Chair in Energy Sector Management

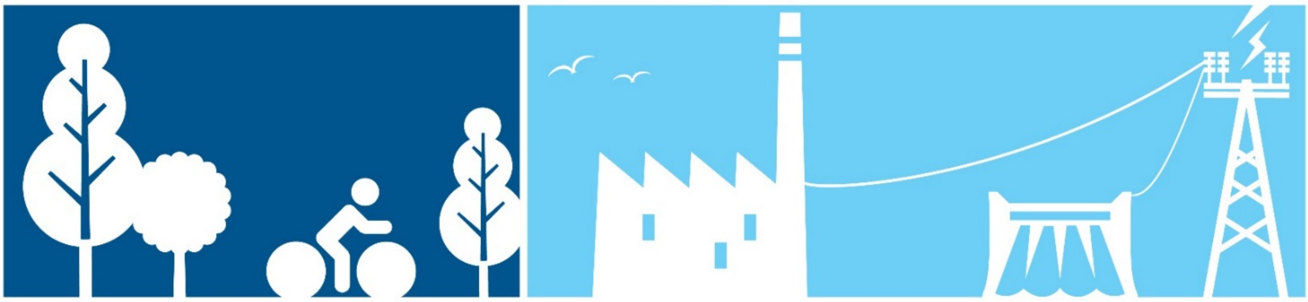
HEC MONTRÉAL

Study Report

Nº 04 | 2018

GHG Emissions from Canadian Refineries: An Analysis of Recent Trends

Daniil **SOKOLOV**



Study Report nº 04 | 2018

GHG Emissions from Canadian Refineries: An Analysis of Recent Trends

Daniil Sokolov
MBA – HEC Montreal

Supervised by Pierre-Olivier Pineau, Professor, Chair in Energy Sector Management, HEC Montréal.

Note aux lecteurs : Les rapports d'étude de la Chaire de gestion du secteur de l'énergie sont des publications aux fins d'information et de discussion. Ils ont été réalisés par des étudiants sous la supervision d'un professeur. Ils ne devraient pas être reproduits sans l'autorisation écrite du (des) auteur(s). Les commentaires et suggestions sont bienvenus, et devraient être adressés à (aux) auteur(s). Pour consulter les rapports d'étude et les cahiers de recherche de la Chaire de gestion du secteur de l'énergie à HEC Montréal, visitez le site energie.hec.ca.

À propos de la Chaire de gestion du secteur de l'énergie : La Chaire de gestion du secteur de l'énergie de HEC Montréal a pour mission d'augmenter les connaissances sur les enjeux liés à l'énergie, dans une perspective de développement durable, d'optimisation et d'adéquation entre les sources d'énergie et les besoins de la société. La création de cette chaire et de ce rapport est rendue possible grâce au soutien d'entreprises partenaires. Pour plus d'information ou pour consulter nos autres publications, visitez le site energie.hec.ca.

December 2018

Chaire de gestion du secteur de l'énergie
HEC Montréal
3000, chemin de la Côte-Sainte-Catherine
Montréal (Québec) Canada
H3T 2A7

Contents

Summary

- Canadian refineries achieved impressive results in tackling GHG emissions throughout the last decade, mainly through improvements in energy efficiency and optimization of refinery fuel intake, switching from more GHG intensive heavy oil and fuel gas to “cleaner” natural gas and electricity.
- However, creeping increase of sourer and heavy oil intake started to weigh on refinery emissions level and led to gradual increase of emissions intensity since 2012. This trend is expected to persist with higher quantities of heavy crude oil entering domestic market in the foreseeable future.
- Stricter sulfur content requirements for motor fuels will require additional hydrotreatment processing, leading to higher hydrogen demand and higher emissions from hydrogen production, if hydrogen comes from its traditional source (steam-methane reforming).
- Each Canadian refinery has a unique set of conditions, defining its levels of emissions: complexity of its configuration, crude diet, access to natural gas, electricity and hydrogen supplies from third parties.

Introduction

In 2015 an article was published by Canadian Fuels Association, entitled "How Canadian refineries are reducing GHG emissions" (CFA, 2015). It cited Michael Kandravy, Suncor Energy Products Partnership director of fuels quality and regulatory affairs, who highlighted the following:

a. Canadian emissions from refinery sector are decreasing, showing 16% decline in a 10 years period (from 2003 to 2013).
b. Energy companies achieved emissions reduction through enhanced energy efficiency. Most emissions come from fuel combustion, therefore 1% energy saving leads to approximately 1% of reduction in emission level.

Having statistics today up to 2016, we can do the following three tasks:

1. Reassess the arguments about declining trend in GHG emissions from Canadian oil refining sector
2. Review key drivers of emissions intensity
3. Define trends in GHG emissions intensity in medium and long-term perspectives

Such analysis is relevant today because Canada is an important crude oil producer and consumer of refined petroleum products. GHG emissions are also increasingly followed and priced. The competitivity of the refinery sector can be affected by its level of GHG emissions.

Refineries and emissions intensity

According to the Canadian Association of Petroleum Producers (CAPP), Canada's refining capacity accounted for 1.9 million b/d in 2017, while crude oil feedstock processed by Canadian refineries totaled more than 1.6 million b/d, including 613,000 b/d of imports to refineries in Eastern Canada (CAPP, 2018).

Table 1. Refinery's crude distillation capacity in Canada (Oil Sands Magazine, 2017) (STATCAN GHG)

Province	Refinery	Capacity, kbd	Emissions 2016, tons of CO2e
Ontario	Imperial oil, Nanticoke	112	1,080,711
Ontario	Imperial oil, Sarnia	121	1,460,941
Ontario	Shell, Corunna	75	735,389
Ontario	Suncor, Sarnia	85	671,765
Quebec	Suncor, Montreal	137	1,142,030
Quebec	Valero, Lévis	235	1,328,086
New Brunswick	Irving oil, Saint John	300	3,007,303
Newfoundland and Labrador	North Atlantic, Come-by-Chance	130	1,139,837
Saskatchewan	Co-op, Regina	135	1,739,093
Alberta	Husky Energy, Lloydminster	29	94,219
Alberta	Suncor, Edmonton	142	1,316,430
Alberta	Imperial oil, Strathcona	191	1,547,094
Alberta	Shell, Scotford	114	843,778
British Columbia	Chevron, North Burnaby	55	506,166
British Columbia	Husky Energy, Prince George	12	112,178
TOTAL		**1,873**	**16,725,019**

One can see that in 2016 the total level of refinery emissions was close to 16.7 million tons (STATCAN GHG) for a combined oil throughout of 1,594 thousand of barrels per day (kbd) (BP, 2018), which corresponds to 85% of capacity utilization. Refinery emissions intensity, in kilograms (kg) of CO2 per bbl of crude processed, amounted to 28.7 kg of CO2e.

Table 2 demonstrates wide range of emissions intensities across Canadian refineries. This variability can be explained, partly, by different levels of refineries' complexity and crude oil intake.

Complexity factor

One of the ways to measure refinery's complexity is the Nelson Complexity Index (NCI)[*]. Calculated values of NCI show relatively high correlation with refinery emissions intensity.

Table 2. Refineries' emissions intensity and complexity (STATCAN GHG), (Oil Sands Magazine, 2017)

Refinery	CO2 per bbl of capacity[†]	NCI
Imperial oil, Nanticoke	26.4	9.7
Imperial oil, Sarnia	33.0	8.7
Shell, Corunna	26.8	7.2
Suncor, Sarnia	21.6	10.7
Suncor, Montreal	22.8	8.8
Valero, Lévis	15.4	8.1

[*] Nelson Complexity Index (NCI) is the sum of secondary units' capacities, each divided by atmospheric distillation capacity and multiplied by complexity factor assigned to a unit's category. Calculated for every refinery, using data from Statistical Handbook for Canada's Upstream Petroleum Industry (CAPP, 2017), see Appendix 1.

[†] Instead of actual throughput, CO2e emissions per bbl of capacity was used as it presents more verifiable data for a single refinery. In all other cases, intensity will be calculated based on actual throughput.

Irving oil, Saint John	27.4	7.9
North Atlantic, Come-by-Chance	24.0	7.2
Co-op, Regina	35.2	8.9
Husky Energy, Lloydminster	8.9	3.4
Suncor, Edmonton	25.3	9.2
Imperial oil, Strathcona	22.1	8.9
Shell, Scotford	20.2	7.7
Chevron, North Burnaby	25.1	10.0
Husky Energy, Prince George	25.5	8.0
	Correlation NCI vs Emissions intensity	55%

The importance of refinery complexity will be further demonstrated when we review key technological factors of GHG emissions.

Crude oil intake factor

Refinery's crude diet is another important determinant of if GHG intensity level. The heavier refinery intake, the more GHG emitted for every bbl of crude processed.

Table 3. Eastern refinery's configuration and emissions intensity in 2016, kg CO2eq/bb (CERI, 2018), (STATCAN GHG)

	Conversion type	**Intensity**	**% Heavy intake[‡]**
Imperial oil, Nanticoke	Medium	26.4	15%
Imperial oil, Sarnia	Complex	33.0	30%
Shell, Corunna	Medium	26.8	22%
Suncor, Sarnia	Medium	21.6	19%
Suncor, Montreal	Medium	22.8	13%
Valero, Levis	Medium	15.4	8%
Irving oil, Saint John	Medium	27.4	6%
		Correlation Heavy oil intake vs Emissions Intensity	62%

We will review further in greater detail the key factors influencing refineries' emissions intensity and review key trends.

[‡] Calculated as (Conventional heavy + bitumen) / total crude intake

Technical overview

From a technical point of view, GHG emissions factors can be grouped into three categories – a) combustion-related, b) emissions from hydrogen production, and c) fugitive emissions.

We will have to analyze each of the factors to understand future dynamics.

Combustion-related emission

Combustion-related emissions are the result of fuel burning by heaters and boilers, as well as coke burn-off via catalyst regeneration process and heat generation for electricity generation.

Level of emission from combustion processes depends on refinery complexity: refineries with deeper conversion capabilities consume more energy and have higher emissions per barrel of crude processed.

At the same time, the series of measures can be implemented to decrease the level of combustion-related emissions:

- **Improving energy efficiency**, through lower energy consumption and therefore smaller amount of fuel burned. Refineries carry out investment projects to achieve better heat recovery and more rational usage of fuel and equipment to spend less fuel on every barrel refined. Many of these investment projects are "low hanging fruits", offering quick pay-off through savings on fuel spending (more details on investment projects - (US EPA, 2010)).
- **Changing refinery fuel structure** through the decrease of consumption of heavy fuel oil and higher use of natural gas has been another key factor. Access to cheap natural gas source is paramount for this condition to materialize. Lowering fuel oil burning was also necessary to tackle air emissions, such as SO_2.
  The example of the North Atlantic Refinery (NAR) is a good illustration of how fuel structure can influence emissions intensity. NAR has relatively low level of complexity (Nelson index 7.2), but still one of the highest emissions intensity levels in Canada. The reason is the lack of natural gas access and predominant usage of heavy fuel oil as a supplement to refinery gas (Office of Climate Change and Energy Efficiency, 2013).
- **Outsourcing electricity generation**. Many refineries buy electricity from the grid and therefore do not have to burn fuel on site for electricity generation.

Hydrogen production

Hydrogen generation is the second largest source of GHG emissions. Hydrogen is produced at the catalytic reforming and steam methane reforming (SMR) units. While catalytic reforming produces hydrogen as a byproduct, SMR is a widely used techniques to supply incremental volumes of hydrogen. Within the SMR unit, "methane, other light hydrocarbons, and steam are reacted via a nickel catalyst to produce hydrogen and CO. The CO generated by the initial reaction further reacts with the steam to generate hydrogen and CO_2" (US EPA, 2010).

Level of hydrogen-related emissions depends on crude oil properties: heavier and sourer crude requires more hydrogen to produce final products with defined characteristics. At the same time, hydrogen demand increases with higher degree of refinery complexity: higher hydrotreatment and hydrocracking capacities require more hydrogen.

Refineries that purchase hydrogen from third parties tend to be less exposed to hydrogen related emissions. However, as reports demonstrate, Canadian refineries are predominately self-sufficient in terms of hydrogen supply, generating it on site (Dalcor Consultants Ltd and Camford Information Services Inc, 2005).

We will model the effects of heavier and sourer crude oil intake on refineries' emissions level, using PRELIM model (Dr. Joule A. Bergerson, 2017). This model is freely available and presents a valuable tool to estimate different levels of emissions and energy use.

For reference, two crude oil grades were used – light sweet Bakken Crude (API gravity 38.4, sulfur 0,07%), and sour heavy West Canadian Select crude (API gravity 20.54, sulfur 3.38%). Feedstocks containing different proportion of Bakken (light) and heavy (WCS) were tested against three different refinery configurations:

- Cracking refinery with fluid catalytic cracking unit (FCC), but without hydrocracker (HCU) and delayed coking unit (medium conversion).
- Refinery with fluid catalytic cracking (FCC) and hydrocracking (HCU) units but without delayed coking unit (medium conversion).
- Hydrocracking and Cracking refinery with Coker units (complex conversion).

In this model, combustion emissions result from heat and steam generation as well as from coke burn-off. Hydrogen category includes emissions related to hydrogen production (including steam generation for SMR unit).

Table 4. Emissions intensity, kg CO2eq/bb[§].

	Light / Heavy		100/0	80/20	60/40	40/60	20/80	0/100
Medium conversion	FCC	Combustion	29.6	28.3	28.0	26.6	26.3	24.5
		Hydrogen	2.0	2.9	4.2	5.9	8.7	11.7
		Total	31.5	31.1	32.2	32.4	35.0	36.1
	FCC+HCU	Combustion	25.2	23.9	23.6	22.1	21.3	19.5
		Hydrogen	8.1	8.8	9.6	10.7	13.0	15.3
		Total	33.3	32.6	33.1	32.8	34.3	34.7
Complex	FCC+HCU+Coker	Combustion	26.8	27.5	28.1	29.0	29.2	29.1
		Hydrogen	10.8	13.6	16.6	19.9	24.7	29.4
		Total	37.6	41.2	44.7	48.9	53.9	58.4

As the table illustrates, refinery receiving heavier and sourer crude tend to have higher demand for hydrogen, which reflects on their level of emissions intensity. For more complex refineries the effect of heavier and sourer crude oil diet on its hydrogen demand and emission level is even more pronounced.

Fugitive emissions

GHG emissions of this type are the result of venting, process leaks, processes related to sulfur recovery and asphalt blowing. This type of emissions account for a smaller portion of total emissions level.

We will consider the impact of combustion and hydrogen-related factors, as the largest contributors to the changing level of refineries intensity.

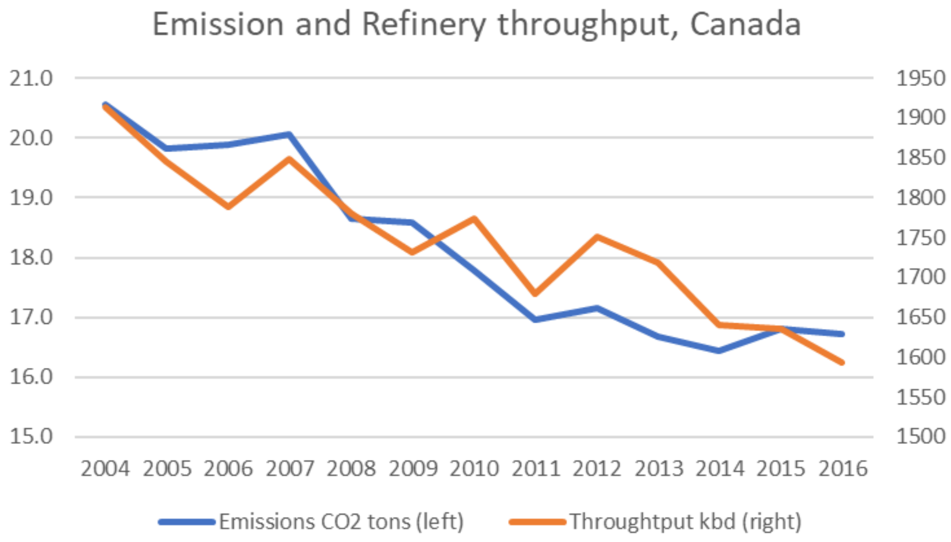
[§] Model inputs: A). Refinery configurations: 1,3,6. B) SR Naphtha C) Pre-hydrotreater D) Electricity excluded E) Amine CO2 removal. Crude assays were used from model's inventory. All other inputs as by default.

Current trends

Total emissions and intensity

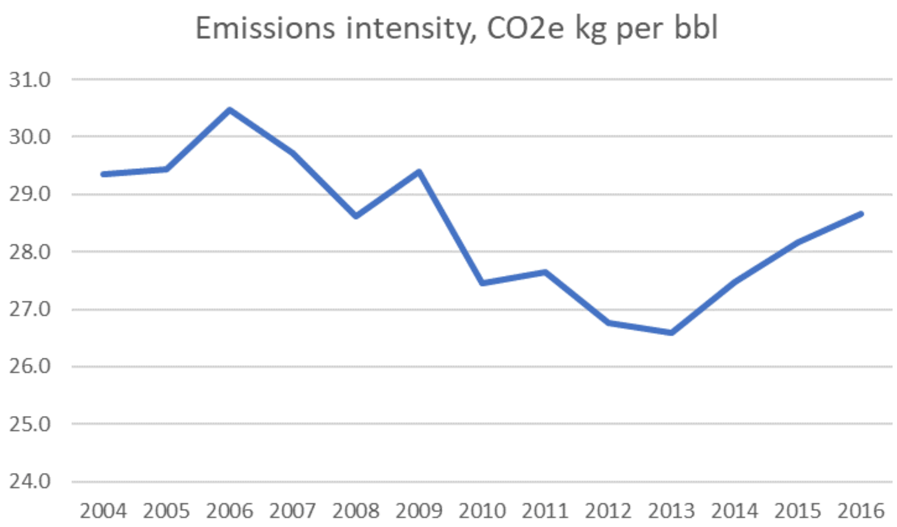
Absolute level of emissions from oil refining sector declined from 20.5 million tons in 2004 to 16.7 million tons in 2016 of CO2e equivalent. However, it also coincided with the decline of oil throughput during this period from 1,913 thousand barrels per day (kbd) to 1,594 kbd.

Graph 1. Emissions and Refinery throughput in Canada (BP, 2018), (STATCAN GHG)



A more objective indicator of refinery emissions is emissions intensity, in kg of CO2e per barrel of crude throughput. It shows less optimistic picture: after hitting its lowest value in 2013, refinery emissions intensity level has been growing, retracting back to 2008 level lately.

Graph 2. Emissions and Refinery throughput in Canada (STATCAN 25-10-0041-01), (STATCAN GHG)



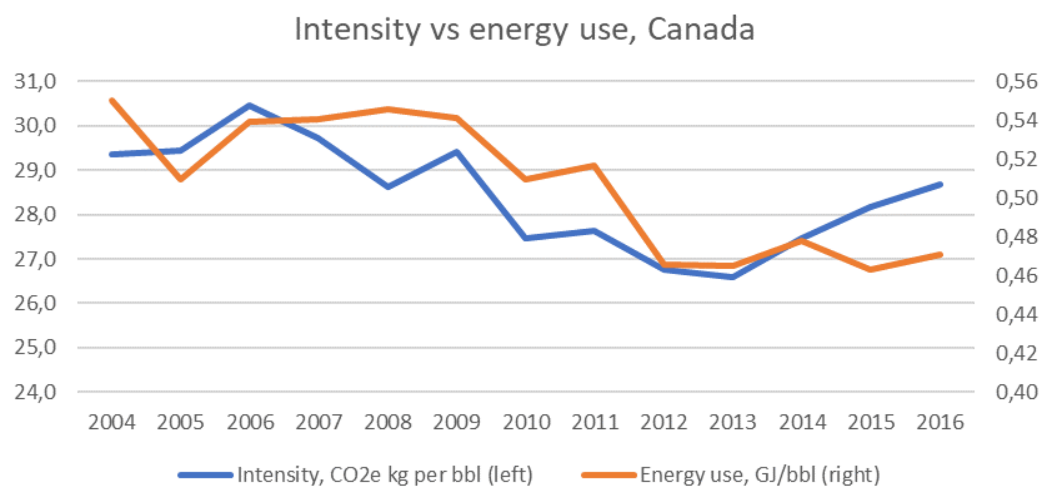
Given the technical conditions described above, we can highlight the following key factors driving the dynamics of GHG emissions in Canadian crude oil sector today.

- In favor of *decreasing* emissions intensity: energy efficiency and energy consumption structure. It helped reduce intensity to the lowest level in 2013.
- In favor of *increasing* emissions intensity: change in refinery diet towards heavy and sour crudes that reversed intensity declining trend after 2013.

Factors favoring declining emissions intensity

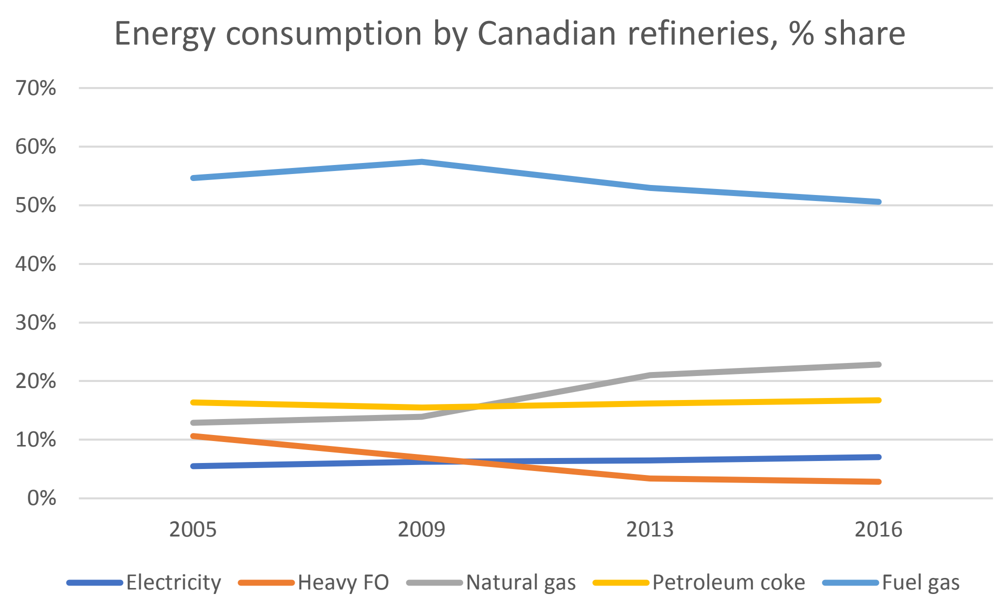
a) Increased energy efficiency. Canadian refineries today consume less energy for every barrel of crude oil refined. Emissions intensity and energy efficiency demonstrate high correlation of 72% (annually for 2004-2016-time period).

Graph 3. Intensity vs energy use, Canada (STATCAN 25-10-0025-01) (STATCAN GHG)



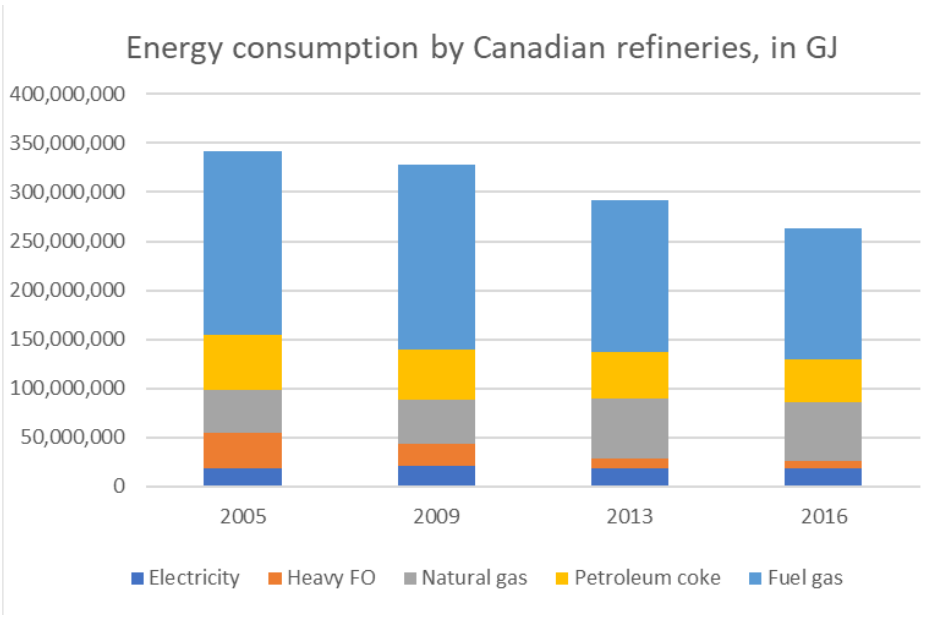
b) Changed structure of energy consumption, namely reduction of heavy fuel oil and coke in absolute and relative terms, and increased share of "cleaner" energy sources, such as natural gas and electricity.

Graph 4. Energy consumption by refineries by fuel type, % share in total (STATCAN 25-10-0025-01)



Source: STATCAN 25-10-0025-01

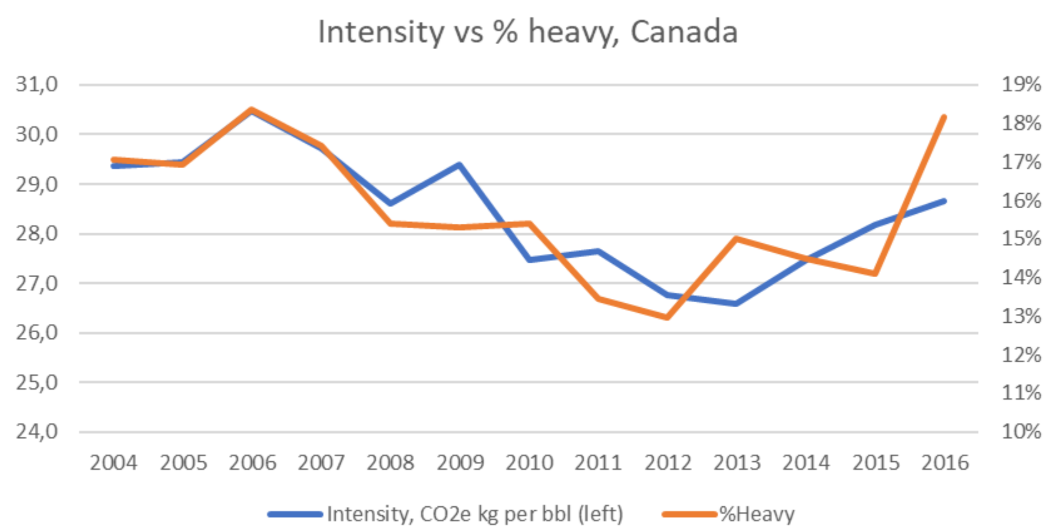
Graph 5. Energy consumption by Canadian refineries by fuel type, absolute volume (STATCAN 25-10-0025-01)



Factors favoring higher emissions intensity

Increase of heavy oil intake is one the key factors behind upwards trend in refinery emissions intensity after 2013. Correlation between these two parameters is at 78% (annually for 2004-2016-time period).

Graph 6. Emissions intensity vs % of heavy oil in total intake in Canada (STATCAN 25-10-0041-01), (STATCAN GHG)



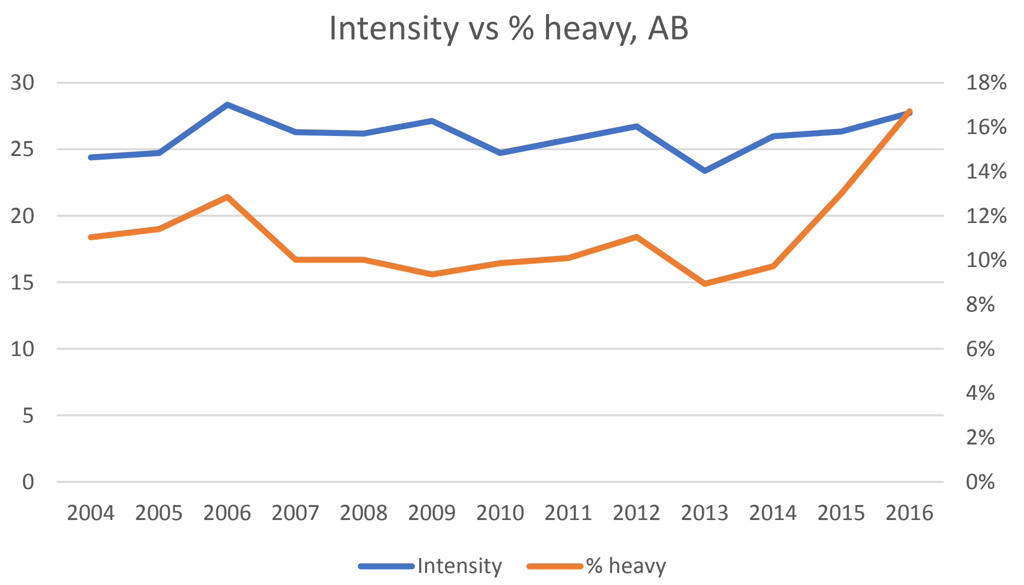
Taking into consideration forecasted increase of heavy oil share in total Canadian production, one can also expect higher heavy oil shipments to domestic refineries in medium term perspective and increased emissions intensity of oil refining in Canada.

Emission intensity: provincial level

Alberta

Heavy crude oil intake has been increasing, and so was the level of GHG intensity. Since crude oil producers have limited export capacity, the increase in heavy crude production is expected to directly affect refinery diet and level of refinery emissions.

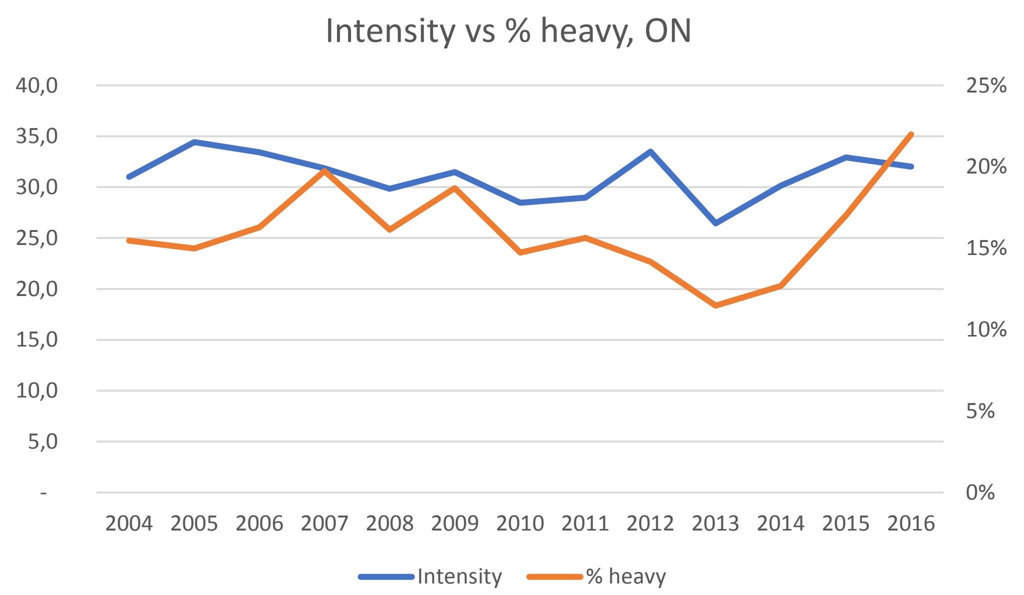
Graph 7. Emissions intensity vs % of heavy oil in total intake in Alberta (STATCAN 25-10-0041-01), (STATCAN GHG)



Ontario

Increase of heavy crude intake resulted in higher emissions intensity since 2013. Ontario refineries have relatively high level of complexity, that places them at the higher end of emissions range across Canada.

Graph 8. Emissions intensity vs % of heavy oil in total intake in Ontario, (STATCAN 25-10-0041-01), (STATCAN GHG)

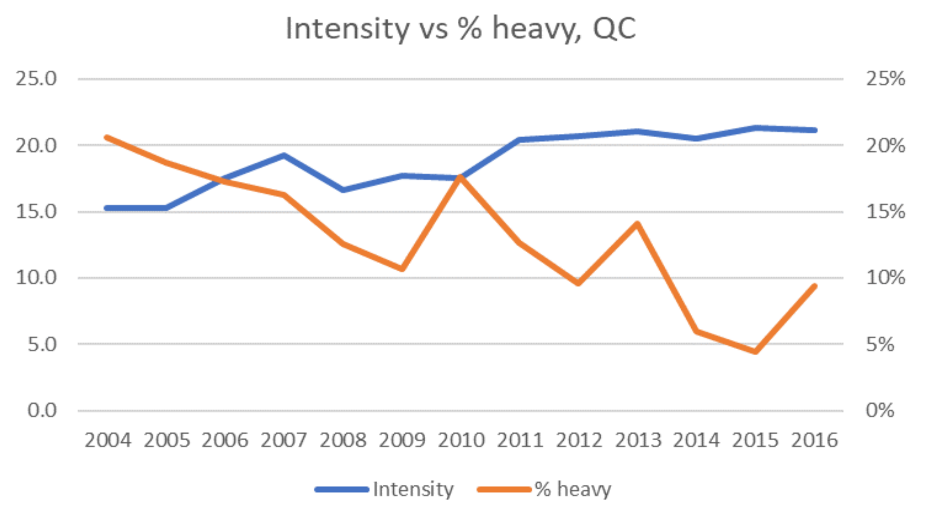


Quebec

Quebec is well positioned vs other provinces in terms of emissions intensity level. Its largest refinery in Lévis is designed mainly to process light crude oils, which results in relatively low level of intensity.

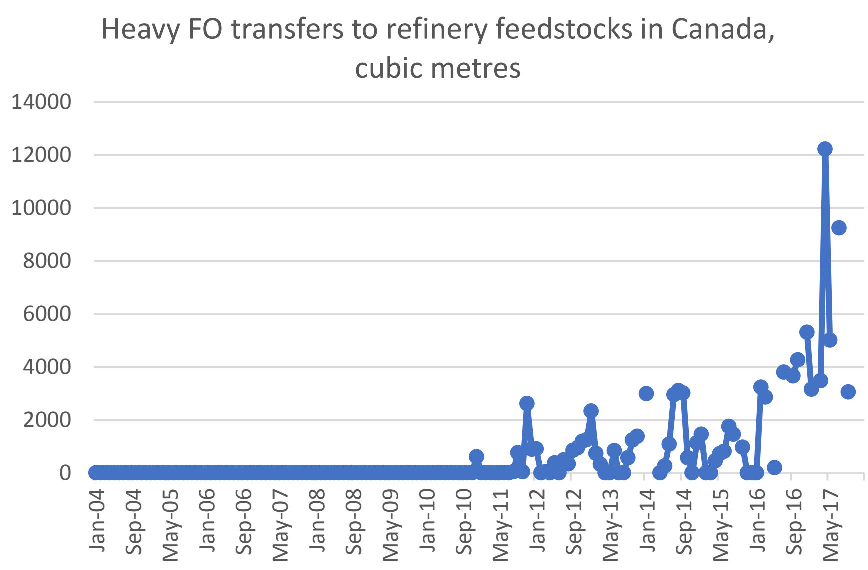
Quebec demonstrated puzzling picture with decreasing heavy oil intake and simultaneous increase of GHG intensity level. Absence of data on fuel consumption structure does not provide enough details for possible explanation.

Graph 9. Emissions intensity and heavy oil intake in Quebec, (STATCAN 25-10-0041-01), (STATCAN GHG)



The hypothesis is that increasing fuel oil availability on the market offers incentive for lower emission refineries to purchase heavy fuel oil for heating and processing, that reflects on their emission intensity levels.

Graph 10. Heavy fuel oil transfers to refinery stocks (STATCAN 25-10-0044-01)



Conclusion

- Refinery GHG emissions are in decline, but effective refinery emission intensity, measured as amount of CO2e per barrel of crude oil refined, has been increasing since 2013.
- Different factors are in play that define the changing level of intensity, the most important are energy efficiency, structure of fuel consumption and the share of heavy oil intake.
- Refineries have managed to achieve better efficiency and reshuffled their fuel oil consumption, but all this could not offset the negative effect of increasing share of heavy oil intake.

Appendix. Nelson Complexity Index calculation

All capacities are in m3		Crude	Vacuum	Thermocrack	Cat crack	Cat reform	Cat hydro crack	Hydrotreat	Polym/Alky	Aromatics/Iso	Asphalt	Lubes	Coker	**NCI**
Complexity factor		1	2	2.75	6	5	6	3	10	15	1.5	60	6	
Ontario														
Imperial	Nanticoke	18045	7631		7711	5326		15739	1908	0	1590	0	0	**9.7**
Imperial	Sarnia	18919	5008	4054	4849	5962	3100	14149	0	0	0	0	850	**8.7**
Shell	Corunna	12242	4102	827	3259	3323	1558	6455	0	0	0	0	0	**7.2**
Suncor	Sarnia	13514	4250		2650	3650	5100	16232	875	0	0	0	0	**10.7**
Quebec														
Suncor	Montreal	21781	8585		5087	5724	3498	19317	779	0	4770	0	0	**8.8**
Valero	Lévis	42130	7788		11129	7791		32750	1219	4626	0	0	0	**8.1**
New Brunswick														
Irving oil	Saint John	47500	17362	3178	15097	6118	7151	24632	2225	1589	0	0	0	**7.9**
Newfoundland and Labrador														
North Atlantic	Come-by-Chance	18275	8740	3178		5006	6039	8820	0	0	0	0	0	**7.2**
Saskatchewan														
Co-op	Regina	21500	6000	1430	7600	1550	4100	16400	1400	635	700	0	385	**8.9**
Moose Jaw	Moose Jaw	2683	1541								1142			**2.8**
Alberta														
Husky Energy	Lloydminster	4620	3590								2495			**3.4**
Suncor	Edmonton	22576	7552	2719	6495	1860	3402	23276	2337				127	**9.2**
Imperial oil	Strathcona	30366	11049		10413	3339		25914	2464	1033	1749	318		**8.9**
Shell	Scotford	15898					5520	24480						**7.7**
British Columbia														
Chevron	North Burnaby	8700	1900		2800	1550		7200	450	1550	350			**10.0**
Husky Energy	Prince George	1908	600		540	280		1727		150				**8.0**

Source: (CAPP, 2017)

References

US EPA. (2010). *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions From the Petroleum Refining Industry.*

BP. (2018). *Statistical Review of World Energy.* Retrieved from https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

CAPP. (2017). *Statistical Handbook for Canada's Upstream Petroleum Industry.* Retrieved from https://www.capp.ca/publications-and-statistics/statistics/statistical-handbook

CAPP. (2018, June). *Crude Oil Forecast, Markets and Transportation.* Retrieved from https://www.capp.ca/publications-and-statistics/crude-oil-forecast

CERI. (2018, January). *An Economic and Environmental assessment of Eastern Canadian Crude Oil Imports, Study No. 167.* Retrieved from https://www.ceri.ca/studies/an-economic-and-environmental-assessment-of-eastern-canada-crude-oil-imports

CFA. (2015, May 08). *How Canadian refineries are reducing GHG emissions,.* Retrieved from http://www.canadianfuels.ca/Blog/May-2015/How-Canadian-refineries-are-reducing-GHG-emissions/

Dalcor Consultants Ltd and Camford Information Services Inc. (2005). *Canadian Hydrogen Survey – 2004/2005. Capacity, Production and Surplus – Update. Dalcor Consultants Ltd and Camford Information Services Inc for Natural Resources Canada.*

Dr. Joule A. Bergerson, C. ©. (2017). *The Petroleum Refinery Life Cycle Inventory Model.* Retrieved from http://www.ucalgary.ca/lcaost/prelim

Office of Climate Change and Energy Efficiency. (2013). *Oil Refining – Newfoundland and Labrador. GHG reduction opportunities & competitive implications. Public Summary report.*

Oil Sands Magazine. (2017, July 31). *Canadian Refineries.* Retrieved from https://www.oilsandsmagazine.com/projects/canadian-refineries

STATCAN 25-10-0025-01. (n.d.). *Manufacturing industries, total annual energy fuel consumption in gigajoules.* Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002501

STATCAN 25-10-0041-01. (n.d.). *Refinery supply of crude oil and equivalent, monthly.* Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510004101

STATCAN 25-10-0041-01. (n.d.). *Refinery supply of crude oil and equivalent, monthly.* Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510004101

STATCAN 25-10-0044-01. (n.d.). *Supply and disposition of refined petroleum products, monthly.* Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=2510004401

STATCAN GHG. (n.d.). *Facility-reported greenhouse gas data.* Retrieved from https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting/data.html