590 K b/d.

The proposed TransCanada Energy East pipeline system, involving conversion of an existing natural gas pipeline, reversal of an existing crude oil pipeline, and construction of new pipeline segments and associated pumping and tank infrastructure, would connect Alberta to a marine terminal in New Brunswick; it would have a capacity of 1.1 MM b/d. This pipeline would become the most likely source of supply of Canadian crude oil to markets in Europe.

The fate of these Canadian pipeline projects is unclear, as each faces well-organized opposition from environmental and First Nation organizations. Meanwhile, the White House continues to defer decision on the Keystone XL project.

[10] Crude oil destined for Europe or Asia currently can be shipped by pipeline or rail to the Gulf Coast (and reportedly to the St. Lawrence Seaway) and then onward by marine transport to the export destination. However, without the Keystone XL pipeline in place, it would be impractical to ship significant volumes to the Gulf Coast for export. Further, even with Keystone XL in place, it may be economically unattractive to ship Canadian crude beyond the Gulf Coast, as its highest value may well be as feed to large, complex Gulf Coast refineries.

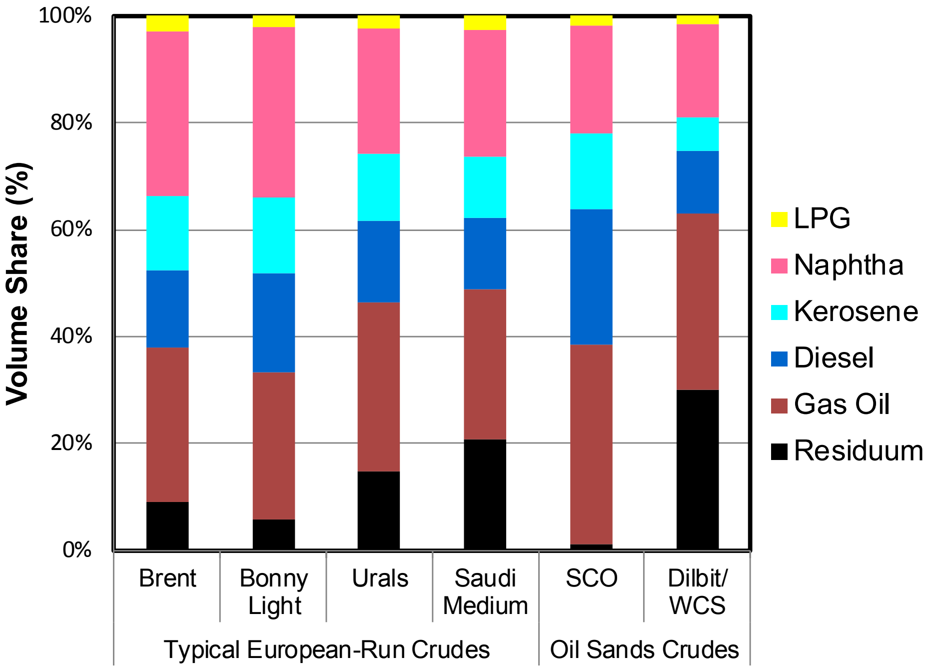
3. PROPERTIES AND PROCESSING OF UNCONVENTIONAL CANADIAN CRUDES

3.1 Properties of Unconventional Canadian Crudes

Canadian SCO, dilbit, and WCS have substantially different yield distributions and properties, and hence different refinery processing requirements, than those of conventional crude oils (even heavy crude oils), including those processed by European refineries. These factors are important determinants of a given refinery's capability to process SCO and dilbits.

Exhibit 4 shows the yield distributions, API gravities, and sulfur contents of four representative conventional crudes processed by European refineries and of representative Canadian SCO and dilbit/WCS.[11] (Of the indicated crude oil fractions, LPG is the lightest and residuum the heaviest.)

Exhibit 4: Yield Distributions of Selected Crude Oils



Crude Oil	Whole Crude API Gravity	Whole Crude Sulfur (wt%)
Brent	38.5	0.36
Bonny Light	37.5	0.14
Urals	32.2	1.17
Saudi Medium	30.3	2.45
Syncrude	31.7	0.15
Dilbit WCS	20.6	3.51

[11] The yield distributions are based on assays obtained by MathPro from public and private sources.

SCO and dilbit/WCS have yield distributions that (i) differ markedly from those of the four conventional crudes and (ii) differ markedly from each other.

- SCO has no or little residuum (because it is destroyed in the upgrading processes used by Canadian producers), very high yields of gas oil and distillate fractions, and very low sulfur content (because hydrotreating is part of the upgrading process).

- Dilbit/WCS has more residuum, about 30%, and less of the lighter crude oil fractions – naphthas, kerosene, and diesel – than any of the conventional crudes.

These differences have strong implications regarding the refinery configurations and capabilities required for processing such crudes, as discussed in Section 3.2.

Exhibit 5 (page 13) shows key properties for the naphthas, distillate, vacuum gas oil, and vacuum resid fractions for the four representative conventional crudes processed by European refineries and for Canadian SCO and dilbit/WCS. Various properties of the oil sands crudes create processing challenges for European refineries.

- SCOs (especially those produced via the coking/hydrotreating route) have vacuum gas oil (VGO) fractions that are low in sulfur, but heavier, higher in aromatics content, and more difficult to process than the VGO fractions in conventional crudes.[12]

  Further, SCO distillate fractions – kerosene and diesel – have very low cetane numbers, making them relatively unattractive as blending components in European diesel fuel, which must meet very high cetane specifications.

  (SCO vacuum resid properties are not important in this context, because SCO contains little or no vacuum resid.)

- Dilbit/WCS crudes have vacuum resid fractions that are heavier and higher in sulfur than the resid fractions in conventional crudes, calling for more robust vacuum resid processing and more extensive secondary processing, including desulfurization in particular.[13]

  Dilbit/WCS VGOs are heavier, higher in sulfur and aromatics content, and more difficult to process than the VGO in conventional crudes.

[12] The API gravities and K-factors of SCO light and heavy VGOs are significantly lower than those of the conventional crudes. *K-factor* is a measure of the relative concentration of paraffins and aromatics. Lower values signify higher aromatics concentrations, which make for more difficult catalytic cracking and hydrocracking operations.

[13] Vacuum resids in dilbit/WCS also has higher *Con Carbon*, a measure of carbon residue. Vacuum resid with high Con Carbon is more difficult to process and has lower yields of high-value products than vacuum resids with low Con Carbon. Refineries may also reduce the cut point temperature for dilbit/WCS vacuum resid to facilitate its processing, but this would increase the volume of vacuum resid to be processed.

As with SCO, the kerosene and diesel fuel fractions have low cetane numbers, making them unattractive blending components in European diesel fuel.

- Both SCO and dilbit/WCS have naphtha fractions that are good reformer feeds (after desulfurization), as indicated by their relative high N + 2A indices.[14]

Exhibit 5: Key Properties for Distillation Fractions of Typical European Crudes and Oil Sands Crudes

Distillation Fraction	Type	Boiling Range (°F)	Property	Typical European-Run Crudes				Oil Sands Crudes	
				UK Brent	Nigerian Bonny Light	Russian Urals	Saudi Medium	SCO	Dilbit/ WCS
Naphthas	Very Light	C5-160	RON	72.8	78.6	68.8	70.5	60.1	69.4
	Light	160-250	N + 2A (vol%)	78.0	24.5	51.3	25.4	54.3	60.0
	Medium	250-325	N + 2A (vol%)	67.8	77.0	51.0	45.3	86.9	88.6
	Heavy	325-375	N + 2A (vol%)	71.7	88.8	55.6	64.8	85.4	95.3
Distillate	Kerosene	375-500	Sulfur (wt%)	0.05	0.07	0.21	0.32	0.02	0.75
			Cetane No.	44.9	41.7	44.0	49.0	31.0	33.3
	Diesel	500-620	API Gravity	34.8	33.6	33.6	35.2	27.3	27.4
			Sulfur (wt%)	0.17	0.12	0.66	1.39	0.07	1.57
			Cetane No.	48.8	49.8	48.2	51.2	37.0	37.3
Vacuum Gas Oil	Light	620-800	API Gravity	29.7	28.1	26.9	26.5	21.7	19.2
			Sulfur (wt%)	0.35	0.19	1.29	2.55	0.24	2.63
			K factor	12.0	11.9	11.8	11.8	11.4	11.2
	Heavy	800-1050	API Gravity	20.7	19.6	20.4	19.1	18.3	14.2
			Sulfur (wt%)	0.75	0.27	1.59	3.19	0.34	3.50
			K factor	12.0	11.9	12.0	11.9	11.7	11.4
Vacuum Resid	Residual Oil	1050+	API Gravity	11.6	11.0	6.7	4.1	15.2	0.6
			Sulfur (wt%)	1.28	0.41	2.67	5.35	0.48	6.26
			Con Carbon (wt%)	25.7	16.9	19.0	25.1	3.5	28.7

3.2 Refining Processes Required for Unconventional Canadian Crudes

3.2.1 SCO and Vacuum Gas Oil (VGO) Processing

Small volumes of SCO can be run (at least for a short time) in most European refineries with little, if any, process additions or modifications. But replacement of a significant share of a refinery's conventional crude slate with SCO would require that the refinery have spare capacity in its VGO conversion processes – *fluid catalytic cracking (FCC)* and/or *hydrocracking*[15] – or

[14] *N+2A* denotes the volume percent of naphthenes (N) plus twice the volume percent of aromatics (A) in a naphtha stream. High N+2A leads to high yields of gasoline from *reforming* – a work-horse refining process for converting low-octane straight run naphthas into a high-octane gasoline blendstock (called *reformate*).

[15] *Cracking* processes convert VGOs to higher-valued, lighter refinery streams that are components of diesel fuel, jet fuel, and gasoline. Cracking processes are often referred to as *conversion* processes.

that it add or expand such capacity, in order to process the high volume fraction of VGO in the SCO. It also might require enhanced secondary processing to improve the cetane number of the straight-run distillate and cracked distillate material (to meet the high cetane standards for European diesel fuel).[16]

On the other hand, introducing SCO into a refinery's crude slate to replace a significant volume of conventional crude would reduce the utilization rate of processes designed for processing low-value residuum. The different yield patterns of SCO and its disparate effects on refining process capacity utilization probably would lead refineries to significantly rebalance their portfolio of crudes to fully take advantage of SCO.

It's not clear how the economics of SCO would play out in the European refining sector. However, the issue may be moot, because most of the forecast increase in Canadian SCO supply likely will be absorbed in the North American market, rather than being exported to other markets.

3.2.2 Dilbit/WCS and Vacuum Residuum Processing

Dilbit/WCS is not an attractive crude oil for most European refineries, as they are now configured. These crudes contain a high volume share of vacuum resid, and relatively few European refineries have existing (or planned) capacity for suitably processing this material on a sustained basis.

Market economics generally dictate that refineries using heavy crudes (conventional or unconventional) either convert the large volume fraction of vacuum resid in these crudes into lighter streams that can be further processed into gasoline, jet fuel, and diesel fuel, or assign unconverted vacuum resid to low-value products, such as asphalt, residual fuel (for power plants), or marine bunker fuel. Markets for residual fuel continue to contract, and sulfur specifications for marine bunker fuel have become tighter, furthering lowering the value of the vacuum resid material in crude oil.

Converting vacuum resid material into lighter, more valuable streams requires certain process units, the most important of which are:

- *Resid processing units*, to convert the vacuum resid material into lighter refinery streams, including VGO material; and

- *VGO processing units* (identified above), to further convert the VGO produced by the resid processing units into lighter refinery streams.

There two most important processes for significantly upgrading very heavy, high-sulfur resids (such as those from dilbit and WCS) are *coking* and *resid hydrocracking*.

[16] The secondary processing could involve processes for dearomatizing material in the distillate boiling range: reducing the aromatics content of distillate material to improve its cetane number for subsequent blending in diesel fuel. Such processes are relatively costly.

- *Coking* is the work-horse process in U.S. refineries for converting vacuum resid material, including that contained in dilbit/WCS, into lighter, more valuable refinery streams. However is not widely used in the European refining sector.

  Coking is a thermal cracking process, in which the large hydrocarbon molecules in vacuum resid are converted into smaller hydrocarbon molecules, along with "excess" carbon, which is rejected in the form of petroleum coke. Cokers produce a range of intermediate refinery streams, including LPG, naphthas, distillate, and vacuum gas oils. Except for LPG, these coker streams have higher aromatics and sulfur content than the corresponding straight-run streams distilled directly from conventional crude oil. Hence, the coker streams require more extensive and severe secondary processing to produce finished products (gasoline, jet fuel, and diesel fuel) that meet market specifications.

- *Resid hydrocracking* processes (e.g., H-Oil™ , LC-FINING™ , and EST™) convert resid streams into lighter hydrocarbons not through carbon rejection, but through the addition of hydrogen. The cracking takes place in a hydrogen-rich environment, producing greater volumes of the lighter intermediate streams (and with substantially lower aromatics and sulfur content) than does coking. Resid hydrocracking is more capital intensive than coking, but it produces more and higher-quality distillate fuels streams.

Coking has been the most widely-used process for converting vacuum resid, but resid hydrocracking is gaining ground (especially outside the U.S.). Numerous techno-economic studies have indicated favorable economics for resid hydrocracking units. But, the high initial capital costs of resid hydrocracking (and the associated hydrogen production) have inhibited its adoption.

Solvent deasphalting (SDA) is another process for upgrading vacuum resid streams. SDA is not a cracking process; rather, it separates vacuum resid into two streams: a lighter stream (deasphalted oil (DAO)), which is a good feedstock for catalytic cracking) and a heavy, highly aromatic stream (pitch), which can go to asphalt production or residual fuel. SDA is a proven commercial process, but it is not used as widely as coking or resid hydrocracking.

Other cracking processes that European refiners now employ to process vacuum resid, such as visbreaking (frequently employed) and thermal cracking (a minor process), are unsuited for processing vacuum resid from dilbit/WCS for both technical and economic reasons. In general, these older technologies are not capable of dealing with the very heavy and high sulfur material comprising dilbit/WCS vacuum resid. Further, visbreaking does not "convert" sufficient volumes of vacuum resid to lighter material to make it economically attractive to process dilbit/WCS.

Asphalt production provides an outlet for the heaviest residue from heavy crude oils, such as dilbit/WCS. Refineries that do not have vacuum resid processing capacity but do have asphalt production capacity may be able to process small volumes of dilbit/WCS. Similarly, the presence of an asphalt plant might increase the amount of dilbit/WCS that a refinery with vacuum resid conversion capacity could process.

Other, less common outlets for vacuum resid include co-located power plants and co-generation facilities. The feasibility of these outlets for vacuum resid from dilbit/WCS is limited by the high sulfur content of this material.

Even in suitably configured refineries, the physical properties of the various dilbit/WCS fractions (e.g., acid content, metals content, aromatics content, etc.) may make dilbit/WCS unsuitable for processing without certain refinery revamps. These include, for example, upgrading process metallurgy to control corrosion, installing facilities to prevent catalyst poisoning, etc.

3.3 Experience with Unconventional Canadian Crudes in the U.S. Midwest Region

The largest export market for Canadian oil sands crudes is the U.S Midwest region.[17] The actions taken by U.S. Midwest refineries to facilitate increased use of oil sands crudes provide insight regarding the processing capabilities that European refiners would have to have to process significant volumes of Canadian oil sands crudes.

Exhibit 6 (page 17) shows two broad changes in crude oil use by Midwestern refineries over the last decade:

- Imports of Canadian heavy crudes (mostly unconventional) increased by about 700 K b/d. The increased volume of these crudes displaced imported crudes originating from numerous sources, including the North Sea, South America, Africa, and the Middle East. The shift to Canadian heavy crude and the displacement of virtually all crudes from other countries significantly decreased the average API gravity and increased the average sulfur content of the imported crude slate processed by the Midwest refineries.

- The unexpected supply of domestic light crude oil, primarily from the Bakken formation (mostly in North Dakota) displaced other domestic crudes. This significantly increased the average API gravity and decreased the average sulfur content of the domestic crude slate processed by the Midwestern refineries.

On net, the Midwestern refining sector's crude slate saw only small increases in average API gravity and sulfur content.

Midwest refineries already were processing significant volumes of Canadian heavy crudes in 2002. Eleven of the 25 refineries in the region processed Canadian heavy crudes in volumes ranging from *de minimis* levels to as much as 80% of crude distillation capacity. On average, Canadian heavy crudes amounted to about 27% of the region's crude distillation capacity.

In response to the growing availability of low-cost Canadian heavy crudes, two Midwest refineries added grassroots coking capacity; another substantially expanded its existing coking capacity; and a fourth currently is expanding and upgrading its heavy crude processing capability

[17] The Midwest region corresponds to Petroleum Administration Defense District 2 (PADD 2).

(expanding coking capacity and revamping its crude distillation unit), raising its heavy crude processing capability to about 50% of crude distillation capacity.

Exhibit 6: Crude Oil Volumes and Properties, U.S. Midwest Refining Region[1]

Crude Oil	Properties	2002	2013
Volumes (K b/d)		**3,218**	**3,522**
Domestic		1,724	1,683
Imports		1,494	1,839
Canadian SCO		284	335
Canadian Heavy[2]		503	1,197
Canadian All Other		159	263
Non-Canadian		548	43
Average Properties			
Pool	API Gravity	32.8	33.2
	Sulfur (wt%)	1.31	1.45
Domestic	API Gravity	35.5	42.6
	Sulfur (wt%)	0.93	0.17
Imports	API Gravity	29.9	25.4
	Sulfur (wt%)	1.73	2.51

1 Midwest corresponds to PADD 2.
2 Includes both oil sands crudes and conventional crudes.
Source: Derived from *EIA Website, Crude Oil Properties and Company-Level Import Data*.

Exhibit 7 (page 18) provides information on the process capacity and crude oil use of Midwest coking refineries in 2013. Total coking capacity expanded from 360 K b/d in 2002 to about 520 K b/d in 2013, an increase of more than 160 K b/d. This increase allowed expanded use of Canadian heavy crudes, from about 19% of crude distillation capacity in 2002 to about 35% in 2013.

Coking refineries also added or significantly expanded hydrocracker capacity and hydrogen production and recovery capacity. It is difficult to ascertain how much of the latter capacity increases were related to increased use of heavy, high sulfur Canadian crudes – as opposed to shifts towards more distillate production and imposition of sulfur controls on gasoline and diesel fuel by the EPA. But, Midwestern refineries added relatively more hydrocracking and hydrogen production capacity over the past decade than did refineries in any other region of the U.S.

In 2013, Midwestern coking refineries used a volume of Canadian heavy crudes equal to, on average, about 35% of distillation capacity. Given that distillation capacity utilization was about

90% in 2013, about 39% of the crude oil slate of Midwest coking refineries was Canadian heavy crude. The volume of residuum from Canadian heavy crudes represented, on average, about 38% to 44% of coking capacity in these refineries, depending on the initial boiling point (*cut point*) of the vacuum resid – 1000°F or 1050°F – used to estimate residuum volumes.[18, 19]

Exhibit 7: Process Capacity and Crude Oil Use, Midwest Refineries with Coking Capacity in 2013

	2002	2013
Average Complexity	**9.6**	**10.3**
Number of Coking Refineries	**12**	**14**
Refining Processes		
Distillation		
Atmospheric	2,555	2,726
Vacuum	1,164	1,362
Conversion		
Coking	358	523
Cat Cracking	816	822
Hydrocracking	120	209
Other		
Asphalt Production	165	151
Hydrogen (MM scf/d)[1]	302	700
Capacity Utilization (%)		
Atmospheric Distillation[2]	92%	90%
Coking	89%	79%
Imported Crude Oil		
As Percent of Distillation Capacity	42%	51%
Canadian SCO	8%	8%
Canadian Heavy[3]	19%	35%
Canadian, All Other	4%	8%
Non-Canadian	11%	0%
Average Properties		
API Gravity	28.5	25.1
Sulfur (wt%)	1.90	2.59
Candian Heavy Residuum as % of Coking Capacity[4]		
Cut point 1050° F		38%
Cut point 1000° F		44%

1 Includes both production and recovery.
2 Average for all refineries, not just coking refineries.
3 Includes both oil sands crudes and conventional crudes.
4 Estimated after accounting for volume of residuum used in aphalt production.
Source: Derived from OGJ data on refining capacity and EIA data.

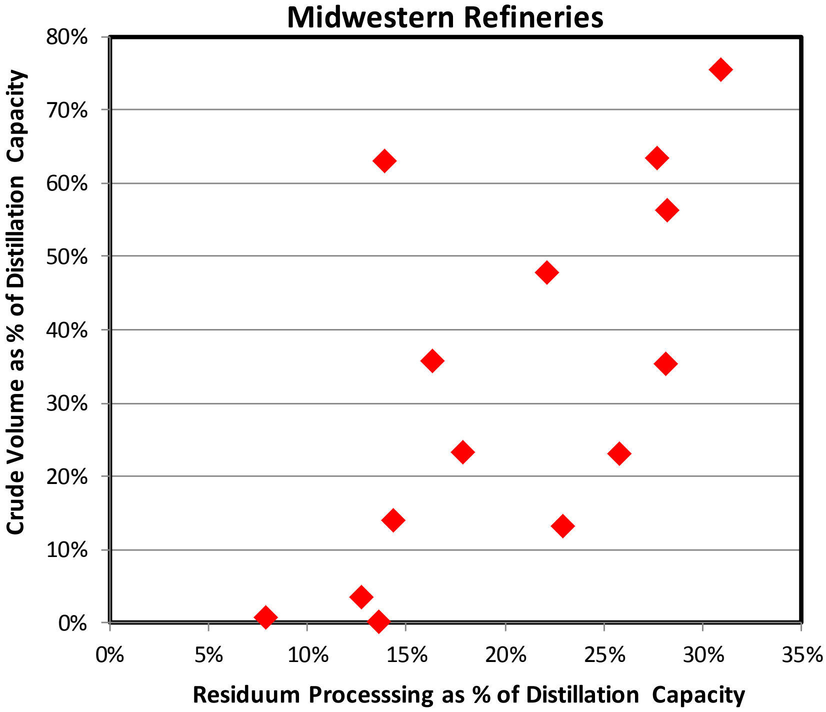
[18] Many coking refineries also produce asphalt from residuum. Asphalt production reduces the call for coking capacity, because residuum volumes that go to asphalt production do not go to coking.

[19] Refiners sometimes set the vacuum resid cutpoint at the lower temperature for heavy, unconventional crudes to improve the performance of the coker and downstream processes.

In individual refineries, residuum from Canadian heavy crudes ranged from about 10% to about 85% of total coking capacity (after subtraction of estimated resid volumes going to asphalt production).

Exhibit 8 shows – for individual Midwest coking refineries – the percentage of distillation capacity accounted for by Canadian heavy crude oil (Y-axis), primarily dilbit, versus the refinery's residuum processing capacity (coking and asphalt plant) expressed as a percentage of crude distillation capacity (X-axis). A priori, one would expect the use of Canadian heavy crude to increase with residuum processing capacity. Exhibit 8 indicates such a relationship, with significant refinery-to-refinery variation, in the Midwestern refining sector.

Exhibit 8: Use of Canadian Heavy Crude Oil vs. Residuum Processing Capacity of U.S. Midwestern Refineries



Note: Residuum processing for Midwestern refineries consists of coking & asphalt production.

Also in 2013, Canadian SCO volumes in Midwestern refineries averaged about 8% of distillation capacity in coking refineries and 9% across all refineries. Data on crude oil imports published by EIA indicates that a majority of Midwestern refineries – 15 out of 25 – used at least some SCO, in volumes ranging from *de minimis* levels to over 35% of crude distillation capacity. Unlike with heavy crudes (conventional and unconventional), which require the presence of robust residuum processing capacity, identifying refineries likely to process SCO is difficult on the basis of publically available information on refinery process capacities alone.

4. CHARACTERIZATION OF THE EUROPEAN REFINING SECTOR

This section provides information on the crude oil sourcing, current capacity and processing capability, and financial condition of the European refining sector. All of these factors influence the sector's current and prospective capability to process significant volumes of Canadian oil sands crudes.

4.1 Crude Oil Sourcing

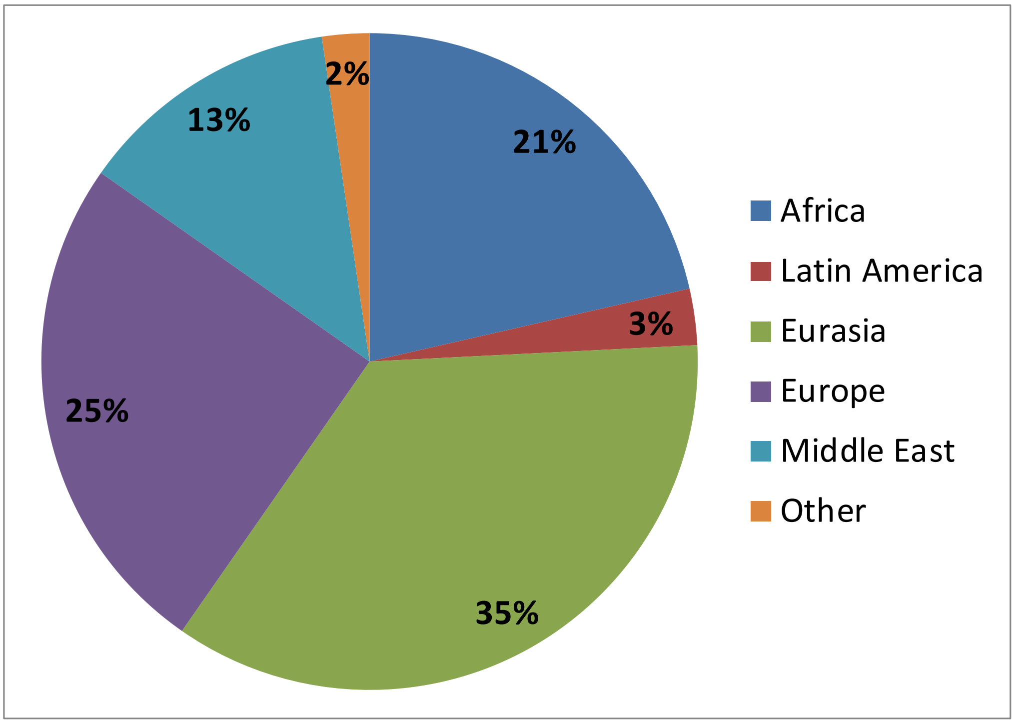
Crude oil run by the European refining sector has average API gravity of around 35^{o} degrees and sulfur content of about 1 wt%.[20] In contrast, crude oil run by the U.S. refining sector averages about 31^{o} API and 1.4 wt% sulfur. Thus, on average, Europe processes a relatively light, low-to-medium sulfur crude slate, consistent with its relatively low index of refining complexity.

Exhibit 9 (page 21) shows the sourcing of the European refining sector's crude oil supplies. The sector currently imports about 75% of its crude oil, primarily from Africa, Eurasia, and the Middle East. The remaining 25% of crude supply comes mainly from the North Sea.

Exhibit 10 (page 22) shows the volumes and volume shares of crude oil imports from countries that supplied more than 400 K b/d of crude to Europe in 2014. Russia is the largest supplier – supplying almost 3 M b/d, over 25% of Europe's crude oil supply. Latin America (primarily Brazil, Colombia, and Venezuela) supplied about 300 K b/d. Notably, Canada supplied about 50 K b/d, across all crude categories.

[20] This is a rough estimate, developed by applying the API gravities and sulfur contents of representative crudes to regions supplying crude oil to Europe.

Exhibit 9: EU Crude Oil Supply in 2014, by Region

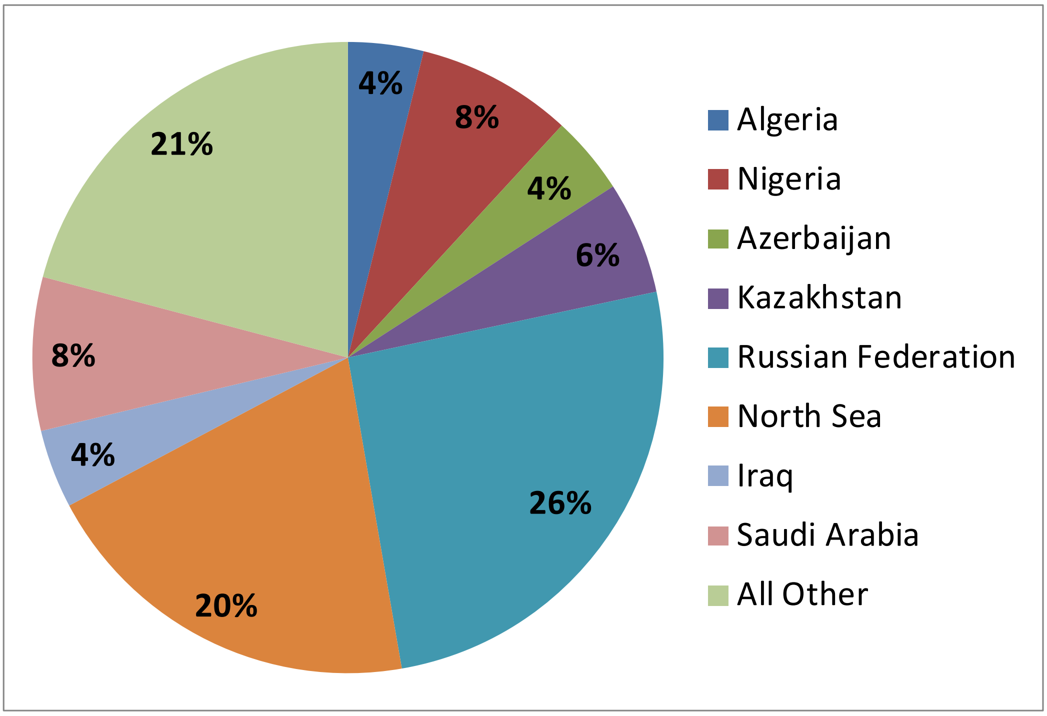


Region	Share	Volume (K b/d)
Africa	21%	2,420
Latin America	3%	313
Eurasia	35%	4,006
Europe	25%	2,829
Middle East	13%	1,460
Other	2%	263
Total	**100%**	**11,290**

Note: Excludes relatively small imports by Norway and Switzerland

Sources: Derived from Import Statistics, European Commission; and International Import and Export Data, EIA

Exhibit 10: EU Crude Oil Supply in 2014, by Country



Country	Share	Volume (K b/d)
Algeria	4%	436
Nigeria	8%	902
Azerbaijan	4%	455
Kazakhstan	6%	652
Russian Federation	26%	2,892
North Sea	20%	2,254
Iraq	4%	455
Saudi Arabia	8%	887
All Other	21%	2,358
Total	**100%**	**11,290**

Notes: Listed countries supplied > 400 K b/d in 2014.
Excludes relatively small imports by Norway and Switzerland
North Sea includes production by the U.K, Norway, and Denmark.
Sources: Derived from Import Statistics, European Commission; and
International Import and Export Data, EIA

4.2 Capacity and Processing Capability

A total of 95 refineries are operating in the European refining sector, with crude running capacity of almost 15 MM b/d.

Exhibit 11 shows aggregate European refinery processing capacity by type of refining process. **Exhibit 13**, at the end of this section, breaks out this information by country.

Exhibit 11: European Refining Sector's Current Process Capacity (K b/d)

Process	Capacity
Distillation	
Atmospheric	14,788
Vacuum	5,809
Vacuum Resid Processing	
Coking	492
Visbreaking & Thermal Cracking	1,535
Resid Hydrocracking	319
Asphalt Production	297
Vacuum Gas Oil Cracking	
Cat Cracking (FCC)	2,251
Hydrocracking[1]	1,485
Gasoline Processes	
Catalytic Reforming	2,159
Gasoline Upgrading[2]	745
Catalytic Hydrotreating	
Naphthas	4,094
Distillate	4,781
Other	1,330
Hydrogen Production & Recovery[3]	3,079
Average Complexity	7.3
Number of Refineries	95

Note: Because we could not locate capacity data for some processes/refineries, aggregate process capacities and refining complexity are somewhat understated.

1 Excludes resid and lube oil hydrocracking.

2 Includes alkylation, polymerization, dimersol, and C5 & C6 isomerization.

3 In million scf/d.

Source: Exhibit 13.

Exhibit 11 indicates that:

- Most of the European refining sector's resid processing capacity is in visbreaking, an older technology unsuited for processing significant volumes of Canadian dilbit/WSC crudes. (Visbreaking constitutes almost 80% of the combined visbreaking and thermal cracking capacity shown in Exhibit 11.)

- The European refining sector has a small amount, ≈ 350 K b/d, of resid hydrocracking capacity. Of this capacity, we estimate that < 100 K b/d is capable of processing the very heavy, high sulfur resid from Canadian dilbit/WSC crudes. (The basis for this estimate is discussed in Section 5.)

- The European refining sector has coking capacity of about 500 K b/d, about 3½ percent of crude distillation capacity.

  The U.S. refining sector has virtually no visbreaking capacity and coking capacity of about 2.4 M b/d, about 15% of crude running capacity.

  The European refining sector has a complexity index of 7.3 (which may be somewhat understated because of some missing process capacity data).[21] (The U.S. refining sector has a complexity index of about 10, the world's highest).

4.3 Financial and Competitive Situation

The European refining sector faces continuing overcapacity; high operating costs; declining supplies of North Sea crudes; declining domestic demand for refined products (except for transportation fuels, whose demand is expected to remain essentially flat); and shrinking export markets (the U.S. East Coast gasoline market in particular).

Consequently, the European refining sector has experienced significant contraction in recent years, marked by refinery closures or conversions to other uses. From 2008 to 2013, fifteen European refineries shut down.[22] Three more, one in the UK and two in Italy, shut down in 2014.[23] These closures have reduced European refining capacity by about 2 M b/d, about 13% of current refining capacity. **Exhibit 12** (page 25) shows the locations of operating refineries, along with those that have been closed (through 2013).[24]

Several analyses published in 2014 suggest that bringing refining sector capacity into balance with market conditions will require reducing European refining capacity by another 2 to 2½ MM

[21] *Complexity index* is a measure of a refinery's capability to produce light, high-value refined products by converting the heaviest fractions in its crude oil slate.

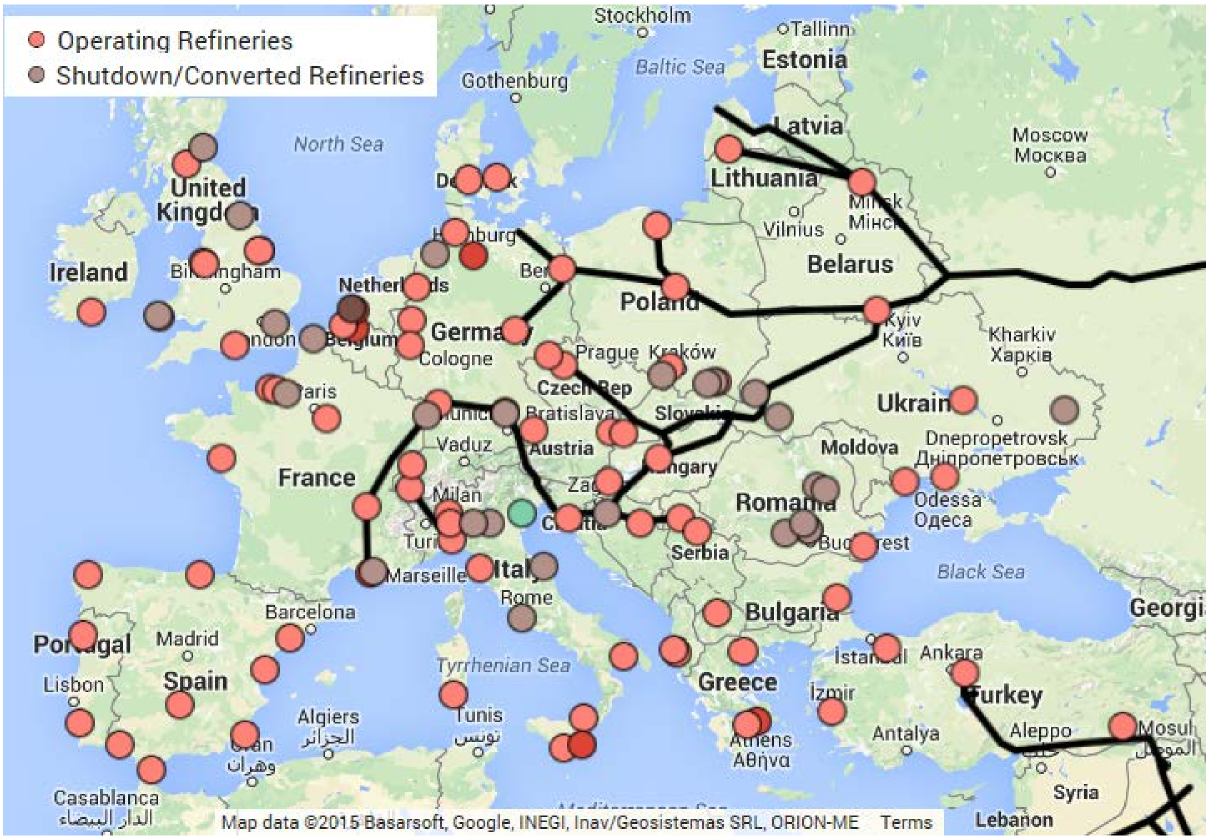
[22] *The Competitiveness of European Refining: Facing the Challenges*; FuelsEurope; Sept. 30, 2014; pg. 21.

[23] *2014 in Refining: Europe is Ailing, Italy is Worse*; ISPI Energy Watch; Italian Institute for International Political Studies; Jan. 13, 2015.

[24] The green dot in Exhibit 12 denotes the former ENI Porto Marghera refinery, converted to a "bio-refinery" producing "green diesel fuel" starting in 2014.

b/d by 2018–2020. Since the publication of these recent forecasts, new refinery closures have reduced refining capacity by another 200 K b/d, due to refinery closures.[25]

Exhibit 12: European Refineries -- Operating and Closed



The unfavorable prospects for the European refining sector stem from a confluence of related factors, including:

- European demand for refined products in general is projected to decline over the next twenty years. European demand for transportation fuels is projected to be flat over the next decade. By contrast, demand for refined products and transportation fuels in particular is projected to grow in other regions, including Asia/Pacific, Latin America, and the Middle East.

- The mix of refined product demand in Europe has shifted away from gasoline and toward diesel fuel, a shift expected to continue (from about 29% of total refined product demand in

[25] Refineries that apparently are at high risk of closure include Eni's Taranto and Livorno refineries in Italy, and Ina's Sisak refinery in Croatia. Reportedly, Total has halved the capacity of its Lindsey refinery in the UK. Total's La Mede refinery is to be converted to a bio-refinery after 2016.

2011 to 39% in 2030). European refineries already produce an excess of gasoline, which must be exported to foreign markets in which they face increasing competition. Conversely, Europe is dependent on imports of jet fuel and diesel fuel.

- The U.S. market for gasoline imports continues to shrink. U.S. East Coast imports of motor gasoline blending components and finished gasoline declined from about 760 K b/d in 2010 to 540 K b/d in 2014, placing pressure on European refineries to find other markets for excess gasoline supplies

- The EU is imposing stricter sulfur standards on marine distillate fuels, independent of final decisions by the International Maritime Organization. In response, the European refining sector has invested in new conversion capacity to (i) increase output of distillate fuels and (ii) shift production of marine fuel used in Sulfur Emission Control Areas (ECA) from high-sulfur resid (3 wt%) to low-sulfur (0.1 wt%) distillate, starting in 2015. More investment will be needed to supply 0.5 wt% sulfur marine fuels outside the ECA starting in 2020.

- Refining capacity is expanding in regions that export refined products to Europe. About 2 M b/d of capacity additions are in train in the Middle East (Saudi Arabia, Iraq, Kuwait, Qatar, UAE, Oman) alone through 2022, with plans announced for an additional 1 M b/d.[26] These "ultra-modern mega-refineries … are expected to swamp Europe with refined products."[27] Significant expansions also are planned in Asia and Africa.[28] Additionally, the shale oil boom in the U.S. has led to increases in U.S. refinery crude runs and expanded exports of gasoline and diesel throughout the Atlantic Basin.

- Energy is the largest single operating cost for refineries, after crude acquisition, and European refineries' energy costs are high relative to those of refineries in other regions (except for Singapore/South Korea).[29]

In combination, these demand, supply, and legislative developments have suppressed refining margins and capacity utilization in European refineries. They are likely to continue to pressure the European refining sector and lead to further refinery closures. Consequently, recent analyses of world refining prospects, such as those published by IEA and OPEC, forecast a generally stagnant European refining sector with little, if any, long term additions in conversion capacity. Refiners such as Total, Royal Dutch Shell, BP, and Eni reportedly plan to substantially reduce their refining capacity in Europe.

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[26] A number of refining projects in the Middle East have been delayed, providing some respite to the European refining sector. However, these projects are expected to be completed soon.

[27] *CORRECTED-European "Refining Spring" Won't Save Plants from the Axe;* Reuters; Feb. 13, 2015.

[28] *European Refining Capacity and Margin View*; JBC Energy; Platt's Middle Distillates Conference; January 2014; pg. 19; and *European Refining Industry in Stormy Waters*; Roland Berger; June 2014, pg. 7.

[29] *European Refining Industry in Stormy Waters*; Roland Berger; June 2014, pg. 11.

The dismal financial situation and prospects of the European refining sector in general suggests that European refineries may be reluctant to undertake capital investments to process significant additional volumes of Canadian oil sands crudes, even if discounted prices for these crudes and refining economics for such processing were to promise improvement in refining margins.

Exhibit 13: Summary of European Refining Sector's Processing Capacity (K b/d unless otherwise specified)

Country	No. Refin-eries	Avg. Com-plexity	Distillation		Resid Processing				VGO Processing		Gasoline Processes		Hydrotreating			Hydrogen
			Atmos	Vacuum	Coking	Thermal Cracking & Visk.	Cat Hydro-Crack	Asphalt Prod.	Cat Crack-ing	Hydro Crack-ing[1]	Catalytic Reform-ing	Gasoline Upgrad-ing[2]	Naph-thas	Dist-illate	Other	Prod. & Recov. (MM scf/d)
AUSTRIA	1	8.5	204	79		13	42	1	28	16	23	22	38	94	2	62
BELGIUM	5	5.7	891	300		51		27	130		115	21	320	330	180	99
BULGARIA	1	7.3	190	70		21	47	2	35	37	14	3	41		23	10
CROATIA	2	6.4	134	50	5	12	12		30		29	5	15	28		
CZECH REPUBLIC	3	7.1	194	79		14		11	24	30	27	7	48	55		112
DENMARK	2	4.2	169	22		68		8			22	6	31	11		
FINLAND	2	11.3	261	146		34	42	7	57	56	50	20	107	128	64	160
FRANCE	8	6.5	1,416	529		111		19	245	77	195	70	416	570	114	132
GERMANY	13	8.3	2,301	1,068	104	308	26	59	350	205	402	133	754	918	290	683
GREECE	4	8.7	423	197	20	49		17	76	84	49	28	144	151	68	125
HUNGARY	1	9.8	161	78	17	14		6	24	29	30	7	31	50	40	76
IRELAND	1	5.0	71								11	8	19	35		10
ITALY	11	6.8	1,855	687		297	62	12	286	246	211	83	497	385	59	360
LITHUANIA	1	8.7	190	89		29			43		46	26		100	54	25
NETHERLANDS	6	6.3	1,265	404	42	91	25	11	104	173	149	24	289	493	35	359
NORWAY	2	4.6	319		23	32			55		35	15	50	58	18	
POLAND	2	7.7	512	265			40	33	33	106	68	27	130	123	7	167
PORTUGAL	2	7.2	304	88		37			41	52	50	5	91	93	17	85
ROMANIA	5	8.0	408	230	56	18		5	104	34	46	10	110	94	65	37
SLOVAKIA	1	11.0	115	55			23	3	18	19	21	11	25	38	24	90
SPAIN	9	6.9	1,518	545	157	149		27	191	182	197	42	267	507	72	300
SWEDEN	5	7.2	437	136		67		27	30	105	71	32	226	14	28	54
SWITZERLAND	1	7.2	60	24		20		5			16	4	27	35		
UNITED KINGDOM	7	8.5	1,390	671	68	102		18	348	36	284	137	418	469	171	133
Total	**95**	**7.3**	**14,788**	**5,809**	**492**	**1,535**	**319**	**297**	**2,251**	**1,485**	**2,159**	**745**	**4,094**	**4,781**	**1,330**	**3,079**

Notes: Excludes aromatics production, oxygenate production, and C4 isomerization.
We were not able to find publicly available capacity data for some processes/refineries. Consequently, aggregate process capacities and average refining complexity are somewhat understated.
1 Excludes hydrocracking capacity listed as resid and lube oil manufacturing.
2 Includes alkylation, polymerization, dimersol, and C5 & C6 isomerization.
Source: Derived from "2015 Worldwide Refinery Survey," *Oil & Gas Journal*, supplemented with data from web searches.

5. European Refineries That Could Process Unconventional Canadian Crudes

In Section 3, we identified the key process units and capabilities that a refinery must have in order to run significant volumes of Canadian SCO or dilbit/WCS in sustained commercial operations. They are summarized below.

Threshhold Processing Capability	Canadian Oil Sands Crude	
	SCO	Dilbit/WCS
Vacuum Gas Oil Processing Catalytic cracking (FCC) Gas oil hydrocracking	●	●
Vacuum Resid Processing Coking Resid hydrocracking Solvent desasphalting		●

These are minimum, or threshold, capabilities – necessary but not sufficient for processing significant volumes of SCO or dilbit/WCS in sustained commercial operations. Other technical and economic factors, many of which are not discernable from publically available information, can determine whether or not a European refinery is capable of or likely to switch some of its crude slate to SCO or dilbit/WCS. These factors include, but are not limited to:

- The refinery's configuration and process capability downstream of the cracking and coking units (e.g., hydrotreating), as needed to upgrade the intermediate refinery streams produced by cracking and coking the heavy fractions of SCO and dilbit/WCS and/or the lighter fractions of these crudes
- The refinery's capacity utilization, in both crude running and conversion processes
- The refinery's location, which determines its access (direct or indirect) to water-borne crude oil supplies and its current sources of crude supply

With these considerations in mind, we established two sets of criteria – one for SCO and one for dilbit/WCS – to assess the European refineries and identify those that are the most prospective candidates to use significant volumes of Canadian oil sands crudes.

5.1 SCO-Capable Refineries

SCO vacuum gas oil has high aromatics content and SCO distillate has high aromatics content and low cetane. These are undesirable properties in European refineries because of Europe's very high cetane standards for diesel fuel. SCO also has an outsized vacuum gas oil fraction (Exhibit 4)

Given these characteristics, the feasibility and incentives for a refinery to process SCO depends on whether the refinery has excess vacuum gas oil conversion capacity (fluid cat cracking and hydrocracking).

Exhibit 14 (page 32) shows all the European refineries that have vacuum gas oil conversion capacity.

We used the following criteria to assess the prospects for European refineries with vacuum gas oil conversion (FCC or hydrocracking) capacity to process SCO:

1. The refinery's vacuum gas oil conversion capacity is $\geq$ 30% of its distillation capacity (a somewhat arbitrary cutoff), on the theory that such refineries are the ones most likely to have some excess conversion capacity to handle SCO.[30]

2. The refinery is located in Western Europe, with easy access to waterborne imported oil and relatively less access to imports from Eastern suppliers (primarily Russia, Azerbaijan, and Kazakhstan).

In Exhibit 14, the refineries designated **Most Likely** are those that meet both criteria; the refineries designated **Less Likely** are those that meet the second criterion (location) but not the first. The remaining European conversion refineries are designated **Unlikely** because they do not meet the second criterion (location); regardless of whether they meet the first criterion.

Finally, even if the Canadian Energy East pipeline project were completed, the volume of SCO processed by European refineries likely would be small because (i) the forecast increase in supply of Canadian SCO is small; (ii) the increase is likely to be absorbed by refineries in North America; and (iii) certain properties of SCO fractions make it a problematic feedstock for European refineries.

5.2 Dilbit/WCS-Capable Refineries

Candidate refineries for processing dilbit/WCS crudes are those that have significant capacity in severe vacuum resid processing, either coking or the newer vacuum resid hydrocracking technologies.[31]

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[30] We have assumed that such refineries have adequate hydrotreating capacity to process added volumes of middle distillates derived from SCO.

[31] An exception to this general rule is the Vitol refinery in Cressiere, Switzerland (included in Exhibit 3), reported as having purchased Canadian crude during each the last five months of 2014. This refinery has thermal cracking and visbreaking capacity, but no coking, vacuum resid hydrocracking, or (apparently) vacuum gasoil processing capacity. This suggests that Vitol is sending intermediate vacuum gas oil streams to another refinery for processing. But, the Vitol refinery has small asphalt plant (5 K b/d capacity, about 9% of crude distillation capacity) that probably is the outlet for the residuum from the heavy Canadian crude.

Exhibit 15 (page 34) shows all the European refineries that meet at least one of the following criteria:

1. The refinery has either coking or severe resid hydrocracking capacity *and* FCC or gas oil hydrocracking capacity to handle the VGO produced by coking.

2. The refinery has other vacuum resid processing capacity or another disposition for vacuum resid, such as an asphalt plant, a nearby power plant, or an on-site co-gen plant.

3. The refinery is identified in a public source – such as *A Barrel Full* – as capable of processing heavy crude oils.

4. The refinery has been reported to or has announced that it is processing dilbit/WCS on a sustained basis.

The refineries designated **Most Likely** are those whose resid processing capacity is > 20% of crude distillation capacity and are favorably located (i.e., in Western Europe); the refineries designated **Less Likely** are those whose resid processing capacity is < 20% of crude distillation capacity but are favorably located. The remaining refineries are designated **Unlikely** by virtue of location and crude oil access, though some of them have resid processing capacity > 20% of crude distillation capacity.

Two refineries in the **Most Likely** category have projects ongoing to add new vacuum resid processing capacity.[32] Another refinery (Total Antwerp) reportedly is planning to add a solvent deasphalting plant.

Vacuum resid processing capacities of some of the refineries in the **Most Likely** category are large relative to distillation capacities – greater than the share of vacuum resid in the crudes they typically process. This suggests that some of these refineries may process intermediate streams, received from other refineries, such as residual fuel oil and vacuum gas oils, in addition to whole crudes. The Phillips 66 refinery in South Killingholme reportedly has such a processing scheme.

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Exhibit 16 (page 36) lists the 95 operating refineries in the European refining sector and shows, for each refinery, whether that refinery is capable of processing SCO, dilbit/WCS, or neither, on the basis of the criteria outlined in this section.

[32] The refineries are ExxonMobil Antwerp (coking) and ENI Sannazarro (solvent deasphalting).

Exhibit 14: Candidate European Refineries for Processing SCO (K b/d)

Country	Company	City	Com-plexity	Distillation: Atmos	Distillation: Vacuum	VGO Processing: Cat Crack-ing	VGO Processing: Hydro Crack-ing[1]	VGO Processing as % of Distillation
Most Likely (VGO Processing > 30% of Distillation Capacity)								
FRANCE	Total SA	Grandpuits	6.7	101	47	31		30%
GERMANY	Bayernoil Raffineriegesellschaft GMB	Vohburg/Neustadt	10.5	206	88	61	40	49%
GERMANY	BP PLC (Ruhr Oel)	Gelsenkirchen	8.8	252	151	29	52	32%
GERMANY	PCK Raffinerie GMBH	Schwedt	9.5	220	141	50	17	30%
GREECE	Hellenic Petroleum SA	Elefsis	6.0	100	45		40	40%
GREECE	Hellenic Petroleum SA	Aspropyrgos	8.8	147	68	45		31%
GREECE	Motor Oil (Hellas) Corinth Refineries	Aghii Theodori	12.9	110	72	31	44	68%
ITALY	Eni SPA	Sannazzaro, Pavia	8.1	200	85	34	30	32%
ITALY	Raffineria di Milazzo SPA	Milazzo, Messina	5.4	241	70	45	34	32%
ITALY	Saras SPA	Sarroch	8.3	300	105	90	120	70%
NETHERLANDS	Total SA	Vlissingen	10.0	148	64		64	43%
PORTUGAL	Galp Energia	Sines	7.0	213	71	41	52	44%
SPAIN	Repsol (Petronor SA)	Muskiz Vizcaya (Bilbao)	8.0	220	90	43	33	35%
SPAIN	Repsol YPF SA	Puertollano, Ciudad Real	8.3	150	56	31	35	43%
SWEDEN	Preem Raffinaderi AB	Brofjorden-Lysekil	7.2	210	65	30	49	37%
UK, England	Essar UK Ltd.	Stanlow	9.3	195	130	68		35%
UK, England	ExxonMobil Refining & Supply Co.	Fawley	10.5	260	107	89		34%
UK, Wales	Valero Energy Corp.	Pembroke, Dyfed	8.8	270	95	90		33%
Less Likely (VGO Processing < 30% of Distillation Capacity)								
AUSTRIA	OMV AG	Schwechat	8.5	204	79	28	16	22%
BELGIUM	ExxonMobil Refining & Supply Co.	Antwerp	6.0	307	137	35		11%
BELGIUM	Total SA	Antwerp	6.9	338	83	95		28%
FRANCE	ExxonMobil Refining & Supply Co.	Fos sur Mer	5.5	143	41	31		21%
FRANCE	ExxonMobil Refining & Supply Co.	Port Jerome/NDG	7.4	236	104	42		18%
FRANCE	Petrolneos Refining Ltd.	Lavera	5.6	207	72	28	16	21%
FRANCE	Total SA	Feyzin	6.1	109	38	29		27%
FRANCE	Total SA	Gonfreville l'Orcher	8.3	247	79		61	25%
FRANCE	Total SA	La Mede	6.0	153	51	35		23%
FRANCE	Total SA	Donges	5.5	219	97	51		23%
GERMANY[2]	Deutsche BP AG Erdol Raffinerie	Lingen	12.3	90	43		17	19%
GERMANY	Deutsche Shell AG	Harburg	9.8	58	44	15		26%
GERMANY	Deutsche Shell AG	Rheinland	9.9	325	178		80	25%
GERMANY	Gunvor Group Ltd. (Petroplus)	Ingolstadt	6.9	110	39	28		25%
GERMANY	Holborn Europa Raffinerie GMBH	Hamburg	5.7	78	15	19		24%
GERMANY	Klesch & Co. (formerly Shell)	Heide	8.1	90	37		16	18%
GERMANY	Mineraloelraffinerie Oberrhein GMBH	Karlsruhe	8.3	310	131	89		29%
GERMANY	Total SA (Buna)	Leuna, Spergau	6.7	227	98	59		26%
ITALY	ExxonMobil Refining & Supply Co.	S. Martino Di Trecate	7.8	127	28	35		27%
ITALY	ExxonMobil Refining & Supply Co.	Augusta, Siracusa	7.0	198	93	50		25%
ITALY	Lukoil	Priolo, Sicily	3.7	225	48	33		15%
ITALY	Lukoil (formerly ERG Raffinerie Medd	Melilli, Sicily	7.1	238	106		62	26%
NETHERLANDS	BP PLC	Rotterdam	5.1	358	77	56		16%
NETHERLANDS	ExxonMobil Refining & Supply Co.	Rotterdam	7.4	191	82		53	27%
NETHERLANDS	Shell Nederland Raffinaderij BV	Pernis	6.3	404	140	48	56	26%
NORWAY	Mongstad Refining (Statoil)	Mongstad	5.3	203		55		27%
SPAIN	BP PLC	Castellon de la Plana	10.8	105	45	27		26%
SPAIN	Cia. Espanola de Petroles SA	Huelva (La Rabida Refinery)	5.4	190	69	19	17	19%
SPAIN	Cia. Espanola de Petroles SA	Cadiz (Gibraltar-San Roque)	5.9	240	40	40		17%
SPAIN	Repsol YPF SA	La Coruna	7.6	120	52	32		26%
SPAIN	Repsol YPF SA	Tarragona	6.4	186	72		47	25%
SPAIN	Repsol YPF SA	Cartagena Murcia	6.4	220	115		50	23%
UK, England	Phillips 66	South Killingholme (Humber)	11.7	221	157	52		23%
UK, England	Total SA	Killingholme South Humberside (	6.3	207	90	50		24%
UK, Scotland	Petrolneos Refining Ltd.	Grangemouth	4.6	210	65		36	17%

Exhibit 14 (cont.): Candidate European Refineries for Processing SCO (K b/d)

				Distillation		VGO Processing		VGO Processing as % of Distillation
Country	**Company**	**City**	**Com-plexity**	**Atmos**	**Vacuum**	**Crack-ing**	**Hydro Crack-ing[1]**	
Unlikely by Virtue of Location & Crude Oil Access								
BULGARIA	Luke Oil/Neftochim	Bourgas	7.3	190	70	35	37	38%
CROATIA	Ina-Industrija Nafte d.d.	Rijeka	6.5	90	34	20		22%
CROATIA	Ina-Industrija Nafte d.d.	Sisak	6.4	44	16	10		23%
CZECH REPUBLIC	Czech Refining Co.	Kralupy	7.0	66	13	24		36%
CZECH REPUBLIC	Czech Refining Co.	Litvinov	8.0	108	59		30	28%
FINLAND	Neste Oil	Naantali	6.8	56	34	14		24%
FINLAND	Neste Oil	Porvoo	12.6	205	112	43	56	48%
HUNGARY	MOL Hungarian Oil & Gas Co.	Szazhalombatta	9.8	161	78	24	29	33%
LITHUANIA	AB Mazeikiu Nafta	Mazeikiai	8.7	190	89	43		23%
POLAND	Grupa Lotos SA	Gdansk	4.9	210	60		32	15%
POLAND	PKN Orlen SA	Plock/Trezebina	9.6	302	205	33	74	36%
ROMANIA	Petrobrazi SA	Ploiesti	10.0	120	51	35	34	57%
ROMANIA	Petromidia SA	Midia	7.1	105	46	24		23%
ROMANIA	Petrotel SA (Lukoil)	Ploiesti	6.1	104	56	21		20%
ROMANIA	Rafo SA	Onesti, Bacau	9.3	70	70	24		34%
SLOVAKIA	Slovnaft Joint Stock Co.	Bratislava	11.0	115	55	18	19	32%
SWEDEN	Preem Raffinaderi AB	Gothenburg	8.8	106			56	53%

1 Excludes hydrocracking capacity listed as resid and lube oil manufacturing.

2 Part of atmospheric resid hydrocracking capacity is allocated to VGO hydrocracking.

Source: Derived from "2015 Worldwide Refinery Survey," *Oil & Gas Journal*, supplemented with data from *A Barrel Full* and web searches.

Exhibit 15: Candidate European Refineries Capable of Processing Unconventional Heavy (Dilbit) Crudes (K b/d)

Country	Company	City	Avg. Com-plexity	Resid Process. as % of Dist.	Distillation: Atmos	Distillation: Vacuum	Coking[1]	Vacuum Resid Processing: Thermal Cracking & Visk.	Vacuum Resid Processing: Catalytic Hydro-Cracking	Vacuum Resid Processing: Solvent De-Asphalt	Vacuum Resid Processing: Asphalt Prod.
Most Likely (Vaccum Resid Processing > 20% of Distillation Capacity)				**31%**	**2,071**	**1,013**	***360***	**205**	**32**	**-**	**55**
BELGIUM	ExxonMobil Refining & Supply Co.	Antwerp	6.0	*30%*	307	137	*Un. Con.*				13
GERMANY	BP PLC (Ruhr Oel)	Gelsenkirchen	8.8	25%	252	151	30	18			15
GERMANY	Deutsche BP AG Erdol Raffinerie	Lingen	12.3	33%	90	43	20		9		
GERMANY	Mineraloelraffinerie Oberrhein GMB	Karlsruhe	8.3	24%	310	131	25	40			11
ITALY	Eni SPA	Sannazzaro, Pavia	8.1	29%	200	85		32	23	Planned	3
NETHERLANDS	ExxonMobil Refining & Supply Co.	Rotterdam	7.4	22%	191	82	42				
SPAIN	Repsol (Petronor SA)	Muskiz Vizcaya (Bilbao)	8.0	36%	220	90	36	40			5
SPAIN	Repsol YPF SA	Cartagena Murcia	6.4	30%	220	115	60				5
SWITZERLAND	Vitol	Cressier	7.2	42%	60	24		20			5
UNITED KINGDOM	Phillips 66	South Killingholme (Humber)	11.7	56%	221	157	68	55			
Less Likely (Vaccum Resid Processing =< 20% of Distillation Capacity)				**13%**	**1,720**	**525**	**104**	**112**	**-**	**-**	**12**
BELGIUM	Total SA	Antwerp	6.9	-	338	83		26		Un. Con.	
GREECE	Hellenic Petroleum SA	Elefsis	6.0	20%	100	45	20				
ITALY	Saras SPA	Sarroch	8.3	14%	300	105		41			
NETHERLANDS	Shell Nederland Raffinaderij BV	Pernis	6.3	19%	404	140		45	25		6
NORWAY	Mongstad Refining (Statoil)	Mongstad	5.3	11%	203		23				
SPAIN	BP PLC	Castellon de la Plana	10.8	17%	105	45	18				
SPAIN	Repsol YPF SA	La Coruna	7.6	17%	120	52	19				2
SPAIN	Repsol YPF SA	Puertollano, Ciudad Real	8.3	20%	150	56	24				5
Unlikely by Virtue of Location & Crude Oil Access				**-**	**1,601**	**797**	**-**	**90**	**141**		**45**
BULGARIA	Luke Oil/Neftochim	Bourgas	7.3	36%	190	70		21	*47*		2
CROATIA	Ina-Industrija Nafte d.d.	Rijeka	6.5	-	90	34	Contract	12	12	yes	
CROATIA	Ina-Industrija Nafte d.d.	Sisak	6.4	-	44	16					
FINLAND	Neste Oil	Porvoo	12.6	33%	205	112		26	42	Un. Con.	
HUNGARY	MOL Hungarian Oil & Gas Co.	Szazhalombatta	9.8	23%	161	78	17	14			6
POLAND	Grupa Lotos SA	Gdansk	4.9	-	210	60	Un. Con.				18
POLAND	PKN Orlen SA	Plock/Trezebina	9.6	18%	302	205			40	yes	15
ROMANIA	Petrobrazi SA	Ploiesti	10.0	15%	120	51	18				
ROMANIA	Petromidia SA	Midia	7.1	19%	105	46	20				
ROMANIA	Petrotel SA (Lukoil)	Ploiesti	6.1	20%	104	56	11	6			4
ROMANIA	Rafo SA	Onesti, Bacau	9.3	26%	70	70	6	12			

Notes: Italics indicates under construction.

The hydrocracker for the refinery in Lingen, Germany probably is an atmosheric resid hydrocracker; we assumed a 65/35 vacuum gas oil/resid split.

The Grupa Lotos refinery in Gdansk has access to imported crude via the North Sea.

1 ExxonMobil has not released the capacity of its new coker; we assume it will be about 80 K b/d.

Source: Derived from "2015 Worldwide Refinery Survey," *Oil & Gas Journal*, supplemented with data from *A Barrel Full* and web searches.

Exhibit 15 (cont.): Candidate European Refineries Capable of Processing Unconventional Heavy (Dilbit) Crudes (K b/d)

Country	Company	City	VGO Processing: Cat Crack-ing	VGO Processing: Hydro Crack-ing[2]	Gasoline Processes: Catalytic Reform-ing	Gasoline Processes: Gasoline Upgrad-ing[3]	Hydrotreating: Naph-thas	Hydrotreating: Dist-illate	Hydrotreating: Other	Hydrogen Prod. & Recov. (MM scf/d)
Most Likely (Vaccum Resid Processing > 20% of Distillation Capacity)			**282**	**234**	**330**	**96**	**507**	**784**	**270**	**678**
BELGIUM	ExxonMobil Refining & Supply Co.	Antwerp	35		38	8	82	152	97	99
GERMANY	BP PLC (Ruhr Oel)	Gelsenkirchen	29	52	28		70	62	29	212
GERMANY	Deutsche BP AG Erdol Raffinerie	Lingen		17	27	8	28	40		128
GERMANY	Mineraloelraffinerie Oberrhein GMB	Karlsruhe	89		53	29	52	133	77	
ITALY	Eni SPA	Sannazzaro, Pavia	34	30	29	15	80			120
NETHERLANDS	ExxonMobil Refining & Supply Co.	Rotterdam		53	33		58	62	21	80
SPAIN	Repsol (Petronor SA)	Muskiz Vizcaya (Bilbao)	43	33	29	7	60	89		39
SPAIN	Repsol YPF SA	Cartagena Murcia		50	26		26	32		1
SWITZERLAND	Vitol	Cressier			16	4	27	35		
UNITED KINGDOM	Phillips 66	South Killingholme (Humber)	52		51	25	24	179	48	
Less Likely (Vaccum Resid Processing =< 20% of Distillation Capacity)			**377**	**251**	**202**	**64**	**494**	**526**	**128**	**483**
BELGIUM	Total SA	Antwerp	95	Un. Con.	56	9	192	121	83	
GREECE	Hellenic Petroleum SA	Elefsis		40						106
ITALY	Saras SPA	Sarroch	90	120	29	9	53	78		75
NETHERLANDS	Shell Nederland Raffinaderij BV	Pernis	48	56	41	7	115	112	0	161
NORWAY	Mongstad Refining (Statoil)	Mongstad	55		24	15	26	10	18	
SPAIN	BP PLC	Castellon de la Plana	27		15	20	51	78		45
SPAIN	Repsol YPF SA	La Coruna	32		20		37	43	27	40
SPAIN	Repsol YPF SA	Puertollano, Ciudad Real	31	35	16	3	19	83		57
Unlikely by Virtue of Location & Crude Oil Access			**269**	**262**	**230**	**71**	**419**	**394**	**192**	**451**
BULGARIA	Luke Oil/Neftochim	Bourgas	35	*37*	14	3	41		23	10
CROATIA	Ina-Industrija Nafte d.d.	Rijeka	20		14	5		23		
CROATIA	Ina-Industrija Nafte d.d.	Sisak	10	yes	15		15	6		
FINLAND	Neste Oil	Porvoo	43	56	43	20	92	99	57	160
HUNGARY	MOL Hungarian Oil & Gas Co.	Szazhalombatta	24	29	30	7	31	50	40	76
POLAND	Grupa Lotos SA	Gdansk		32	25	10	28	20	7	
POLAND	PKN Orlen SA	Plock/Trezebina	33	74	43	17	102	103		167
ROMANIA	Petrobrazi SA	Ploiesti	35	34	13	4	39	46		22
ROMANIA	Petromidia SA	Midia	24		12		36		38	6
ROMANIA	Petrotel SA (Lukoil)	Ploiesti	21		11	2	20	21	3	4
ROMANIA	Rafo SA	Onesti, Bacau	24		10	3	16	28	24	4

Note: Italics indicates under construction.

2 Excludes hydrocracking capacity listed as resid and lube oil manufacturing.

3 Includes alkylation, polymerization, dimersol, and C5 & C6 isomerization.

Source: Derived from "2015 Worldwide Refinery Survey," *Oil & Gas Journal*, supplemented with data from *A Barrel Full* and web searches.

Exhibit 16: European Refineries Capable of Processing SCO or Dilbit/WCS

Country	Company	City	Capable of Processing SCO	Capable of Processing Dilbit	Capable of Processing Neither
AUSTRIA	OMV AG	Schwechat	•		
BELGIUM	AB Nynas Petroleum NV	Antwerp			•
BELGIUM	ExxonMobil Refining & Supply Co.	Antwerp	•	•	
BELGIUM	Total SA	Antwerp	•	•	
BELGIUM	Vitol Group	Antwerp			•
BELGIUM	Gunvor	Antwerp			•
BULGARIA	Luke Oil/Neftochim	Bourgas	•	•	
CROATIA	Ina-Industrija Nafte d.d.	Rijeka	•	•	
CROATIA	Ina-Industrija Nafte d.d.	Sisak	•	•	
CZECH REPUBLIC	Czech Refining Co.	Kralupy	•		
CZECH REPUBLIC	Czech Refining Co.	Litvinov	•		
CZECH REPUBLIC	Paramo AS	Pardubice			•
DENMARK	AS Dansk Shell	Fredericia			•
DENMARK	Dansk Statoil AS	Kalundborg			•
FINLAND	Neste Oil	Naantali	•		
FINLAND	Neste Oil	Porvoo	•	•	
FRANCE	ExxonMobil Refining & Supply Co.	Fos sur Mer	•		
FRANCE	ExxonMobil Refining & Supply Co.	Port Jerome/NDG	•		
FRANCE	Petrolneos Refining Ltd.	Lavera	•		
FRANCE	Total SA	Donges	•		
FRANCE	Total SA	Feyzin	•		
FRANCE	Total SA	Gonfreville l'Orcher	•		
FRANCE	Total SA	Grandpuits	•		
FRANCE	Total SA	La Mede	•		
GERMANY	BP PLC (Ruhr Oel)	Gelsenkirchen	•	•	
GERMANY	Deutsche BP AG Erdol Raffinerie	Lingen	•	•	
GERMANY	Deutsche Shell AG	Rheinland	•		
GERMANY	Deutsche Shell AG	Harburg	•		
GERMANY	Gunvor Group Ltd. (Petroplus)	Ingolstadt	•		
GERMANY	Hestya Energy BV (Conoco Phillips)	Wilhelmshaven			•
GERMANY	Holborn Europa Raffinerie GMBH	Hamburg	•		
GERMANY	Klesch & Co. (formerly Shell)	Heide	•		
GERMANY	Mineraloelraffinerie Oberrhein GMBH	Karlsruhe	•	•	
GERMANY	OMV AG	Burghausen			•
GERMANY	PCK Raffinerie GMBH	Schwedt	•		
GERMANY	Total SA (Buna)	Leuna, Spergau	•		
GERMANY	Bayernoil Raffineriegesellschaft GMB	Vohburg/Neustadt	•		

Exhibit 16 (cont.): European Refineries Capable of Processing SCO or Dilbit/WCS

Country	Company	City	Capable of Processing		
			SCO	Dilbit	Neither
GREECE	Hellenic Petroleum SA	Aspropyrgos	•		
GREECE	Hellenic Petroleum SA	Elefsis	•	•	
GREECE	Hellenic Petroleum SA	Thessaloniki			•
GREECE	Motor Oil (Hellas) Corinth Refineries S	Aghii Theodori	•		
HUNGARY	MOL Hungarian Oil & Gas Co.	Szazhalombatta	•	•	
IRELAND	Phillips 66	Whitegate			•
ITALY	Api Raffineria di Ancona SPA	Falconara, Marittima			•
ITALY	Eni SPA	Taranto			•
ITALY	Eni SPA	Livorno			•
ITALY	Eni SPA	Sannazzaro, Pavia	•	•	
ITALY	ExxonMobil Refining & Supply Co.	Augusta, Siracusa	•		
ITALY	ExxonMobil Refining & Supply Co.	S. Martino Di Trecate	•		
ITALY	Iplom SPA	Busalla			•
ITALY	Lukoil (formerly ERG Reffinerie Medd	Melilli, Sicily	•		
ITALY	Lukoil	Priolo, Sicily	•		
ITALY	Raffineria di Milazzo SPA	Milazzo, Messina	•		
ITALY	Saras SPA	Sarroch	•	•	
LITHUANIA	AB Mazeikiu Nafta	Mazeikiai	•		
NETHERLANDS	BP PLC	Rotterdam	•		
NETHERLANDS	ExxonMobil Refining & Supply Co.	Rotterdam	•	•	
NETHERLANDS	Kuwait Petroleum Europoort BV	Rotterdam			•
NETHERLANDS	Shell Nederland Raffinaderij BV	Pernis	•	•	
NETHERLANDS	Total SA	Vlissingen	•		
NETHERLANDS	Koch Partnership Refinery	Rotterdam			•
NORWAY	ExxonMobil Refining & Supply Co.	Slagen			•
NORWAY	Mongstad Refining (Statoil)	Mongstad	•	•	
POLAND	Grupa Lotos SA	Gdansk	•	•	
POLAND	PKN Orlen SA	Plock/Trezebina	•	•	
PORTUGAL	Galp Energia	Leca da Palmeira, Porto			•
PORTUGAL	Galp Energia	Sines	•		

Exhibit 16 (cont.): European Refineries Capable of Processing SCO or Dilbit/WCS

Country	Company	City	Capable of Processing		
			SCO	Dilbit	Neither
ROMANIA	Petrobrazi SA	Ploiesti	•	•	
ROMANIA	Petromidia SA	Midia	•	•	
ROMANIA	Petrotel SA (Lukoil)	Ploiesti	•	•	
ROMANIA	Rafo SA	Onesti, Bacau	•	•	
ROMANIA	Steaua Romania SA	Cimpina			•
SLOVAKIA	Slovnaft Joint Stock Co.	Bratislava	•		
SPAIN	BP PLC	Castellon de la Plana	•	•	
SPAIN	Cia. Espanola de Petroles SA	Cadiz (Gibraltar-San Roque	•		
SPAIN	Cia. Espanola de Petroles SA	Huelva (La Rabida Refinery	•		
SPAIN	Cia. Espanola de Petroles SA	Tenerife			•
SPAIN	Repsol (Petronor SA)	Muskiz Vizcaya (Bilbao)	•	•	
SPAIN	Repsol YPF SA	Cartagena Murcia	•	•	
SPAIN	Repsol YPF SA	La Coruna	•	•	
SPAIN	Repsol YPF SA	Puertollano, Ciudad Real	•	•	
SPAIN	Repsol YPF SA	Tarragona	•		
SWEDEN	AB Nynas Petroleum	Gothenburg			•
SWEDEN	AB Nynas Petroleum	Nynashamn			•
SWEDEN	Preem Raffinaderi AB	Brofjorden-Lysekil	•		
SWEDEN	Preem Raffinaderi AB	Gothenburg	•		
SWEDEN	Keele Oy (previously Shell Raffinader	Gothenburg			•
SWITZERLAND	Vitol	Cressier		•	
UK, England	AB Nynas Petroleum	Eastham			•
UK, England	Essar UK Ltd.	Stanlow	•		
UK, England	ExxonMobil Refining & Supply Co.	Fawley	•		
UK, England	Phillips 66	South Killingholme (Humber	•	•	
UK, England	Total SA	Killingholme South Humbers	•		
UK, Scotland	Petrolneos Refining Ltd.	Grangemouth	•		
UK, Wales	Valero Energy Corp.	Pembroke, Dyfed	•		

Source: Exhibits 14 & 15.

6. Concluding Comments

As we have seen, SCO and dilbit/WCS have substantially different physical and chemical properties and different distributions of light vs. heavy product yields than those of conventional crude oils (even heavy crude oils). Moreover, SCO and dilbit/WCS have properties and yield distributions that differ markedly from each other. The special characteristics of SCO and dilbit/WCS are key determinants of the refinery configurations and capabilities required for sustained processing of SCO and/or dilbit/WCS, and hence of any given refinery's capability for sustained processing of such crudes with its existing facilities.

Many European refineries could run small volumes of *SCO* temporarily with little, if any, process additions or modifications. A smaller number of European refineries could run small volumes of *dilbit/WCS* temporarily. Refineries might do so for various reasons, such as assessing the economics of running these unconventional heavy crudes or identifying the specific facilities and equipment that would require revamping in order to support sustained operations with these crudes in the refinery crude slate.

However, permanent replacement of a significant share of a refinery's conventional crude slate with SCO or dilbit/WCS would require that the refinery have, at a minimum, certain key process units and capabilities. For *SCO*, this means adequate conversion capacity for vacuum gas oil (catalytic cracking or hydrocracking); for *dilbit/WCS*, it means adequate conversion capacity for both vacuum resid (coking, resid hydrocracking, or solvent deasphalting) and for vacuum gas oil (catalytic cracking or hydrocracking).

These threshold capabilities must be augmented with facilities and capabilities for upgrading both the intermediate refinery streams produced by cracking and coking the heavy fractions of SCO and dilbit/WCS and the lighter fractions of these crudes. In addition to these technical requirements, refineries seeking to process SCO or dilbit/WCS must have economic access (direct or indirect) to water-borne crude oil supplies and be located so as to have economic incentive to switch away from some current sources of crude supply.

On the basis of these considerations and the criteria outlined in Section 5, we identified refineries in the European refining sector most likely to be capable of incorporating some SCO and WCS/dilbit into their crude slates in sustained operations. As Exhibits 14-16 indicate, a significant number of refineries meet the criteria that we established.

The long-term prospects for significant volumes of SCO and dilbit/WCS to become a permanent part of the European refining sector's crude slate are unclear. Assessing these prospects would require significant analytical effort, in part because only limited information on refinery capabilities is available in the open literature. Moreover, some refineries that have the economic incentive to process SCO and dilbit/WCS may not be in a financial position to invest in the necessary revamping of their refineries.

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