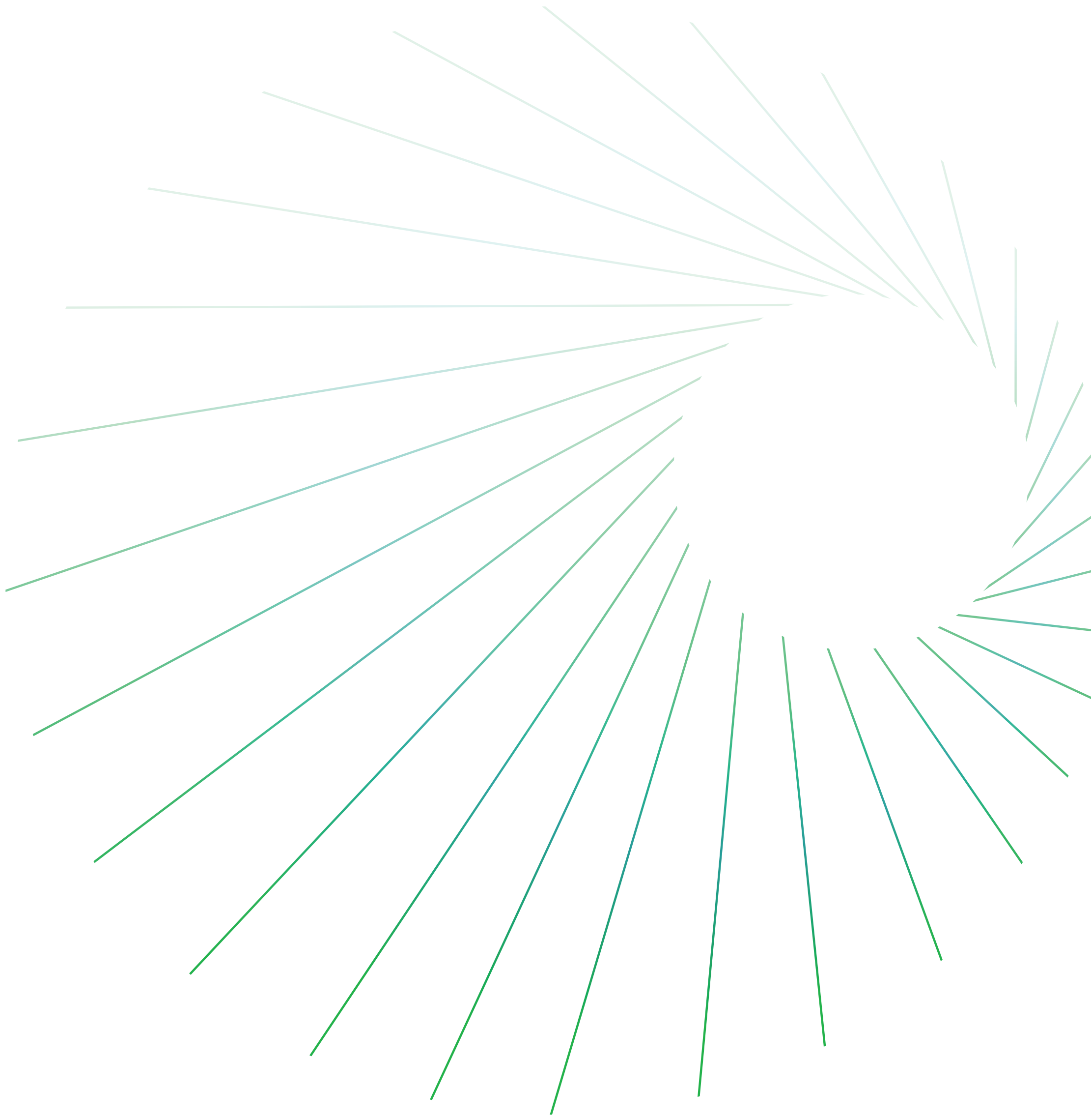
The GHG intensity of Canadian oil sands production: A new analysis

7 July 2020



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Crude Oil Markets | **Strategic Report**

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The GHG intensity of Canadian oil sands production: A new analysis

Kevin Birn, Vice President

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In 2018, IHS Markit made public a comprehensive analysis of the upstream greenhouse gas (GHG) intensity of the Canadian oil sands. The study included an analysis of past GHG emissions from 2009 to 2017 and an outlook about how emissions could evolve to 2030. Using the latest data available, as well some modeling improvements, this report updates and extends the analysis of upstream oil sands GHG emission intensity to 2018. It identifies the latest trends and discusses the sources of change to date.

Key insights

- The overall weighted average of the upstream GHG intensity of Canadian oil sands continued to decline in 2018—falling 2% from 72 kilograms of carbon dioxide equivalent per barrel (kgCO_2e/bbl) in 2017 to 70 kgCO_2e/bbl in 2018. This is about 20% lower than a decade earlier in 2009.

- The primary driver of the overall GHG emission intensity reduction in 2018 was not evenly distributed across the sector, with average intensity of mining emissions declining 10% year on year, while thermal operations increased 2% year on year. The scale of the reduction in emissions intensities in mining operations outweighed the rise in thermal operations.

- The ramp-up of a new oil sands mining operation with a GHG emissions intensity below the mining average, coupled with reductions in four out of the five legacy mining operations, contributed to a 10%, or 8 kgCO_2e/bbl, drop in the upstream GHG emissions intensity of oil sands mining to 75 kgCO_2e/bbl in 2018 compared with 2017.

- The average GHG emissions intensity of steam-assisted gravity drainage (SAGD) production—the dominant source of thermal extraction—increased by 1 kgCO2e/bbl, or about 2%, to 65 kgCO_2e/bbl in 2018. Meanwhile, the average intensity of cyclic steam stimulation (CSS) rose 9%, reaching 110 kgCO_2e/bbl compared with 2017.

- The variability in the Canadian oil sands emissions intensity in 2018 was the largest estimated by IHS Markit, spanning roughly 160 kgCO_2e/bbl—from 40 kgCO_2e/bbl to 201 kgCO_2e/bbl. This result means the most GHG-intensive operation was more than fourfold greater than the least intensive operation and implies the weighted average may do a poor job of representing any one operation.

—7 July 2020

About this report

In 2018, IHS Markit made public a comprehensive review of past and future oil sands emission intensity in a report titled *Greenhouse gas intensity of oil sands production: Today and in the future*. The historical component of that study spanned 2008–17 for mining operations and 2009–17 for thermal operations. This report extends the historical assessment to 2018 and documents the sources of emissions intensity changes in recent years.

Context. This report is part of a series of reports from the IHS Markit Canadian Oil Sands Dialogue. The dialogue convenes stakeholders to participate in an objective analysis of the benefits, costs, and impacts of various choices associated with the development of the Canadian oil sands. Stakeholders include representatives from governments, regulators, oil companies, shipping companies, and nongovernmental organizations.

This report and past Canadian Oil Sands Dialogue reports can be downloaded at www.ihsmarkit.com/oilsandsdialogue.

Methodology. IHS Markit conducted its own extensive research and analysis on this topic, both independently and in consultation with stakeholders. Historical performance was derived using publicly available regulatory data and two purpose-built bottom-up GHG emission models for oil sands thermal operations and oil sands mining operations, respectively. A description and explanation of IHS Markit historical estimation models and methodology can be found in Appendix B from the 2018 IHS Markit study titled *Greenhouse gas intensity of oil sands production: Today and in the future*. IHS Markit has full editorial control over this report and is responsible for its content.

Structure. This report has five sections and two appendixes.

- Introduction
- The IHS Markit method
- GHG intensity of oil sands past: 2008–18
- Comparability and consistency
- Concluding remarks
- Appendix A
- Appendix B

Introduction

The Canadian oil sands is one of the most scrutinized sources of crude oil supply in the world. The industry as it exists today was born during a time of high prices and scarce oil supply. Over the past decade, from 2009 to 2018, supply more than doubled from 1.6 MMb/d to nearly 3.5 MMb/d.[1] Greenhouse gas (GHG) emissions from production also rose, albeit at a slower rate, increasing 34 million metric tons of carbon dioxide equivalent (MMtCO$_2$e), or 62%, from 2009 to 2018.[2] Rising oil sands output, and GHG emissions along with it, has occurred amid a backdrop of growing global warming concerns and rising ambitions in Canada to reduce emissions. The Government of Canada is advancing a suite of policies aimed at tackling Canadian emissions reduction targets and recently announced its intention to develop a plan to achieve net-zero emissions by 2050.[3] A better understanding of Canadian oil sands GHG emissions and the factors influencing their evolution has only become more important.

IHS Markit has performed extensive analysis into the GHG emissions associated with production from the Canadian oil sands: absolute emissions, per unit of output or intensity, and how that compares with other sources of supply. In 2018, IHS Markit made public a comprehensive analysis of the historical upstream GHG emissions intensity of the Canadian oil sands and an outlook of future emissions based on existing trends to 2030. Using the latest available data, this report provides a fresh assessment of the upstream GHG emissions and emissions intensity of the Canadian oil sands to 2018 and documents the major sources of change.

This report is focused on the upstream emissions associated with oil sands production and can be considered the "Canadian-centric" share of emissions because most oil sands product is exported to be refined and combusted abroad. However, with most (70–80%) emissions occurring at combustion, a more holistic look at emissions over the entire life of a hydrocarbon is also important, and an update of the full life-cycle emissions is included toward the end of the report.

The report includes five sections and two appendixes. Appendix A provides detail data tables on study results. A discussion of sources of discrepancies between the prior IHS Markit analysis and this report is included in Appendix B.

Throughout this report, numerous oil sands terms are referenced. For more information, please refer to the box "Oil sands GHG primer."

The IHS Markit method

In 2018, IHS Markit made public a comprehensive review of the upstream GHG intensity of Canadian oil sands extraction from 2009 to 2017. It involved the creation of two new bespoke oil sands emissions models—one for mining and one for thermal operations—which together provided incredible granularity into the drivers of oil sands emissions and sources of change. The study also included a detailed review of how future emissions could evolve based on existing technology and efficiency opportunities to 2030. The report was titled *Greenhouse gas intensity of oil sands production: Today and in the future* and forms the foundation for this study. Throughout this report, the 2018 report is referenced as IHS Markit (2018). Since that report was published, additional historical information has become available to enable the historical analysis to be extended to include 2018.

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[1] Owing to blending requirements, supply is greater than production. Over the same period, production rose from 1.4 MMb/d to 2.9 MMb/d.

[2] "2020 National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990–2018," Environment and Climate Change Canada (ECCC), 15 April 2020, https://unfccc.int/ghg-inventories-annex-i-parties/2020, retrieved 16 April 2020.

[3] "Government of Canada releases emissions projections, showing progress towards climate target," Government of Canada, 20 December 2019, https://www.canada.ca/en/environment-climate-change/news/2019/12/government-of-canada-releases-emissions-projections-showing-progress-towards-climate-target.html, retrieved 30 March 2020.

Oil sands GHG primer

The oil sands are perhaps the most scrutinized source of crude oil in the world. This attention is due, at least in part, to the sheer scale of the resource potential and concerns about environmental impacts. Recent estimates place the amount of remaining economically recoverable reserves in the oil sands at 164 billion bbl, making oil sands the world's third-largest proven oil reserve (after Saudi Arabia and Venezuela).*

The oil sands are grains of sand covered with water, bitumen, and clay. The "oil" in the oil sands is bitumen, an extra-heavy crude oil with high viscosity. Accessing, separating, and marketing bitumen from the oil sands require energy, resulting in GHG emissions. The intensity of upstream production emissions depends on the reservoir characteristics, the extraction method, and each facility's unique configuration (performance and energy sources). Two forms of extraction dominate: mining and in situ.

Mining. About 20% of currently recoverable oil sands reserves are close enough to the surface to be mined. In a surface mining process, the overburden (vegetation, soil, clay, and gravel) is removed and used in associated infrastructure, such as roads and embankments, or stockpiled for later use in reclamation. The layer of oil sands ore is excavated using large shovels that scoop the material, which is then transported by truck to a processing facility. The ore is crushed or sized and then mixed with warm water and agitated, which causes the bitumen to separate. The energy used to power the vehicles involved in the mining process comes from fossil fuels, as does the heat used in the separation plant. In 2018, about two-fifths of supply came from mining, but, by 2030, as other forms of production are expected to outpace mining growth, mining's share of output will fall to about one-third. There are two forms of mining extraction:

- **Integrated mines or mined synthetic crude oil (SCO).** Legacy mining operations invested in and constructed heavy oil processing units upstream in the oil sands, which are often found integrated downstream into complex heavy oil refineries. Known as upgraders, these specialized processing units convert bitumen into a lighter SCO. As a result, upgraders add to upstream "mined SCO" emissions, which otherwise would occur downstream.

- **Unintegrated mines or mined dilbit (PFT).** In more recent years, two new mining operations have been completed that do not feature an integrated upgrader. Through a process known as paraffinic froth treatment (PFT), some of the heaviest components found in bitumen are precipitated out. The recovered bitumen is then diluted with lighter hydrocarbons (typically a natural gas condensate) and shipped to market as a bitumen blend or specifically a diluted bitumen (dilbit). This process avoids the energy associated with upgrading, reducing upstream GHG production emissions. However, the marketed dilbit is thereby more GHG intensive to refine, increasing downstream refining emissions. Still, on a net or full life-cycle basis, mined dilbit (PFT) is lower than mined SCO (this result can been seen in the life-cycle comparison discussed in the section titled "Comparability and consistency"). The PFT process has also been found to produce a modestly higher-quality bitumen and results in a dilbit product with a ratio of approximately four-fifths bitumen to one-fifth condensate.

In situ. About 80% of the recoverable oil sands deposits are too deep to be mined and are recovered by drilling. These deposits are the largest-growing source of oil sands production. In 2018, more than three-fifths of oil sands supply came from in situ operations, and, by 2030, it is expected to exceed two-thirds. Both primary and thermal extraction methods are deployed in situ. The primary extraction method is much more akin to conventional oil production and in 2018 accounted for about 5% of supply. However, as growth of other supply sources continues to outpace primary extraction, the primary extraction share of output is expected to decline to about 3% by 2030. Thermal production accounts for more than half of oil sands supply today (and nearly 90% of in situ supply). Thermal methods inject steam into the reservoir to lower the viscosity of the bitumen and allow it to flow to the

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**ST98: 2018: Alberta's Energy Reserves & Supply/Demand Outlook: Executive Summary*, Alberta Energy Regulator (AER), p. 7, https://www.aer.ca/documents/sts/ST98/ST98-2018_Executive_Summary.pdf, retrieved 15 April 2020.

Oil sands GHG primer (continued)

surface. Natural gas is used to generate the steam, which results in GHG emissions. Bitumen produced from in situ operations is also too viscous to permit transport by pipeline and must be diluted with lighter hydrocarbons, making a bitumen blend. The most common blend is dilbit with a ratio of about 70% bitumen to 30% condensate. There are two dominant forms of thermal in situ extraction.

- **Steam-assisted gravity drainage (SAGD)** is the fastest-growing method, accounting for more than two-fifths of total oil sands supply in 2018 (nearly 75% of in situ supply), and is expected to dominate growth, accounting for about 55% of oil sands supply by 2030.

- **Cyclic steam stimulation (CSS)** was the first thermal process used to commercially recover oil sands in situ. CSS currently makes up 8% of oil sands supply. Growth in other sources of supply is expected to outpace CSS, and CSS share of total supply is expected to fall to 7% by 2030.

This section summarizes the method IHS Markit used to evaluate oil sands GHG emissions.

Estimating historical oil sands emission intensities

This study is focused on the upstream GHG emissions of oil sands extraction and initial processing and documents the sources of emission intensity changes over time. Unless otherwise expressly stated, this report makes use of the same methodology, boundary conditions, and models deployed in IHS Markit (2018). For a detailed description of the IHS Markit method, please see IHS Markit (2018).

Our analysis included a detailed review of the two primary sources of oil sands extraction: oil sands mining and in situ thermal extraction (principally SAGD). Other forms of production—primary, experimental, and enhanced oil recovery (EOR) techniques used in the oil sands region—were included in the total oil sands industry average shown in this report using estimates from prior IHS Markit reports and other analysis but are not modeled in this study.

Differences in data and production processes necessitate distinct modeling approaches for mining and in situ operations. Data limitations affect the period for which historical estimates were possible: 2008–18 for mining operations and 2009–18 for in situ operations. Although this study period overlaps with IHS Markit (2018), the entire period was reestimated for this report. In addition to new facility and production data for the 2018 calendar year, new cogeneration performance data from Alberta Environment and Parks for 2015–17 were incorporated in our analysis and impacted thermal oil sands estimates over the entire study period.

Boundary conditions are critical

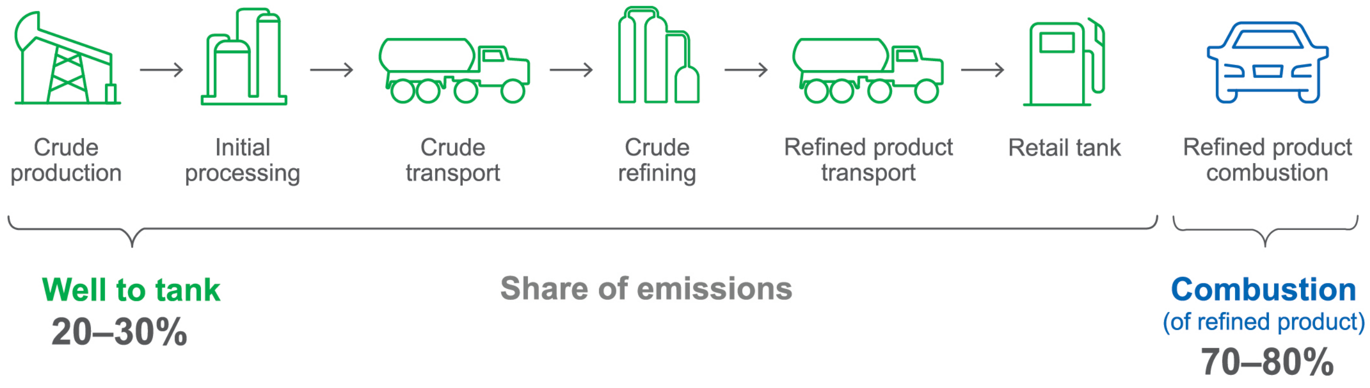
Understanding the emissions or system boundaries is critical when reviewing GHG estimates of crude oil and other hydrocarbons. Emission boundaries set the parameters for which emissions are being counted or included in the estimate and can, for obvious reasons, affect the results.

Interest in the GHG emissions intensity of oil and gas extends from upstream production all the way to its end use or combustion (see Figure 1). This is known as life-cycle analysis.

This study is focused on the upstream GHG emissions associated with crude production and initial processing as depicted in Figure 1. However, the scope of emissions considered by IHS Markit is broader and includes emissions associated with upstream production of fuel, such as natural gas or diluent used in the production and creation of diluted bitumen, as well as the import and export of electricity that can arise from facility use and cogeneration.

Figure 1

Life-cycle GHG emissions of petroleum fuels



Source: IHS Markit

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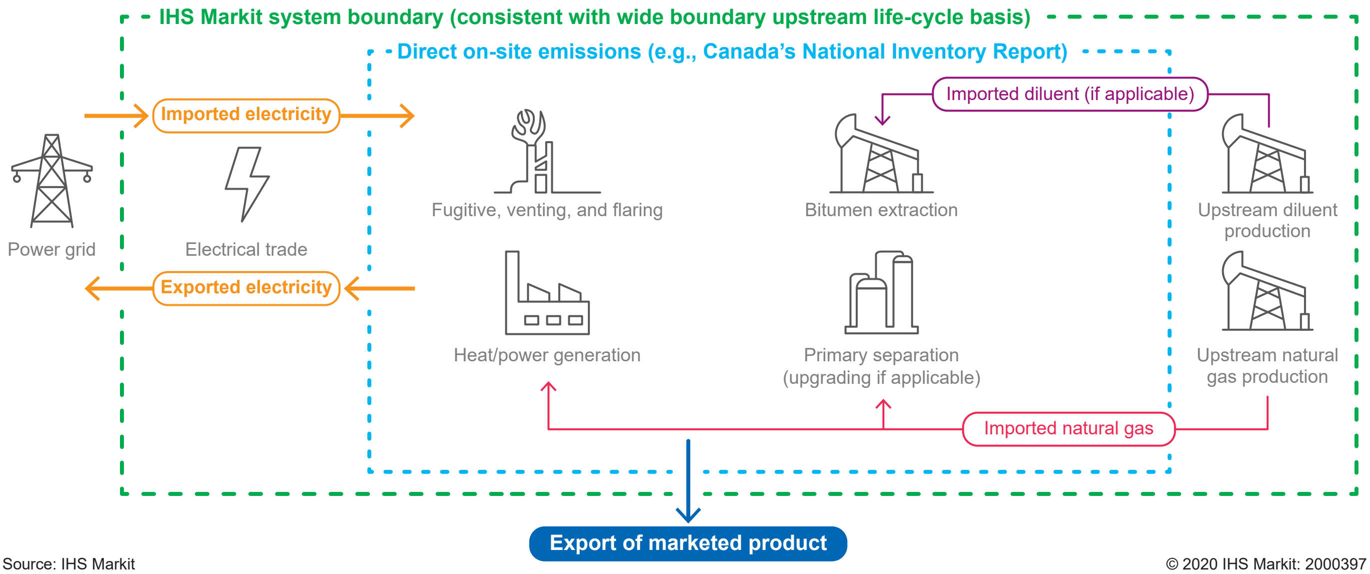
These system boundaries are consistent with prior IHS Markit research, which allows for apple-to-apple comparisons and integration with our existing work. In a few instances, different emissions boundaries are considered in this report, which are clearly marked.

See Figure 2 for a visual description of boundary conditions used in this report.

Figure 2

System boundaries



Source: IHS Markit

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It should be noted that these emission boundaries differ from emissions captured by Canada's National Inventory Report (NIR), which focuses and reports solely on Scope 1 or direct emissions.[4] A comparison of IHS Markit results with absolute emissions as reported in Canada's NIR is made in the fourth section of this report: "Comparability and consistency."

Results are presented as the weighted average of the marketed product by extractive technology to best represent the GHG intensity of production that is sold and processed by downstream refineries. Where possible, estimates of minimum and maximum intensity are provided as well. Results include mined SCO, mined dilbit (PFT), total mining, SAGD dilbit, and CSS dilbit.

GHG intensity of oil sands past: 2008–18

The Canadian oil sands continued its decade-long emission intensity reduction trend in 2018. This trend is shown in Figure 3. The weighted average upstream GHG intensity of the Canadian oil sands came in just under 70 kilograms of carbon dioxide equivalent per barrel (kgCO_2e/bbl)—down 2% from 2017 levels. Since 2009, the weighted average emission intensity has fallen 20%, or about 17 kgCO_2e/bbl.[5]

There is considerable variability in the GHG intensity of upstream extraction in the oil sands. The most intensive operation is over four times more GHG intensive than the least. IHS Markit has found a similar degree of variation in other plays globally, and caution is advised when interpreting the weighted average values as they may not represent any individual operation.[6]

The lower bound of the GHG intensity range in 2018 was set by a SAGD dilbit operation at 40 kgCO_2e/bbl. This level was nearly tied with that of a mined dilbit (PFT) facility. Meanwhile, the upper bound of the GHG intensity range rose to 201 kgCO_2e/bbl from a CSS operation, which is best classified as an outlier, representing less than 1% of total CSS output (or about one-fifth of a percent of total thermal production). The range of emission intensity associated with CSS operations is not depicted in Figure 3 simply because the figure becomes difficult to interpret (too many overlapping areas). CSS emissions are included in the weighted average presented in Figure 3.

The primary drivers for the continued decline in the average GHG intensity of the Canadian oil sands were the result of increasing production from lower GHG-intensive mined dilbit (PFT) and ongoing efficiency improvements of mined SCO, with three out of the four legacy operations experiencing GHG emission intensity reductions in 2018. These drivers as well as historical emissions by each major oil sands subsegment are documented in the following section. These subsegments include mining (mined SCO and mined dilbit [PFT]) and in situ (SAGD dilbit and CSS dilbit). Oil sands mining and thermal in situ (SAGD and CSS) accounted for more than 90% of all oil sands supply in 2018.

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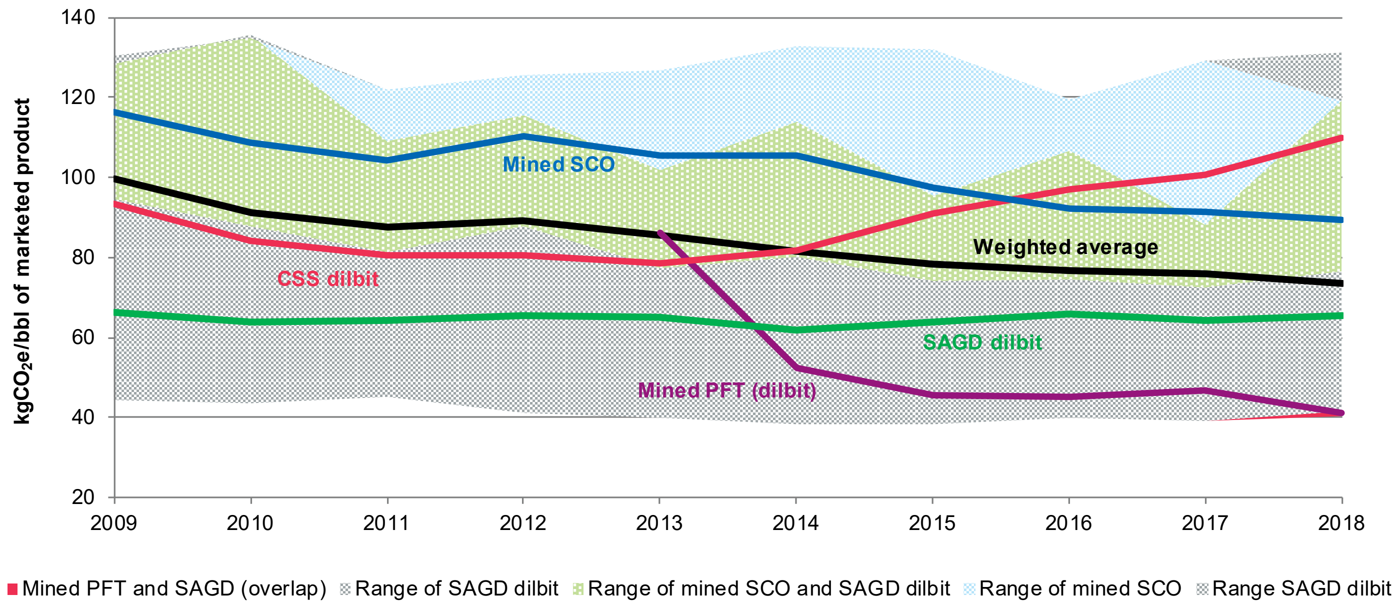
4. "Canada's official greenhouse gas inventory," Government of Canada, https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html, retrieved 30 March 2020.

5. Estimate of total oil sands average includes oil sands CSS, SAGD, mined SCO, mined dilbit (PFT), primary, experimental, and EOR. GHG intensity estimates of primary, experimental, and EOR were held static and sourced from the IHS Markit Strategic Report *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*.

6. See the IHS Markit *Understanding the GHG intensity of Crude Oil: The challenge of averages*.

Figure 3

Range and average of GHG intensity of oil sands extraction by year and by technology on a marketed product basis, 2009–18



Note: Estimate of total oil sands average includes oil sands CSS, SAGD, mined SCO, mined dilbit, primary, experimental, and EOR. Estimates for primary, expermential, and EOR are a very small share of oil sands production, and constant values were used.
Source: IHS Markit

GHG intensity of oil sands mining in 2018

Oil sands mining made up more than two-fifths of oil sands supply in 2018. Production is composed of two forms of surface mining operations. One is mined SCO, which is a mine that incorporates heavy oil conversion capacity known as an upgrader, which enables the production and marketing of light SCO. The second is mined dilbit (PFT), which is a mine capable of marketing bitumen without an upgrading unit. The mined dilbit (PFT) process lowers the upstream energy and thus GHG emissions of production but also requires blending the raw bitumen with diluent to enable its transportation to market by pipeline. Mined SCO accounted for nearly 30% of oil sands supply in 2018 and mined dilbit (PFT) just over 13%.

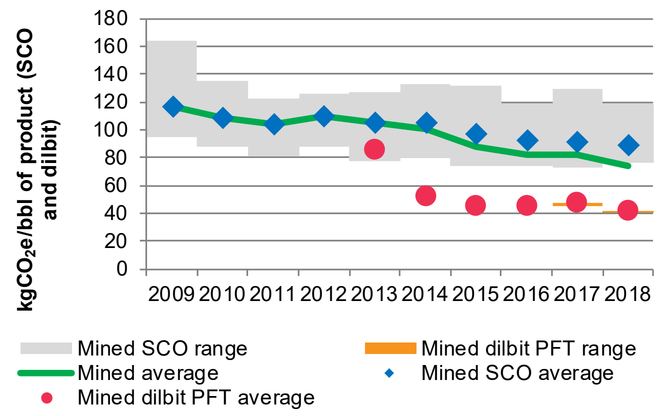
IHS Markit found that the weighted average GHG intensity of oil sands mining continued its decade-long trend of year-on-year reductions in 2018. As shown in Figures 4 and 5, the average intensity of oil sands mining fell by 10%, or 8 kgCO_2e/bbl, to 75 kgCO_2e/bbl from 2017 to 2018. This was the second-greatest year-on-year drop in the estimated history of oil sands mining emissions. The largest was a 12% reduction during 2014–15.

The variability or range of mining emissions spanned over 78 kgCO_2e/bbl, with the least GHG-intensive mining operation being a mined dilbit (PFT) facility at about 41 kgCO_2e/bbl and the most GHG-intensive operation at 119 kgCO_2e/bbl from mined SCO—a nearly threefold range from top to bottom.

The major driver for the intensity reduction between 2017 and 2018 was the ramp-up of the latest oil sands mining operation, the Fort Hills Partnership. As a mined dilbit (PFT) facility, it has a much lower upstream GHG emission intensity than the average (on an upstream basis, the GHG intensity of mined dilbit [PFT] is roughly half that of mined SCO; on a full life-cycle basis, the difference is smaller as dilbit is more GHG intense to refine). As shown in Figure 5, the ramp-up of this new operation accounted for nearly three-quarters of the 8 kgCO_2e/bbl reduction. As production ramped up over 2018, it pulled down the average GHG intensity of mining.

Figure 4

Historical GHG emission intensity of mined oil sands by marketed product (SCO and dilbit)



Source: IHS Markit

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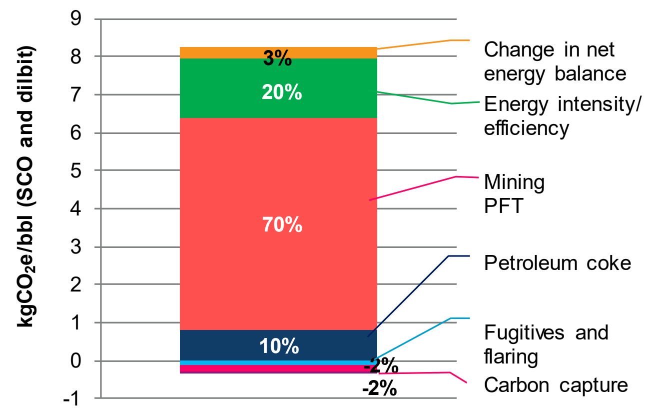
Figure 5

Source of oil sands mining GHG intensity improvement (2017–18, 8 $kgCO_2e/bbl$ of product)



Source: IHS Markit

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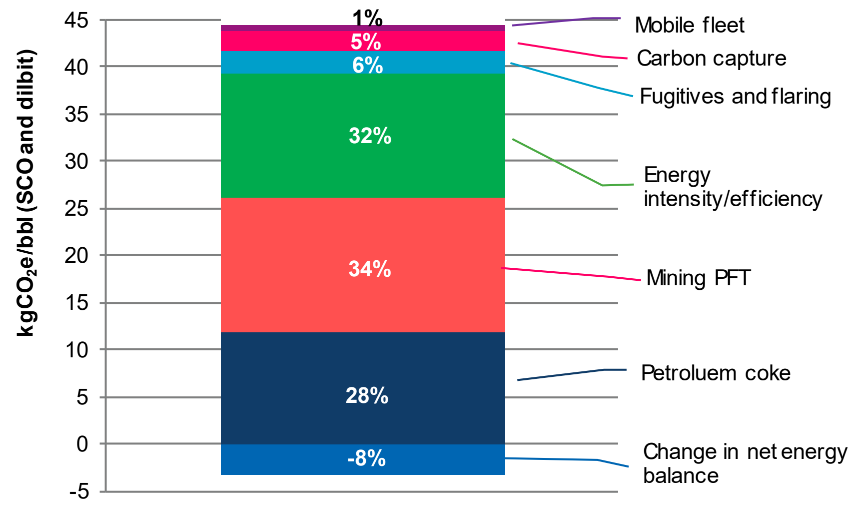
The next largest contributor came from energy efficiency improvements, followed by further reductions in the use of petroleum coke.[7] Much of the energy efficiency gain can be attributed to improvements at one larger operation that has historically had above-average GHG intensity compared with its peer group. In 2018, this one operation experienced a nearly 10 $kgCO_2e/bbl$ drop in upstream intensity. With large volumes coming from few facilities, the performance of one operation can materially affect the average.

Figure 6

Source of oil sands mining GHG intensity improvement (2009–18, 42 $kgCO_2e/bbl$ of product)



Source: IHS Markit

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Reductions over the past decade now total 42 $kgCO_2e/bbl$, or 36%, from 2009 to 2018.[8] Figure 6 presents a breakdown of the major drivers of emission reductions over the past decade.

Mined SCO

Although both mined SCO and mined dilbit (PFT) are both first and foremost surface mining operations, they are distinct and should be looked at separately.

In 2018, the average intensity of mined SCO continued its decade-long trend in reductions, falling 2 $kgCO_2e/bbl$, to 89 $kgCO_2e/bbl$. This result represents a 3% reduction from 2017. Over the past decade, the emissions intensity of SCO fell nearly a quarter, or 27 $kgCO_2e/bbl$. The primary driver of the emission intensity reductions was attributable to improvements

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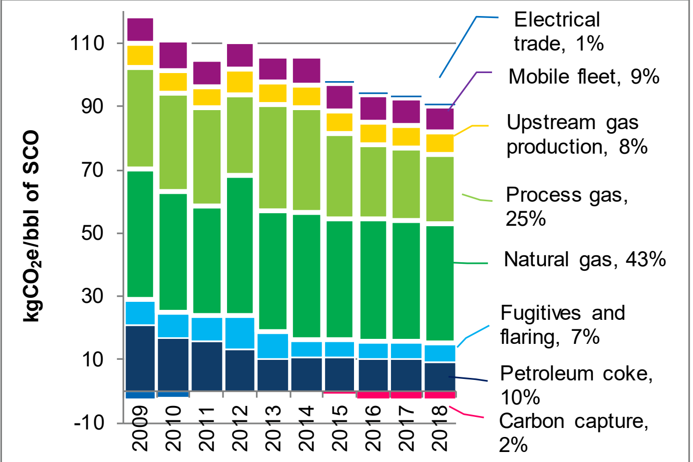
7. It is also important to note that a petroleum coke emission intensity reduction can result from actual reductions in the use of petroleum coke or an increase in output produced without the use of petroleum coke (i.e., increases in production while petroleum coke consumption is held constant).

8. For the first data point IHS Markit has in 2008, emission reduction is less pronounced, falling about 39 $kgCO_2e/bbl$ owing to slightly lower emissions in 2008 versus 2009. See Appendix A for data tables for more information.

in energy efficiency or fuel use per unit of output, which includes petroleum coke, and mobile mining fleet efficiency. These changes are depicted in Figures 7 and 8.

Figure 7

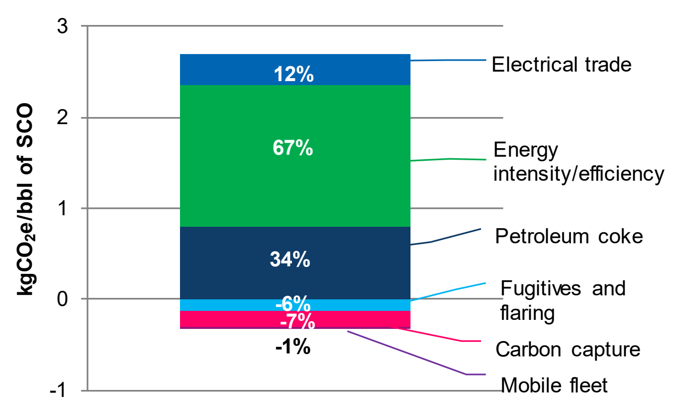
Composition of mined SCO intensity, 2009–18



Source: IHS Markit © 2020 IHS Markit

Figure 8

Source of oil sands mining GHG intensity improvement (2017–18, 2 $kgCO_2e/bbl$ of product)



Source: IHS Markit © 2020 IHS Markit

Mined dilbit (PFT)

Mined dilbit (PFT) is the newest form of oil sands mining extraction. Presently, there are only two mines operating that market dilbit.[9] They are Imperial's Kearl facility, which came online in 2013, and the Fort Hills Partnership, which achieved first oil late in 2017 and ramped up over 2018.

In 2018, the average intensity of mined dilbit (PFT) fell by nearly 6 $kgCO_2e/bbl$, or 12%, to average 41 $kgCO_2e/bbl$. This result is visible in Figure 9 and was surprising given the majority of the ramp-up of Fort Hills occurred over 2018. Typically, during the ramp-up of new oil-producing operations emission intensity tends to be higher than normal as production generally would lag the ramp-up of energy use. However, in 2018 the impact of the ramp-up of the Fort Hills project did not appear to hurt average mined dilbit (PFT) intensity. This result was in part due to the initial stages of the ramp-up, which began in late 2017, splitting part of the ramp-up over two calendar years (partially visible in Figure 9). The other part of the story behind the muted impact of the ramp-up on the emission intensity was due to what appears to have been a relatively efficient ramp-up where power consumption came up with output and the facility was able to export surplus power to the grid, which under IHS Markit boundary conditions offset part of the emissions intensity rise. In Figure 10, some characteristics that would be expected of a large facility ramping up operations are more visible, such as the impact of the rise in fleet movement with production lagging output, the impact of the ramp-up of cogeneration increasing exports to the electrical grid, and the improvement in energy use as production increases. This latter point was assisted by improvements at Kearl, where emission intensity declined as output rose.

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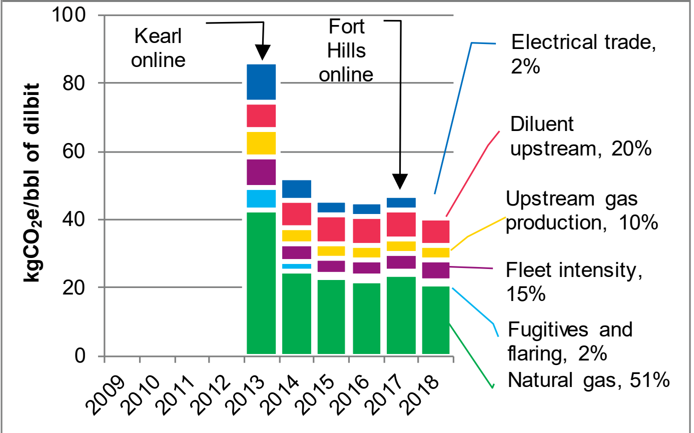
[9] Technically, the first mining operation to make use of PFT was Albian Sands, which made use of PFT to stabilize the bitumen for transport to its upgrader located in Edmonton, Alberta. However, this facility only markets SCO.

Figure 9

Composition of mined dilbit (PFT) intensity, 2009–18



Source: IHS Markit

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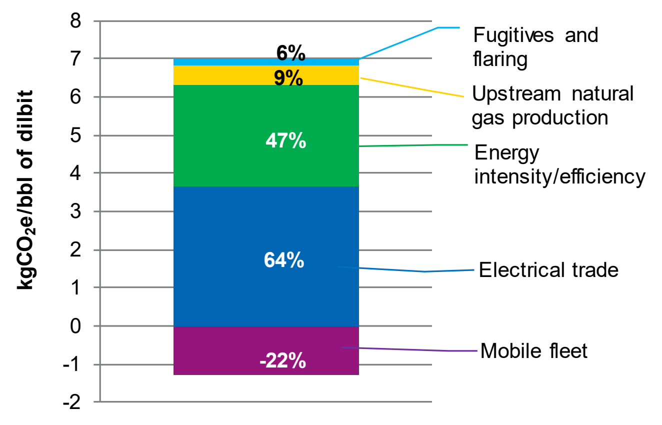
Figure 10

Source of oil sands mined dilbit PFT GHG intensity improvement (2017–18, 6 $kgCO_2e$/bbl of product)



Source: IHS Markit

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GHG intensity of oil sands thermal extraction in 2018

Thermal oil sands extraction accounted for more than half of total oil sands supply in 2018. Primary, experimental, and EOR in the oil sands region (which is not necessarily oil sands reservoirs) made up about 7% of oil sands supply. SAGD is the dominant form of production and the fastest-growing source of oil sands supply over the past decade. SAGD involves the continuous horizontal injection of steam into oil sands reservoirs and recovery of bitumen and water. Over the past decade (2009–18), SAGD was responsible for nearly three-fifths of oil sands supply growth and in 2018 accounted for more than two-fifths of total supply.

CSS, also known as huff and puff, makes use of vertical wells for temporal periods of steam injection and recovery back up the same well (hence huff and puff). Over the past decade, CSS production levels have not materially changed and in 2018 accounted for about 8% of oil sands supply. CSS is not anticipated to grow in the IHS Markit outlook. Although CSS is included in our study, our analysis is focused on SAGD given it is the single-largest form of source of supply and is expected to dominate growth. Although SAGD and CSS are both thermal forms of extraction, the choice between them relates primarily to reservoir characteristics, and thus we treat them separately. This situation differs from mining where there is fundamentally no differences in the underlying resource that influence the choice of extractive approach.

SAGD dilbit

Consistent with the prior IHS Markit report, the GHG intensity of SAGD was relatively unchanged. As shown in Figure 11, the average intensity of SAGD dilbit increased by 1 $kgCO_2e$/bbl, from 64 $kgCO_2e$/bbl in 2017 to 65 $kgCO_2e$/bbl in 2018. Meanwhile, the range of GHG intensity in 2018 expanded owing to relatively low-volume, higher GHG-intensive operations. In 2018, the least GHG-intensive SAGD operation was 40 $kgCO_2e$/bbl, with the most GHG-intensive operation being 131 $kgCO_2e$/bbl—a span of 91 $kgCO_2e$/bbl. These outliers contributed to the modest increase in the annual average emission intensity and marks the first time in nearly a decade that the upstream GHG intensity of a SAGD dilbit operation exceeded that of mined SCO.

Interestingly, although there was a greater range or variability in the span of emissions, the variance or dispersion of facilities from the mean continued to decline in 2018. This relationship is visible in Figure 12, which shows the distribution of all SAGD operations' steam-to-oil ratio (SOR) by year.[10] It is also visible that

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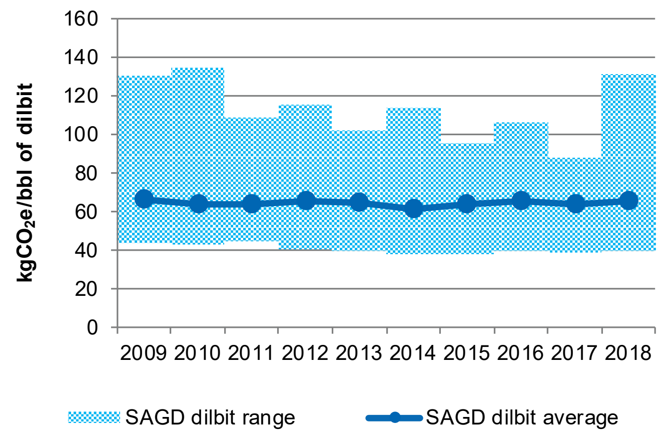
[10] SOR is the volume of steam required to produce one barrel of bitumen and is highly correlated with GHG emissions.

Figure 11

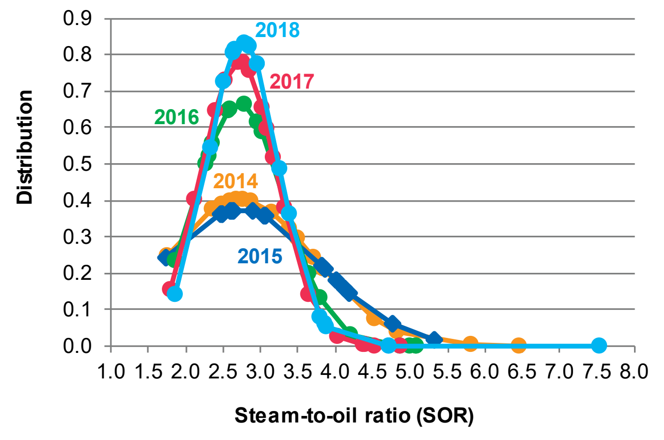
Historical GHG intensity of SAGD dilbit, 2009–18



Source: IHS Markit

Figure 12

Distribution of SAGD SOR by year



Source: AER, IHS Markit

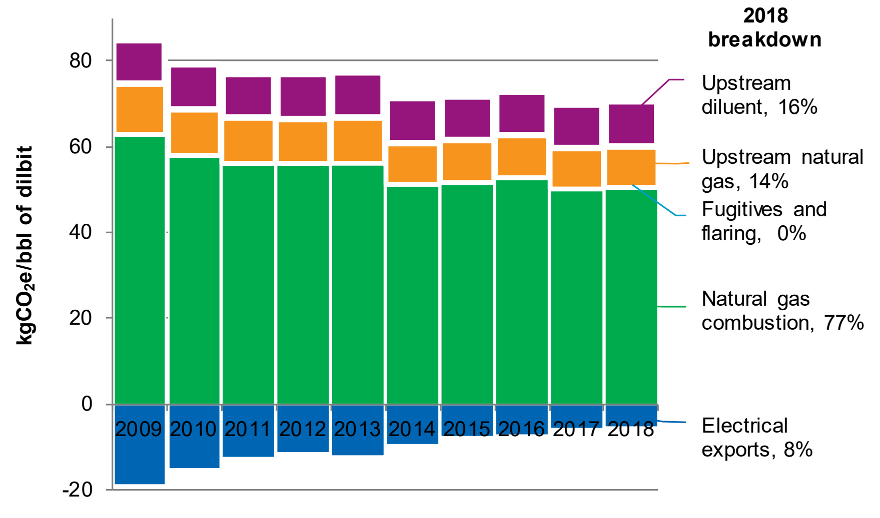
the number of higher SOR outliers declined each year, while in 2018 there was one very pronounced extreme outlier setting that upper bound of SAGD intensity.[11]

The drivers of the long-standing stagnation of the average GHG intensity of SAGD dilbit are in part attributable to the choice of emissions boundaries deployed by IHS Markit and the industry's historical relationship with cogeneration.

IHS Markit analysis includes energy that is bought and sold from the electrical grid. Over time, as SAGD production has grown, facilities increased their own use of the electrical power from their cogeneration units. On a net basis, the greater use of on-site electrical power generation has led to declining electrical exports and associated intensity credits (as per IHS Markit emissions boundaries used in this report). Over the same period, SAGD operations have become more efficient with declining steam or natural gas per barrel. These two factors are clearly visible in Figure 13, with natural gas combustion intensity and electrical export intensity declining consistently over the past decade. The net impact of these two factors largely offset each other, leaving overall emission intensity relatively flat under IHS Markit emission boundaries. If we were to change the emission boundary conditions to be consistent or comparable with Canada's NIR, which includes only Scope 1 or direct emissions (see

Figure 13

Composition of historical SAGD dilbit GHG intensity, 2009–18



Source: IHS Markit

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[11] Facilities in ramp-up are typically removed from the distributions and IHS Markit estimate of range as they tend to have a high intensity and lower production volume; however, if operations persist after what would be considered normal ramp-up they would be included.

Figure 2), we find emission intensity would have declined by 19%, or 12 $kgCO_2e/bbl$, over this same period.[12] This point underscores the importance of understanding emission boundaries or which emissions are included in an estimate.

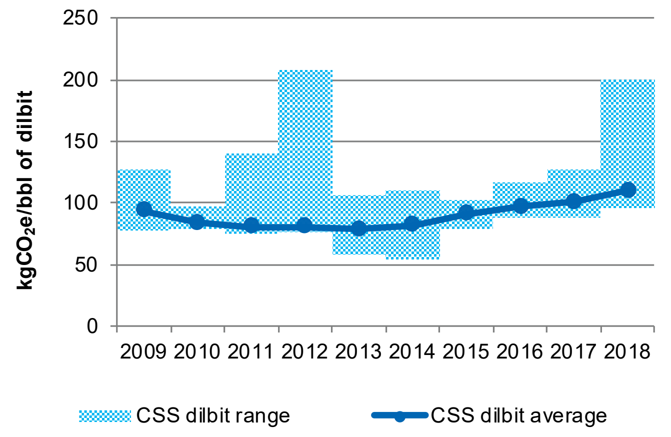
CSS dilbit

CSS dilbit is the only form of oil sands extraction that has been on an upward emission intensity trend in recent years (see Figures 14 and 15). After the emissions intensity reached a low point in 2012, increasing volumes of steam, and thus natural gas, have been used per barrel of dilbit produced, leading to a rise in GHG emissions intensity. Over this same period, from 2012 to 2018, output also generally declined.

The average intensity of CSS dilbit increased 9%, or 9 $kgCO_2e/bbl$, from 2017 to 2018 to reach 110 $kgCO_2e/bbl$. CSS dilbit output is highly consolidated with only three existing operations, and more than 90% of output coming from the two largest ones. In recent years, the smaller of the three operations has had the greatest rise in GHG emission intensity, and despite being a highly consolidated sector the variability across CSS operations has increased considerably. This result is visible in Figures 14 and 15. In 2018, the range of CSS dilbit spanned from 96 $kgCO_2e/bbl$ to 201 $kgCO_2e/bbl$. The top end of the CSS range of 201 $kgCO_2e/bbl$ was also the upper bound across all oil sands operations.

Figure 14

Historical GHG intensity of CSS dilbit, 2009–18



Source: IHS Markit

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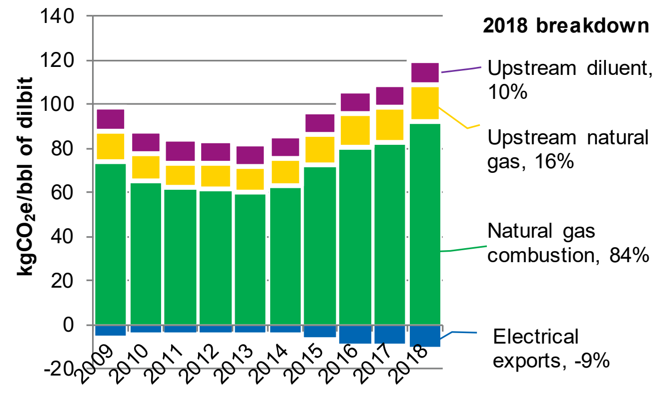
Figure 15

Composition of historical CSS dilbit GHG intensity, 2009–18



Source: IHS Markit

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IHS Markit does not expect CSS dilbit to materially grow in the future, and the current rise in emission intensity has the potential to moderate in the near term. The recent upward trend in emissions intensity may be a result of the combination of the maturity in both producing wells and CSS operations. The most productive period of any well is early in its operation. As oil is recovered from a given reservoir, recovery rates tend to decline or require more work to maintain. This result puts upward pressure on GHG emission intensity. Eventually, these wells will be retired and replaced with new wells to maintain output or mitigate production declines. The rate of this replacement may have been impacted by the lower price environment in recent years, and with fewer operations and less volume than SAGD, operational changes may be more apparent. Longer term, it remains to be seen how the most recent price collapse of 2020 may impact upstream investment in CSS and future GHG emissions intensity.

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[12] Estimate is based on barrel of bitumen basis, on a per barrel of dilbit basis.

Comparability and consistency—Playing with boundary conditions

There is uncertainty associated with estimating the GHG intensity of crude oil. Uncertainty can lead to reliability issues and differences in emissions boundaries (which emissions are included), which can lead to differences between estimates and studies. This section compares the current IHS Markit analysis with our prior work as well as with Canada's NIR, which makes use of different boundary conditions. Also included is the IHS Markit estimate of absolute oil sands emissions subject to the Alberta oil sands emissions limit (100 megatonne [MT] cap) and an update of the full life-cycle GHG emissions intensity of key oil sands production streams.

IHS Markit estimates are consistent with prior work

IHS Markit has conducted several studies about the GHG intensity of Canadian oil sands. This report makes use of the same general assumptions as our prior IHS Markit (2018), including the same base models. Although some new information became available, notably the GHG emissions intensity of SAGD and CSS cogeneration, the latest IHS Markit report's finding ranged on average within 4% compared with that in our prior analysis. Table 1 provides a high-level comparison of the two studies' primary results.

Table 1

IHS Markit (2020) and IHS Markit (2018) industry weighted average oil sands intensity compared*
(kgCO_2e/bbl of product)

Source	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
IHS Markit (2018)	89	84	79	81	79	76	73	70	70	*67***
IHS Markit (2020)	88	86	82	83	80	77	74	72	72	70
Total	**-1%**	**1%**	**4%**	**3%**	**2%**	**2%**	**2%**	**4%**	**2%**	**4%**

*Includes primary, experimental, and EOR operations not modeled in this analysis. **IHS Markit (2018) estimate for 2018 was a projection as opposed to an actualized estimate based on operating data.

Source: IHS Markit

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The sources of discrepancies between the two studies are associated with changes to estimates of SAGD, CSS, and mined dilbit (PFT). Both thermal operations' (SAGD and CSS) emissions intensities were impacted by additional cogeneration performance data from Alberta Environment and Parks. This outcome resulted in a modest increase in our estimate of the GHG intensity of SAGD and CSS from 2015 to 2018. It also contributed to a small reduction in the GHG intensity of CSS dilbit for 2009 to 2011. Updates to mined dilbit (PFT) output and changes in our blend rate (dilute requirement per barrel of bitumen) assumption reduced our estimate of the historical GHG emission intensity compared with that in our prior analysis. A minor error was also found in our estimation of upstream GHG emission intensity for natural gas use for all mining projects. This did not have a material impact on the results.

The largest source of the difference shown in Table 1, however, was a result of a change in the modeling of CSS dilbit.[13] Alignment issues were discovered in the rate of year-on-year intensity change and year-on-year change in steam demand for CSS dilbit. The prior approach relied in part on the steam intensity relationship of SAGD adjusted to CSS steam demand. In this report, the CSS dilbit relationship to SAGD was severed and modeled separately.[14] The change resulted in an upward revision in the GHG intensity of CSS dilbit for 2010–17.

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13. If CSS dilbit is removed from the weighted average comparison, shown in Table 1, the difference over the study period falls to 1%.

14. Because CSS dilbit was not part of the forecast emissions intensity in the prior IHS Markit analysis, the modeling approach relied on some simplifications compared with the approach taken in modeling SAGD. Changes in CSS steam demand were estimated based on estimated energy intensity of SAGD adjusted for CSS steam intensity. This approach to CSS in the prior report was believed to be equivalent, but rounding issues appear to have contributed to some misalignment.

The net impact of these changes resulted in a modestly lower GHG intensity estimate in 2009 and a modestly higher GHG intensity estimate in the latter years in the study period compared with that in our prior analysis. Appendix B provides a more detailed discussion of differences between the studies.

IHS Markit estimates within 3% of the Canada's National Inventory Report

When it comes to GHG emissions, Canada's NIR prepared by the ECCC is regarded by many as the gold standard for Canadian emissions. The NIR provides annual absolute estimates of Scope 1 or direct emissions of key sectors, including upstream oil and gas and oil sands. These estimates differ from IHS Markit intensity estimates, which include a wider scope of emissions. Figure 2 at the beginning of this report provides a visual comparison of the differences in emissions boundary conditions between IHS Markit analysis and Canada's NIR.

IHS Markit, however, was able to make an apple-to-apple comparison of our estimates to the ECCC NIR. First, IHS Markit emission boundaries were adjusted to include only on-site direct emissions and then multiplied by annual production volumes to obtain absolute annual emission estimates. The NIR estimate was then adjusted by removing emissions associated with oil sands upgrading in Saskatchewan and the North West Redwater (NWR) refinery, which IHS Markit understands to be included as part of the ECCC NIR assessment of oil sands upgrading emissions. Both facilities are not included in the IHS Markit estimate. The NIR provides an estimate of Saskatchewan oil sands upgrading emissions, which we removed from total oil sands emissions reported in the NIR. Emissions associated with NWR for 2017 and 2018 were also removed from the NIR total using data from Canada's large facilities emitters database.[15]

After normalizing both the NIR emissions scope and IHS Markit emission boundaries, a comparison can be made, which is shown in Table 2. The results show that despite independent modeling approaches, IHS Markit estimates were on average over the past five years within 1% to those of the NIR. However, a more detailed comparison does reveal greater differences at individual production technology streams, particularly in 2016. It is our view that these discrepancies are within a reasonable error given the different modeling approaches. For more information, see Appendix B.

Table 2

Comparison of IHS Markit absolute oil sands emissions to Canada's NIR (adjusted)*

($MMtCO_2e$)

Source	2014	2015	2016	2017	2018
National Inventory Report (adjusted)*	**68**	**72**	**71**	**77**	**80**
Mining and upgrading (adjusted)*	39	39	36	39	39
In situ	29	33	35	38	41
IHS Markit (2020)	**69**	**71**	**71**	**77**	**80**
Mining and upgrading	37	35	31	35	36
In situ	32	36	40	42	43
Total	**2%**	**0%**	**-1%**	**1%**	**-1%**

*IHS Markit assessment did not include emissions associated with Husky Bi-Provincial Upgrader (BPU) located in Saskatchewan and the North West Redwater (NWR) Partnership Sturgeon refinery. The NIR (2020) assessment for oil sands mining and upgrading emissions shown here in Table 2 was adjusted by deducting the NIR (2020) assessment of Saskatchewan upgrading, which was assumed to be BPU, and by deducting reported emissions for the Sturgeon refinery from the ECCC large emitters database for 2017 and 2018.

Source: IHS Markit, ECCC NIR: Greenhouse Gas Sources and Sinks in Canada 1990–2018 (NIR 2020), ECCC: Greenhouse Gas Emissions from Large Facilities, 2019 and 2020

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[15] IHS Markit understands that Canada's NIR includes emissions from the Husky Energy Bi-Provincial Upgrader (BPU) in Saskatchewan as part of oil sands upgrader emissions, along with emissions from the NWR refinery. The BPU is not included in the IHS Markit analysis because it is not dedicated to upgrading oil sands bitumen as it also processes other non–oil sands–derived heavy crude oil. The NIR estimates of the Saskatchewan oil sands upgrader were removed from the NIR totals shown in Table 2 . This would be similar to using Alberta oil sands totals found in the NIR. In addition, NWR is also not part of the IHS Markit analysis as it is designed to market refined products. IHS Markit removed emissions associated with NWR using the ECCC Greenhouse Gas Emissions from Large Facilities database for 2017 and 2018. Please see "Greenhouse gas emissions from large facilities," Government of Canada, https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions/large-facilities.html, retrieved 1 June 2020.

Understanding Alberta's 100 MT oil sands cap

A good example of the importance of understanding emissions boundaries in GHG estimation is in discussions involving the Oil Sands Emissions Limit Act announced in 2016. The act would limit absolute oil sands emissions in Alberta to 100 MT. This is also known colloquially as the "100 MT cap."

The 100 MT cap includes a distinct definition of which emissions are subject to or included as part of the emissions cap, differing from the definition in Canada's NIR. Under the 100 MT cap, emissions associated with electrical power generation and use; emissions arising from primary, experimental, and EOR crude oil production (occurring within the oil sands region); and emissions associated with upgraders that start up after 2015 are excluded.[16] As a result of these differences, emissions subject to the cap are lower than those found in the NIR.

In 2018, IHS Markit estimates this difference adds up to more than 13 $MMtCO_2e$—about 9 MT associated with electrical power generation and use; 2 MT associated with "new upgrading"; and nearly 3 MT associated with primary, experimental, and EOR extraction. A comparison of the IHS Markit estimate of direct oil sands emissions consistent with Canada's NIR and emissions subject to the 100 MT cap over the past five years is shown in Table 3.

Putting IHS Markit analysis on a full life-cycle basis

The latest IHS Markit analysis focuses on upstream GHG emissions associated with oil sands extraction and primary processing (i.e., upgrading). However, an estimate of the full life-cycle GHG intensity—from extraction to combustion—was completed to allow for comparison with prior IHS Markit work.

Table 3

Comparison of absolute direct oil sands emissions by year and emissions included in 100 MT
($MMtCO_2e$)

Source	2014	2015	2016	2017	2018
Direct boundary	69	71	71	77	80
100 MT cap	56	57	58	63	66
Difference	**13**	**14**	**13**	**14**	**13**

Source: IHS Markit

IHS Markit made use of its prior analysis for downstream processing, transportation, and combustion emissions to complete the estimate with the exception of mined dilbit (PFT).[17] IHS Markit undertook a new estimate for the downstream (or refining) GHG emission intensity associated with processing mined dilbit (PFT) because the prior estimate from 2014 assumed a crude assay similar to SAGD dilbit. Mined dilbit (PFT) has lower asphaltenes and a lower blending requirement (volume of diluent required to meet pipeline specification) and, as a result, a different downstream GHG emission intensity. This work revised the refining emission intensity for mined dilbit (PFT) from the prior assumption of 70 $kgCO_2e/bbl$ of refined product to 55 $kgCO_2e/bbl$ of refined product. The full life-cycle GHG emissions intensity of mined dilbit (PFT) was reassessed at 1.6% below the US average in 2018.[18] For more information on the downstream mined dilbit (PFT) GHG emissions estimation, see Appendix B.

Figure 16 depicts the average intensity of major production streams compared with our prior estimates and the average intensity of crude oil refined in the United States. Inclusive of the minimum and maximum of operations (shown with purple dots in Figure 16), IHS Markit found the average life-cycle intensity of the Canadian oil sands in 2018 to range from 1.6% below the US average to 19% above—the greatest variation to date. Note CSS is not included in Figure 16 as it represents a limited share of total production.

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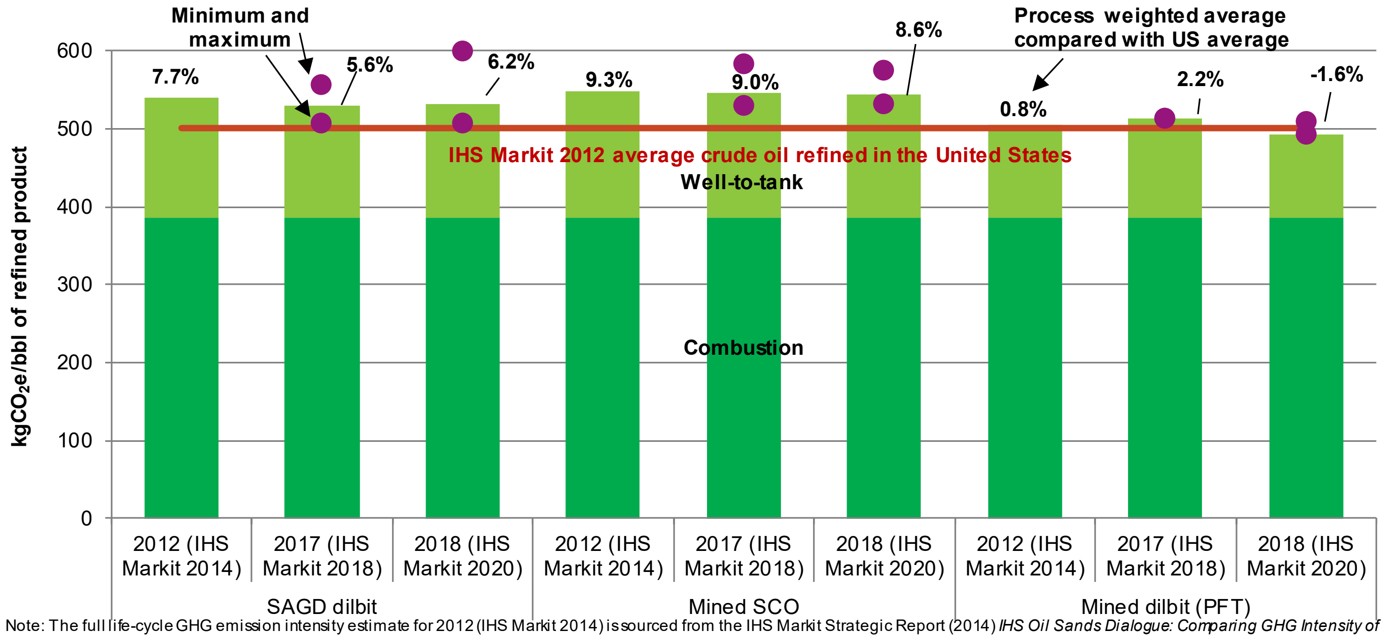
[16] *Oil Sands Emissions Limit Act,* Province of Alberta, https://www.qp.alberta.ca/documents/Acts/O07p5.pdf, retrieved 17 April 2020.

[17] Prior transportation through combustion estimates were derived from the IHS Markit Strategic Report (2014) *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*.

[18] The US average is an estimate derived from the IHS Markit 2014 Strategic Report IHS *Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil,* which estimated the life-cycle GHG intensity of crude oil refined and processed in the United States in 2012. For more information, see www.ihsmarkit.com/oilsandsdialogue.

Figure 16

Oil sands life-cycle GHG emissions cases compared



Note: The full life-cycle GHG emission intensity estimate for 2012 (IHS Markit 2014) is sourced from the IHS Markit Strategic Report (2014) *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*. Upstream estimates for 2017 (IHS Markit 2018) are sourced from the IHS Markit Strategic Report (2018) *Greenhouse gas intensity of oil sands production: Today and in the future*. Upstream estimate for 2018 (IHS Markit 2020) is published in this report. Estimates of downstream SAGD dilbit and SCO emissions for all estimates are derived from (IHS Markit 2014).
Source: IHS Markit

It should be noted that IHS Markit has included a comparison of life-cycle GHG emission intensity from various studies over time, and caution should be advised in drawing conclusions about sources of change on that basis. Differences in the estimation methods used in this analysis and the previous IHS Markit assessment may contribute to differences in the results from study to study.

Concluding remarks

At the time of the release of this report, the world and the global oil market were still amid the global pandemic of 2020 and the greatest economic shock the world has seen in more than a generation. In a time of increased uncertainty, a greater array of alternative futures can seem plausible. However, the importance of climate change and decarbonization appears set to remain a key policy priority. Indeed, many governments are discussing targeting economic recovery stimulus to accelerate energy transition. Still, the ubiquitous nature of oil and gas is likely to ensure it continues to make significant contributions to meeting global energy demand for the foreseeable future. Oil and gas, however, will not be immune to global pressures to decarbonize, and the importance of understanding GHG emissions from production to end use will rise.

The Canadian oil sands is one of the most studied resources in the world, and yet we continue to learn more about their GHG emissions and the drivers of emission intensity reductions. For example, in this report we found that the GHG emission intensity of the Canadian oil sands has continued to decline as new lower GHG emission intensity forms of production increased output and as legacy mining operations experienced intensity improvement. Meanwhile, an improved understanding of downstream emission intensity associated with newer forms of oil sands production reduced the IHS Markit estimate of the lower bound of the range of life-cycle GHG emissions to 1.6% beneath the US average (the lowest to date).[19]

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[19] The US average is the average life-cycle GHG intensity of crude oil refined or processed in the United States in 2012, as reported in the IHS Markit Strategic Report *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*.

Although 2018 set a new low in the average upstream GHG intensity of Canadian oil sands production, efforts to decarbonize upstream oil production are increasing. If upstream operations are increasingly going to be asked to compete on GHG emissions intensity, the Canadian oil sands industry may have to accelerate its efforts to maintain its place in global supply.

Appendix A: Detail result tables

Table A-1

Oil sands GHG emissions intensity summary results

		History											Percent change,	Percent change,
	Units	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2009–18**	**2017–18**
CSS	kgCO$_2$e/bbl of dilbit	n/a	94	84	81	80	78	82	91	97	101	110	18%	9%
SAGD	kgCO$_2$e/bbl of dilbit	n/a	66	64	64	65	65	62	64	66	64	65	-1%	2%
In situ average	**kgCO$_2$e/bbl of dilbit**	**n/a**	**79**	**73**	**71**	**71**	**69**	**67**	**71**	**72**	**71**	**73**	**-8%**	**2%**
Mined SCO	kgCO$_2$e/bbl of SCO	112	116	109	104	110	106	105	98	92	91	89	-24%	-3%
Mined dilbit	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	86	52	45	45	47	41	n/a	-12%
Mining average	**kgCO$_2$e/bbl of product**	**112**	**116**	**109**	**104**	**110**	**105**	**100**	**88**	**82**	**82**	**75**	**-36%**	**-10%**
Average (of shown)	**kgCO$_2$e/bbl of product**	**n/a**	**100**	**91**	**88**	**89**	**86**	**82**	**78**	**77**	**76**	**74**	**-26%**	**-3%**
	Share of supply	**0%**	**84%**	**86%**	**86%**	**85%**	**85%**	**86%**	**88%**	**90%**	**92%**	**93%**		
Average (including primary and experimental)	**kgCO$_2$e/bbl of product**	**n/a**	**88**	**86**	**82**	**83**	**80**	**77**	**74**	**72**	**72**	**70**	**-20%**	**-2%**
	Share of supply	**0%**	**84%**	**84%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**		

Source: IHS Markit

Table A-2

Mined oil sands emissions intensity by process and component

		History											Percent change,	Percent change,
	Units	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2009–18**	**2017–18**
Mined SCO														
Natural gas	kgCO$_2$e/bbl of SCO	41	41	38	35	45	38	40	38	38	38	38	-8%	-1%
Process gas	kgCO$_2$e/bbl of SCO	29	32	31	31	25	34	33	27	24	23	22	-31%	-6%
Petroleum coke	kgCO$_2$e/bbl of SCO	20	21	17	16	13	10	11	11	10	10	9	-56%	-8%
Mobile mine fleet	kgCO$_2$e/bbl of SCO	9	9	10	9	9	8	9	9	8	8	8	-6%	0%
Fugitive, venting, and flaring	kgCO$_2$e/bbl of SCO	9	8	8	8	10	9	6	6	6	6	6	-28%	2%
Carbon capture	kgCO$_2$e/bbl of SCO	0	0	0	0	0	0	0	-1	-3	-2	-2		-7%
Direct emissions (within plant gate)	**kgCO$_2$e/bbl of SCO**	**108**	**111**	**104**	**99**	**102**	**99**	**98**	**90**	**84**	**83**	**81**	**-27%**	**-2%**
Electrical balance (import/export)	kgCO$_2$e/bbl of SCO	-4	-3	-2	-1	0	-1	0	1	1	1	1	-129%	-27%
Upstream natural gas production	kgCO$_2$e/bbl of SCO	8	8	7	7	8	7	8	7	7	7	7	-8%	-1%
Upstream diluent	kgCO$_2$e/bbl of SCO	0	0	0	0	0	0	0	0	0	0	0		
IHS Markit upstream life-cycle basis	**kgCO$_2$e/bbl of SCO**	**112**	**116**	**109**	**104**	**110**	**106**	**105**	**98**	**92**	**91**	**89**	**-24%**	**-3%**
Mined dilbit (PFT)														
Natural gas	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	43	25	23	22	24	21		-11%
Process gas	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	-	-	-	-	-	-		
Petroleum coke	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	-	-	-	-	-	-		
Mobile mine fleet	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	9	5	5	5	5	6		26%
Fugitive, venting, and flaring	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	7	3	1	1	1	1		-14%
Carbon capture	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	-	-	-	-	-	-		
Direct emissions (within plant gate)	**kgCO$_2$e/bbl of dilbit**	**-**	**-**	**-**	**-**	**-**	**58**	**33**	**29**	**28**	**30**	**28**		**-5%**
Electrical balance (import/export)	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	11	7	4	4	4	1		-85%
Upstream natural gas production	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	8	5	4	4	4	4		-11%
Upstream diluent	kgCO$_2$e/bbl of dilbit	-	-	-	-	-	8	8	8	8	8	8		
IHS Markit upstream life-cycle basis	**kgCO$_2$e/bbl of dilbit**	**-**	**-**	**-**	**-**	**-**	**86**	**52**	**45**	**45**	**47**	**41**		**-12%**

Table A-2

Mined oil sands emissions intensity by process and component (continued)

		History												
	Units	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent change, 2009–18	Percent change, 2017–18
Mined average	**Units**													
Natural gas	kgCO$_2$e/bbl of product	41	41	38	35	45	38	39	35	35	35	33	-20%	-7%
Process gas	kgCO$_2$e/bbl of product	29	32	31	31	25	32	30	22	19	19	15	-52%	-18%
Petroleum coke	kgCO$_2$e/bbl of product	20	21	17	16	13	10	10	9	8	8	6	-69%	-20%
Mobile mine fleet	kgCO$_2$e/bbl of product	9	9	10	9	9	8	8	8	8	8	8	-13%	1%
Fugitive, venting, and flaring	kgCO$_2$e/bbl of product	9	8	8	8	10	8	6	5	5	5	4	-46%	-9%
Carbon capture	kgCO$_2$e/bbl of product	0	0	0	0	0	0	0	-1	-2	-2	-2		-19%
Direct emissions (within plant gate)	**kgCO$_2$e/bbl of product**	**108**	**111**	**104**	**99**	**102**	**98**	**92**	**78**	**73**	**73**	**65**	**-41%**	**-10%**
Electrical balance (import/export)	kgCO$_2$e/bbl of product	-4	-3	-2	-1	0	0	0	1	2	2	1	-127%	-57%
Upstream natural gas production	kgCO$_2$e/bbl of product	8	8	7	7	8	7	7	7	7	7	6	-20%	-7%
Upstream diluent	kgCO$_2$e/bbl of product	0	0	0	0	0	0	1	2	2	2	3		53%
IHS Markit upstream life-cycle basis	**kgCO$_2$e/bbl of product**	**112**	**116**	**109**	**104**	**110**	**105**	**100**	**88**	**82**	**82**	**75**	**-36%**	**-10%**

Source: IHS Markit

Table A-3

Oil sands SAGD dilbit historical GHG emission intensity, 2009–18

		History										
Component	Units	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent change, 2009–18	Percent change, 2017–18
Natural gas	kgCO$_2$e/bbl of dilbit	63	58	56	56	56	51	51	52	50	51	-19%	1%
Flaring and fugitives	kgCO$_2$e/bbl of dilbit	0	0	0	0	0	0	0	0	0	0	0%	0%
Direct emissions (within plant gate)	**kgCO$_2$e/bbl of dilbit**	**63**	**58**	**56**	**56**	**56**	**51**	**52**	**53**	**50**	**51**	**-19%**	**1%**
Electrical import/export	kgCO$_2$e/bbl of dilbit	-19	-15	-13	-11	-12	-9	-8	-7	-6	-5	-72%	-7%
Upstream natural gas production	kgCO$_2$e/bbl of dilbit	12	11	10	10	10	10	10	10	9	9	-19%	1%
Upstream diluent production	kgCO$_2$e/bbl of dilbit	10	10	10	10	10	10	10	10	10	10	0%	0%
IHS Markit upstream life-cycle basis	**kgCO$_2$e/bbl of dilbit**	**66**	**64**	**64**	**65**	**65**	**62**	**64**	**66**	**64**	**65**	**-1%**	**2%**

Source: IHS Markit

Table A-4

Oil sands CSS dilbit historical GHG emission intensity, 2009–18

		History										
Component	Units	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Percent change, 2009–18	Percent change, 2017–18
Natural gas	kgCO$_2$e/bbl of dilbit	74	65	62	61	60	63	72	80	83	92	25%	11%
Flaring and fugitives	kgCO$_2$e/bbl of dilbit	0	0	0	0	0	0	0	0	0	0	0%	0%
Direct emissions (within plant gate)	**kgCO$_2$e/bbl of dilbit**	**74**	**65**	**62**	**62**	**60**	**63**	**73**	**81**	**83**	**92**	**24%**	**11%**
Electrical import/export	kgCO$_2$e/bbl of dilbit	-5	-4	-4	-3	-4	-4	-6	-9	-9	-10	105%	18%
Upstream natural gas production	kgCO$_2$e/bbl of dilbit	14	12	12	12	11	12	14	15	16	17	25%	11%
Upstream diluent production	kgCO$_2$e/bbl of dilbit	10	10	10	10	10	10	10	10	10	10	0%	0%
IHS Markit upstream life-cycle basis	**kgCO$_2$e/bbl of dilbit**	**94**	**84**	**81**	**80**	**78**	**82**	**91**	**97**	**101**	**110**	**18%**	**9%**

Source: IHS Markit

Appendix B: Notes of comparison to prior analysis

This study refreshes and extends the historical oil sands GHG emission estimates first made in the IHS Markit report titled *Greenhouse gas emissions intensity of Canadian oil sands production: Past and in the future* released in 2018. The underlying models, method, and assumptions used for our prior study were deployed in this analysis. Despite the incorporation of some new data, changes to CSS dilbit modeling and a reestimation of the average intensity over the entire study period remained relatively consistent with that in the prior study. However, differences do exist and are more pronounced at the individual production stream level. Changes in our modeling approach impacted estimates for SAGD dilbit, CSS dilbit, and mined dilbit (PFT).

This appendix provides a detailed comparison between this study's results and IHS Markit (2018). For detailed information on our original methodology, please see IHS Markit (2018). Table B-1 provides a comparison between our current results and the IHS Markit (2018) results. What follows are several sections documenting major changes or updates in this most recent analysis compared with our prior 2018 report.

Table B-1

Detailed comparison of IHS Markit (2020) and IHS Markit (2018) analysis

			History										Percent change,	Percent change,
Category	**Source**	**Units**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018****	**2009–18**	**2017–18**
Weighted average*	IHS Markit (2018)	kgCO$_2$e/bbl of product	89	84	79	81	79	76	73	70	70	67	-24%	-4%
	IHS Markit (2020)	kgCO$_2$e/bbl of product	88	86	82	83	80	77	74	72	72	70	-20%	-2%
Difference			*-1%*	*1%*	*4%*	*3%*	*2%*	*2%*	*2%*	*4%*	*2%*	*4%*		
Mined SCO	IHS Markit (2018)	kgCO$_2$e/bbl of SCO	115	108	104	110	105	105	97	92	91	88	-24%	-4%
	IHS Markit (2020)	kgCO$_2$e/bbl of SCO	116	109	104	110	106	105	98	92	91	89	-24%	-3%
Difference			*1%*	*1%*	*1%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*		
Mined dilbit (PFT)	IHS Markit (2018)	kgCO$_2$e/bbl of dilbit	0	0	0	0	98	57	48	47	46	45	n/a	-1%
	IHS Markit (2020)	kgCO$_2$e/bbl of dilbit	0	0	0	0	86	52	45	45	47	41	n/a	-14%
Difference			*0%*	*0%*	*0%*	*0%*	*-12%*	*-7%*	*-6%*	*-4%*	*3%*	*-9%*		
SAGD dilbit	IHS Markit (2018)	kgCO$_2$e/bbl of dilbit	66	63	64	65	65	62	62	64	63	62	-6%	-1%
	IHS Markit (2020)	kgCO$_2$e/bbl of dilbit	66	64	64	65	65	62	64	66	64	65	-1%	2%
Difference			*1%*	*1%*	*1%*	*1%*	*1%*	*0%*	*3%*	*3%*	*2%*	*6%*		
CSS dilbit	IHS Markit (2018)	kgCO$_2$e/bbl of dilbit	96	77	69	68	71	73	76	89	90	n/a	n/a	n/a
	IHS Markit (2020)	kgCO$_2$e/bbl of dilbit	94	84	81	80	78	82	91	97	101	110	18%	9%
Difference			*-3%*	*10%*	*17%*	*19%*	*11%*	*12%*	*20%*	*9%*	*12%*	*n/a*		

Note: Estimates shown for IHS Markit (2018) for 2018 calendar year were projections and not based on historical data. *Includes primary, experimental, and EOR operations not modeled in this analysis. GHG emission intensity estimate for these additional forms of oil sands extraction was extrapolated from existing IHS Markit research and remained unchanged from IHS Markit (2018). **Estimate for 2018 from IHS Markit (2018) was part of forecast emissions, and the basis of estimation was fundamentally different. No forecast of CSS dilbit was completed for IHS Markit (2018).

Source: IHS Markit

Study period extension to include 2018

In the current study, IHS Markit was able to incorporate an additional year of operational data for oil sands facilities to extend the historical outlook to include 2018. Thermal in situ operational data were updated, consistent with prior report, based on the Alberta Energy Regulator (AER) report ST53: Alberta In Situ Oil

Sands Production Summary.[20] Mining data were sourced from the AER report ST39: Alberta Mineable Oil Sands Plant Statistics Monthly Supplement.[21]

Expanded thermal cogeneration intensity data

The IHS Markit estimate of the GHG emissions associated with thermal in situ extraction—SAGD and CSS—is affected by the GHG emissions intensity of cogeneration. In our prior analysis, estimates of the GHG intensity of cogeneration were made using data obtained upon request from Alberta Environment and Parks. Alberta's Specified Gas Emitters Regulation (SGER) collected data on cogeneration emissions, which IHS Markit was able to access to estimate the GHG emissions intensity of cogeneration by year (kgCO$_2$e/MWh). In IHS Markit (2018), estimates of 2013 and 2014 were made based on Alberta's SGER database. The 2014 estimate (786 kgCO$_2$e/MWh) was used for both SAGD and CSS and extrapolated over the entire study period.

In this current analysis, IHS Markit was able to obtain three additional years of cogeneration data from Alberta Environment and Parks, increasing the data set to 2013–17. As a result of the expanded coverage, the constant GHG cogeneration intensity estimate was replaced with corresponding annual estimates for 2013–17. For 2009–12, the 2013 estimate was used, and for 2018, data from 2017 were used.

Although the GHG emission intensity of cogeneration fluctuated by year, it was on average from 2013 to 2017 higher than the 2014 value used throughout our prior study (averaging 836 kgCO$_2$e/MWh). The change in cogeneration intensity was the primary driver behind the differences in SAGD dilbit and contributed to some variation in CSS dilbit visible in Table B-1. In IHS Markit (2018), 2018 was a projection and not based on historical data; however, the 2018 projection was nonetheless impacted by the prior cogeneration intensity estimate. The primary factor behind the difference between the projected SAGD dilbit GHG estimate in 2018 was moderately higher SOR compared with that of 2017 than IHS Markit had modeled for 2018.

Change to CSS dilbit estimation

IHS Markit updated its approach to modeling CSS dilbit to perfectly align with SAGD. In our prior analysis, because CSS dilbit is a comparatively smaller source of oil sands supply and not anticipated to grow materially in the IHS Markit outlook, the future emission intensity was not forecast in our prior 2018 report. As a result, estimated thermal energy demand relied on SAGD thermal energy intensity adjusted for CSS stream demand and output. Alignment issues between the rate of change in the CSS SOR and the IHS Markit intensity estimate for CSS dilbit resulted in the removal of the dependence on SAGD relationships. This change resulted in an upward revision to our estimate of CSS dilbit for 2010–17 to varying degrees. If CSS dilbit is removed from the weighted average comparison, shown in Table 1, the difference between study estimates falls to 1%.

Mined dilbit (PFT) production

The IHS Markit (2018) estimate of mined dilbit (PFT) GHG emission intensity made use of bitumen delivereies as reported in ST39 converted to a dilbit basis as the denominator in the emissions intensity calculation. We decided in this analysis to make use of bitumen production to better reflect actual throughput or output of ongoing operations and better align with SCO production used to estimate GHG intensity from mined SCO facilities. This change reduced the GHG emission intensity during the ramp-up of the Imperial Kearl operation

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[20] "ST53: Alberta In Situ Oil Sands Production Summary," AER, https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st53.html, retrieved 17 April 2020.

[21] "ST39: Alberta Mineable Oil Sands Plant Statistics Monthly Supplement," AER, https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st39.html, retrieved 17 April 2020.

compared with IHS Markit (2018) and contributed to changes in the estimated intensity of mined dilbit (PFT) visible in Table B-1.

Mined dilbit (PFT) blending

IHS Markit estimates of emission intensity are presented on a marketed product basis to represent the intensity of a barrel of product being sold and align with prior and ongoing life-cycle assessments. SAGD, CSS, and mined dilbit (PFT) market diluted bitumen barrels. Mined dilbit (PFT) has been found to precipitate out some of the heavier components found in mined bitumen, resulting in a slightly lower-density bitumen. As a result, it requires less diluent per barrel compared with SAGD dilbit or CSS dilbit. In our prior IHS Markit (2018), we assumed a blend rate of 20% diluent to 80% bitumen for mined dilbit (PFT). We now believe a blend rate closer to 22% diluent and 78% bitumen may be more accurate and have adjusted our blend rate in the model. This development also contributed to changes shown in Table B-1 for mined dilbit (PFT).

Mined dilbit (PFT) downstream emissions

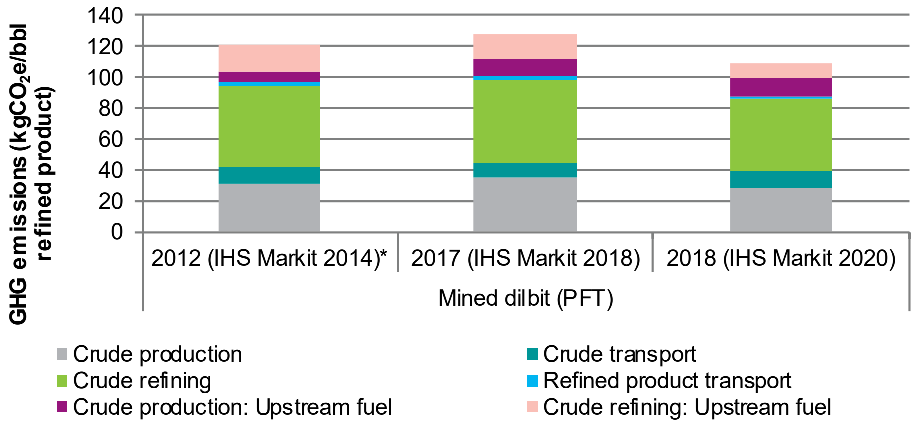
IHS Markit undertook a new estimate for the downstream GHG emissions associated with the refining of mined dilbit (PFT). IHS Markit made use of the open-source Petroleum Refinery Life Cycle Inventory Model (PRELIM) for this estimate.[22] PRELIM is a Microsoft Excel–based tool that estimates the energy use and GHG emissions, among a variety of other parameters, associated with processing crude oil in a range of refinery configurations. There is crude assay information preloaded in PRELIM (149 crude assays in Version 1.3 at the time of this publication). IHS Markit used the crude assay available in PRELIM for Imperial's Kearl oil sands mined dilbit (PFT) operation, which can be found in the public model. IHS Markit chose to model a deep conversion coking refinery including a fluid catalytic cracker (FCC). PRELIM was run assuming that the refinery was processing 100% Kearl dilbit. In reality, refineries typically process a blend of various crudes at any given time.

This work resulted in a revised estimate of the downstream refining emission intensity for mined dilbit (PFT) of 55 $kgCO_2e$/bbl of refined product, which is lower than the previous estimate of 70 $kgCO_2e$/bbl of refined product. The results, on an energy basis, were confirmed with an internal IHS Markit refining model. A comparison of the well-to-tank GHG emissions associated with mined dilbit (PFT) as estimated by IHS Markit in our 2014 and 2018 reports is shown in Figure B-1.

A direct comparison of the estimates in Figure B-1 is difficult because of differences in the estimation methods.

Figure B-1

IHS Markit estimates of well-to-tank GHG emissions for mined dilbit (PFT)



Note: *The completion of the full life-cycle assessment for 2012 (IHS Markit 2014) is from the IHS Markit Strategic Report *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil*. Upstream estimates for 2017 (IHS Markit 2018) are from the IHS Markit Strategic Report *Greenhouse gas intensity of oil sands production: Today and in the future*. Upstream estimate for 2018 (IHS Markit 2020) is published in this report. Estimates of downstream SAGD dilbit and SCO emissions for all estimates are derived from IHS Markit 2014.

Source: IHS Markit

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[22] PRELIM can be downloaded from the Life Cycle Assessment of Oil Sands Technologies research group (University of Calgary). Version 1.3 of PRELIM was used for this analysis.

Previous assessments of downstream emissions intensities were drawn from IHS Markit (2014). The IHS Markit (2014) report sourced the downstream estimates for refining of dilbit from a Jacobs Consultancy report prepared for the Alberta Petroleum Marketing Commission in 2012 titled "EU pathway study: life cycle assessment of crude oils in a European context" (Jacobs 2012). Downstream GHG emissions values from Jacobs (2012) were used to calculate an average value for refining dilbit (including direct refining emissions as well as emissions associated with upstream fuels used in refining). Mined dilbit (PFT) was treated the same as SAGD dilbit. Table B-2 is a comparison of the methods used for estimating downstream emissions of mined dilbit (PFT) for this study with those used in previous IHS Markit assessments.

Table B-2

GHG estimation method comparison with previous IHS Markit assessments

Stage of life	IHS Markit, 2020	IHS Markit, 2018 and 2014
Crude production: Upstream fuel	Accounts for natural gas and imported electricity, based on ST39 data.	Accounts for natural gas and imported electricity, based on Jacobs model for extraction energy.
Crude transport	Value: 8.2 $kgCO_2e$/bbl refined product. Estimate generated based on transport distance of 4,000 km by pipeline. Refer to Table 3 for other assumptions.	Value: 10 $kgCO_2e$/bbl refined product. Meta-analysis based on Jacobs (2012), Charpentier (2011), and CARB-OPGEE (2012). The value was generated by taking an average of the range of values cited. Estimates ranged from 3.5 to 34.
Refining	Value: 47 $kgCO_2e$/bbl refined product (FCC). Model: PRELIM (Version 1.3). Refinery configuration: FCC coking. Key crude properties: API: 22. Refinery yield: 1 bbl dilbit: 0.9 bbl fuels.	Value: 54 $kgCO_2e$/bbl refined product. Models: Various including PetroPlan. Refinery configuration: FCC coking. Key crude properties: API: 21. Refinery yield: 1 bbl dilbit: 1 bbl fuels.
Refining: Upstream fuel	Value: 9 $kgCO_2e$/bbl refined product (FCC). Model: PRELIM. Accounts for natural gas and imported electricity.	Value: 17 $kgCO_2e$/bbl refined product. Model(s): Various including PetroPlan. Accounts for natural gas, imported electricity, and isobutane.

Note: See the IHS Markit Strategic Reports *Greenhouse gas intensity of oil sands production: Today and in the future* and *IHS Oil Sands Dialogue: Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil.*
CARB-OPGEE (2012): To support California's Low Carbon Fuel Standard, the California Air Resources Board (CARB) released draft carbon intensities for various crude oils consumed in California (posted 17 September 2012). Estimates were made using the Oil Production Greenhouse gas Emissions Estimator (OPGEE).
Charpentier (2011): Charpentier et al., "Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: GHOST Model Development and Illustrative Application," published July 2011.

Source: IHS Markit

IHS Markit believes that the recent estimates are more representative of downstream GHG emissions intensity for mined dilbit (PFT) than those from our previous assessments.

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