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Forecasting the impacts of oilsands expansion

Measuring the land disturbance, air quality, water use, greenhouse gas emissions, and tailings production associated with each barrel of bitumen production

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June 2013

In the debate over the environmental impacts of oilsands development, you'll often hear industry proponents cite one set of statistics, and critics another. That's because proponents often talk in the present tense — pointing, for instance, to the fact that oilsands emissions today represent a fraction of global greenhouse gas emissions — while critics point to the future, measuring today's environmental concerns against industry's growth projections. It's common to hear critics state, for example, that oilsands emissions matter because their rapid growth is cancelling out the progress made in other sectors, and because this growth is the main reason Canada is unlikely to meet its global climate commitments.

While both perspectives may be accurate, when it comes to managing the impacts of oilsands development the long view is the one that counts.

TERMS AND MEASUREMENTS

Intensity: this is a measure of the amount of consumption, emissions or waste per unit of production. For example, water intensity is presented in "barrels of water used per barrel of bitumen produced"

Cubic metres vs. barrels: The oilsands sector uses both sets of units for fluid volume measurement. One cubic metre (1000 litres) is equivalent to 6.29 barrels.

Last year, the oilsands industry produced 1.9 million barrels of bitumen each day.[1] A decade from now, total bitumen production is projected to reach 3.8 million barrels per day,[2] and the Canadian Association of Petroleum Producers expects the industry will surpass 5 million barrels a day by the end of 2030.[3] (In fact, regulators have already approved this level of production based on today's technology — despite industry's own forecasts[4] showing that critical ecosystem and air quality limits are likely to be exceeded in some areas.) In total, the industry has announced or disclosed plans to produce more than 9 million barrels of bitumen per day.[5]

While it's challenging to project how the impacts of oilsands development will change over time, there are two key elements that shape the overall footprint of oilsands development: the *pace* and *scale* of oilsands production (barrels of bitumen produced each day) and per barrel environmental impacts of oilsands production.

Many forces determine the pace and scale of oilsands production, including access to finance, key markets, oilsands resources, and critical inputs such as labour and materials. Equally important are the limits Canadian regulators establish on environmental impacts — because these limits, if designed properly, could set the ground rules for responsible oilsands development.

Why consider per-barrel impacts

The oilsands industry's growth plans have significant implications for environmental management, but it can be challenging to understand production on such a massive scale and given uncertain timelines. Distil the industry's footprint down to the impacts of producing a single barrel of bitumen from the oilsands, however, and the picture becomes clearer.

The main environmental concerns related to oilsands development today include: how much water the industry consumes, how much land is disturbed and (in the case of wetlands) may never be properly restored, the volume of toxic tailings waste produced and how it is managed, and the greenhouse gas and air pollution emitted. It's also critical to understand how the effects of each project, when measured together rather than in isolation, can have serious implications for wildlife, the integrity of nearby ecosystems, and the health of people living in the vicinity of oilsands development — now and into the future.

This fact sheet aims to quantify each of these things (land disturbance, air emissions, water use, greenhouse gas emissions, and tailings production) on a per-barrel basis, using publicly available government and industry data, as well as peer-reviewed literature. It also looks at how such impacts are likely to change in the future, as production ramps up — starting from 2010 and 2012 and projecting out to 5 million barrels a day of oilsands production in 2030.

OILSANDS EXTRACTION

Oilsands can be **mined** when the oilsands deposit is close to the surface. Deeper deposits are accessed through **in situ** technologies that include injecting steam underground to enable extraction of the bitumen. Mining and in situ oilsands extraction have different environmental impacts and data is presented here for both extraction methods separately. Cumulative data is based on the current and projected production levels of both extraction types.

Conducting this kind of analysis requires many assumptions about the technologies, practices, and regulations that determine the impacts of oilsands production. Our assumptions and methodology are outlined in detail in the "Methods" section at the end of this publication. Looking forward, we see significant potential to improve the environmental performance of Canada's oilsands industry. But that improvement requires significantly strengthening policies governing oilsands development in Alberta, aggressively setting targets to reduce the per-barrel impacts of production, and moderating the pace of oilsands development where necessary to respect science-based environmental limits.

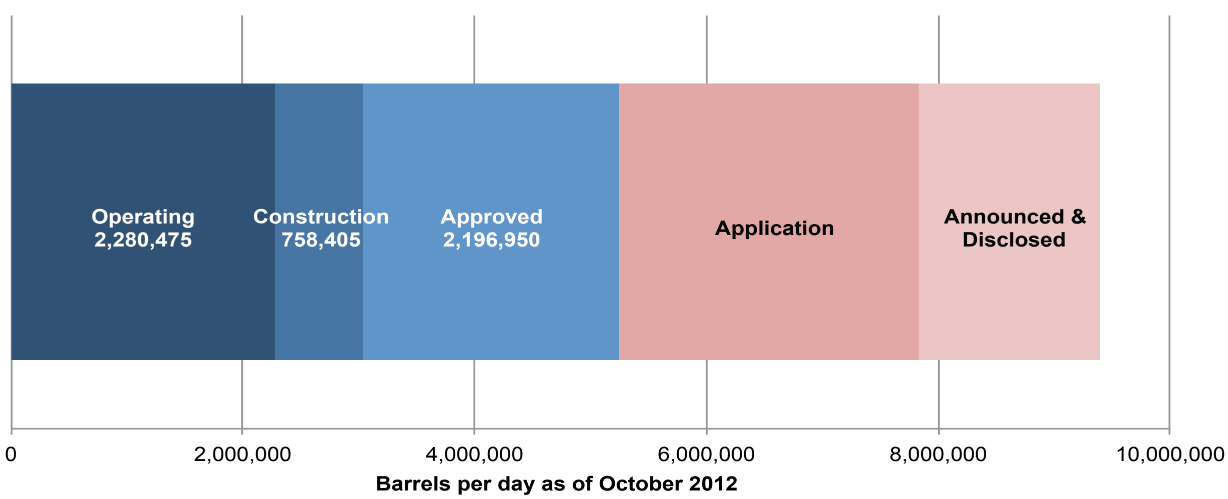
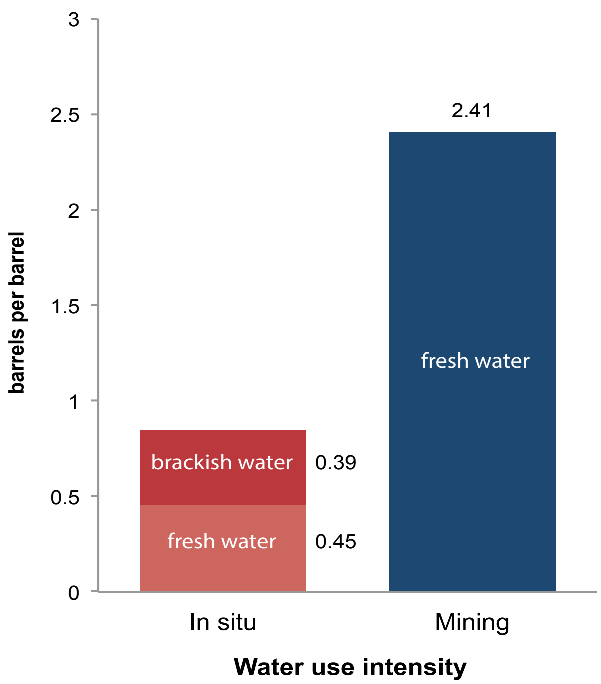


Figure 1. Oilsands expansion plans: As of October 2012, regulators have approved more than five million barrels of bitumen production per day (Data Source: Oilsands Review)[6]

Water use intensity

Oilsands extraction consumes large amounts of water, despite current recycling efforts. In 2011, oilsands operators used approximately 170 million cubic metres (1.1 billion barrels) of water, equivalent to the residential water use of 1.7 million Canadians — or roughly the amount of water used by everyone living in Calgary and Edmonton combined. The Athabasca River is the primary source of fresh water for the industry, and oilsands mining uses three times as much fresh water as conventional oil production.[7]



Fresh water use intensity:

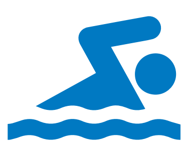
In situ: 0.45 bbl/bbl
Mining: 2.41 bbl/bbl

Brackish water use intensity:

In situ: 0.39 bbl/bbl
Mining: Not applicable

Data source:

Oil Sands Information Portal[8]
Years: 2009-2011
Unit: Barrels of water used per barrel of bitumen or SCO produced (bbl/bbl)

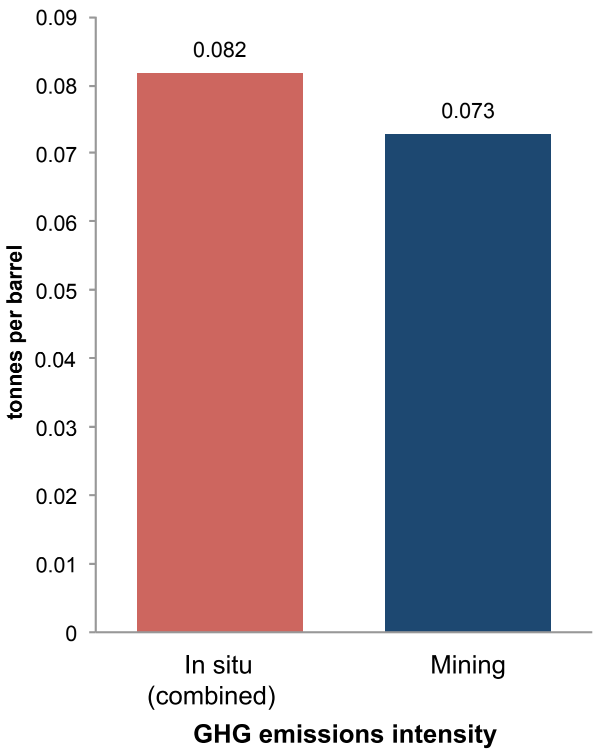


309 OLYMPIC POOLS EVERY DAY

Daily freshwater use in 2022 is projected to be 4,861,389 barrels = 772,900 m^3. This is equivalent to filling 4.8 million bathtubs or 309 Olympic swimming pools of freshwater every day.[9,10]

Greenhouse gas emissions intensity

The oilsands extraction process consumes large amounts of energy, derived from coal-based power, natural gas, and diesel fuel. Oilsands' greenhouse gases (GHGs) are the fastest growing source of climate change pollution in Canada. Average oilsands production is significantly more GHG-intensive than conventional oil production.[11]



GHG emissions intensity:

In situ with cogeneration: 0.083 tonnes CO_2e/bbl
In situ without cogeneration: 0.074 tonnes CO_2e/bbl
Combined: 0.082 tonnes CO_2e/bbl

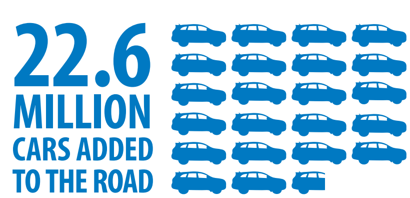
Mining: 0.073 tonnes CO_2e/bbl
(includes GHG emissions from on-site upgrading to produce upgraded bitumen or synthetic crude oil)

Future projections for in situ GHG emissions intensity were made using the combined value. See note under "Additional Methodological Details" for further description.

Data source:

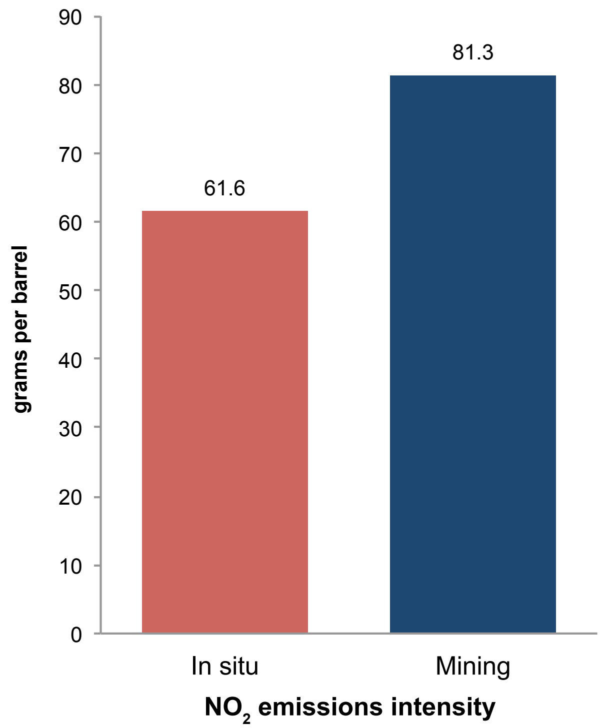
Government of Alberta GHG Reporting Program[12]
Years: 2009-2010
Unit: tonnes of carbon dioxide equivalent emitted per barrel of bitumen or SCO produced (tonnes CO_2e/bbl)

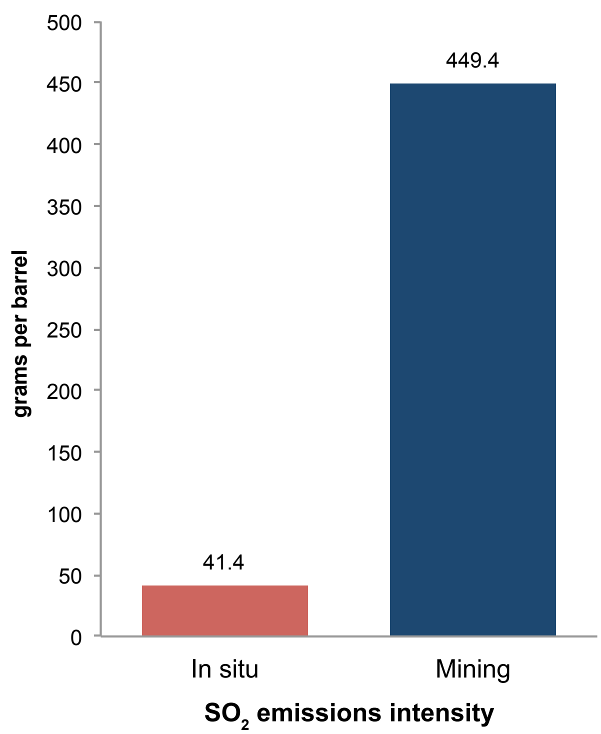
Greenhouse gas emissions from oilsands production in 2022 are projected to be the equivalent to adding 22.6 million cars to the road in the U.S.[13]



Air emissions intensity

Oilsands extraction is a major point source of air pollutants such as nitrogen dioxide and sulphur dioxide. Forecasted growth in oilsands will present challenges for meeting ambient air quality standards in north-eastern Alberta. While there have been some improvements in reducing the volumes of air pollutants produced per barrel, the overall growth in the industry means that absolute growth in air emissions will impact air quality for communities who reside in the region.





Nitrogen oxides (NO_x) emissions intensity:

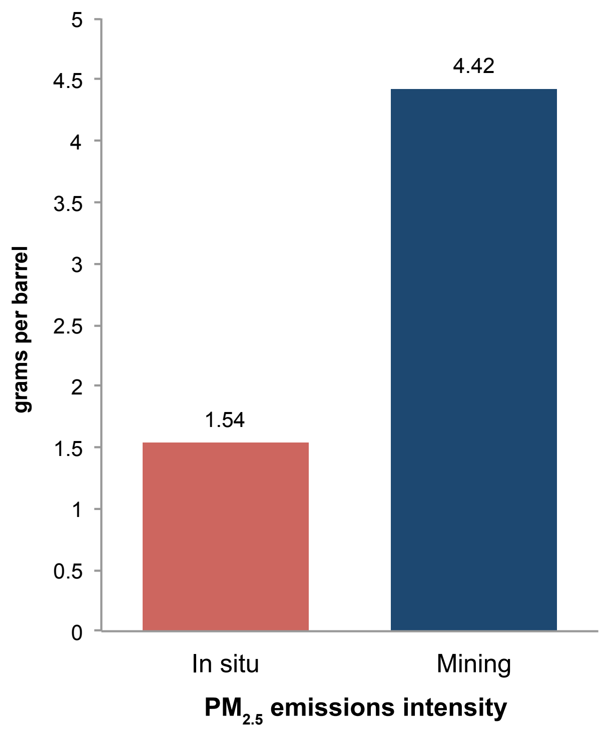
In situ: 61.57 g/bbl
Mining: 81.32 g/bbl

Sulphur dioxide (SO_2) emissions intensity:

In situ: 41.4 g/bbl
Mining: 449.4 g/bbl

Particulate matter ($PM_{2.5}$) emissions intensity:

In situ: 1.5 g/bbl
Mining: 4.4 g/bbl

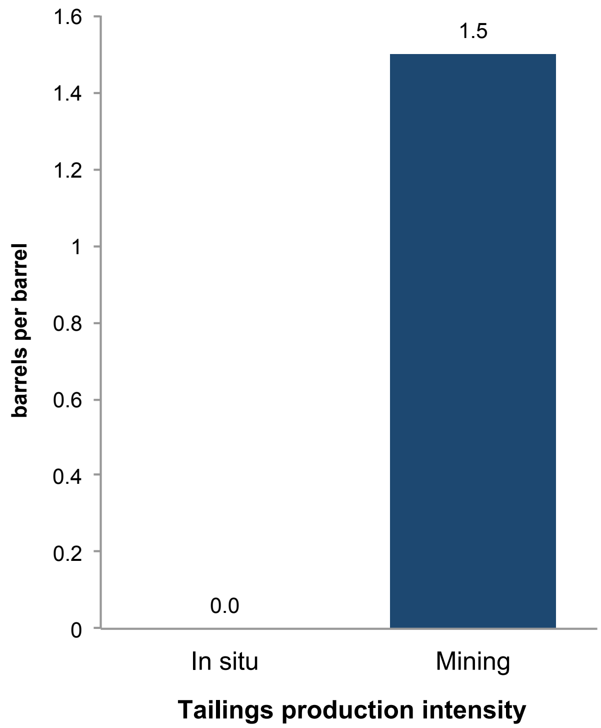


Data source:

National Pollution Release Inventory[14]
Years: 2009-2010
Unit: grams of air pollutant emitted per barrel of bitumen or SCO produced (g/bbl)

Tailings production intensity

Tailings are a waste by-product of the oilsands mining extraction process that consist of water, clay, sand and residual bitumen, along with various salts, heavy metals and other compounds that can be toxic if concentrations are high enough. These "ponds" currently cover 176 square kilometres of the landscape, and contain 830 million cubic metres of tailings waste. There remains considerable uncertainty as to whether the tailings ponds can be reclaimed to a level that sustains functional ecosystems equivalent to those that were in existence prior to mining, and no method for regenerating displaced peatlands has been developed.[15]



Tailings production intensity:

In situ: Not Applicable
Mining: 1.5 bbl/bbl[16]

Data source:

Mikula (2012)[17]
Years: N/A
Unit: Barrels of mature fine tailings (MFT) produced per barrel of bitumen or SCO (bbl/bbl)

In 2010, the total volume of mature fine tailings in northeastern Alberta was 830 million cubic metres.[18] That's enough tailings waste to cover the entire city of Vancouver to a depth of over 7 metres.[19] But regulators have already approved 2.4 million barrels per day of oilsands mining,[20] and each barrel of bitumen produced from mining results in the production of about 1.5 barrels of mature fine tailings.[21] Accordingly, approved minable production would produce 1.4 billion barrels of mature fine tailings[22] and by 2022, oilsands mining is expected to produce enough toxic liquid tailings to submerge New York's Central Park to a depth of just over 11 feet every month.[23]

Land disturbance intensity

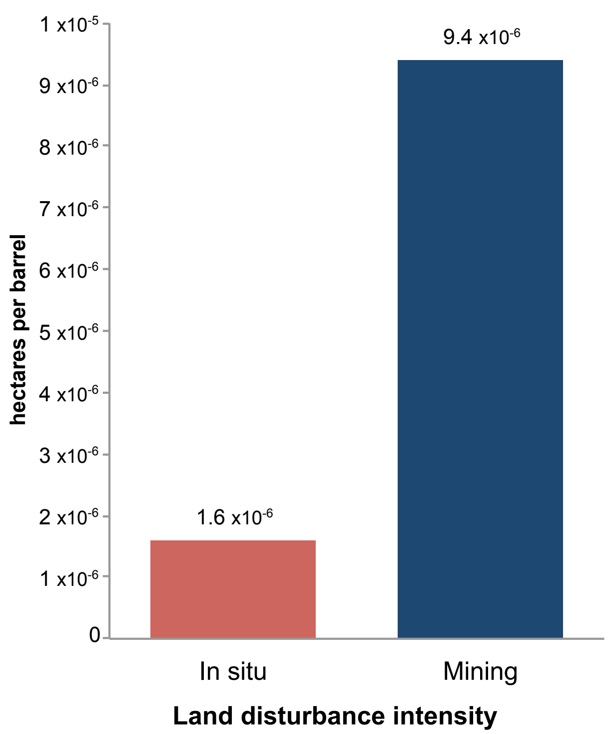
Determining the exact impact of each facility requires specific knowledge of where it is being built and the techniques used for forest clearing and construction. However, because any clearing will have some impact on wildlife, the following calculations are based on the total project footprint.

Footprint = the total land disturbance over the life of the project
Bitumen production = the total expected production associated with that footprint

In situ

In situ oilsands extraction requires the development of a dense network of roads, pipelines, wellpads and processing facilities across the boreal forest. A typical deep oilsands project may clear more than eight per cent of the forest in a lease. The forest is fragmented by an average of 3.2 kilometres of roads, pipelines and other disturbances for every single square kilometer of forest. The surface disturbance associated with in situ oilsands development is many times greater than the disturbance associated with conventional oil or gas fields, to which in situ is often compared.[24]

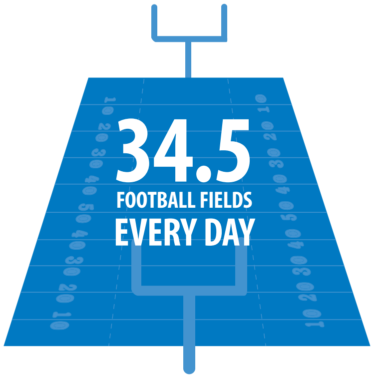
Previous analysis by the Pembina Institute has demonstrated that average in situ land use intensity is equal to the project land use intensity (based on footprint area and bitumen production volumes) over the total project lifetime. This equals 1.4 hectares (ha) per million barrels [25] or $1.4\text{x}10^{-6}$ ha per barrel of bitumen produced. Additionally, academic research has concluded in situ oilsands development has a land use intensity of $1.8\text{x}10^{-6}$ ha per barrel.[26,27] Therefore, for the purposes of this analysis we estimate that in situ oilsands production has an average land use intensity of $1.6\text{x}10^{-6}$ ha per barrel. It is important to note that this metric measures surface disturbance only, and not habitat fragmentation adjacent to in situ operations.



Mining

Mining operations result in the disturbance of large areas to produce bitumen. Before mining can begin, the forest, wetlands and soil are cleared, drained and removed. Rivers and streams are diverted and forests are clear cut, with merchantable timber being harvested and the remainder being piled and burned. In addition, wetlands must be drained and excavated.

There is limited publicly available information on the land use intensity of oilsands mine operations. The recent proposed Shell Jackpine Mine Expansion project has a total lease size of 12,723 hectares,[28] a forecasted production rate of 100,000 barrels of bitumen per day[29] and a project lifetime of 40 years.[30] Total production over the life of the project is therefore 1.5 billion barrels of bitumen. For this project, Shell would disturb 0.094 m^2 of land per barrel of bitumen produced or 9.4 hectares of disturbance per million barrels of production.



By 2022, it is projected that mining and in situ oilsands development will result in the daily clearing of 18.6 hectares of forest, or the equivalent of 34.5 football fields, every day.[31]

Summary of extrapolation calculations

Impact		Category	Intensity	Unit	OSIP Data 2010 Daily	OSIP Data 2010 Annual	ERCB Data and Projections 2012 Daily	ERCB Data and Projections 2012 Annual	ERCB Data and Projections 2022 Daily	ERCB Data and Projections 2022 Annual	Total Approved Projects (November 2, 2012) Total Approved Daily	Total Approved Projects (November 2, 2012) Total Approved Annual
Production		In situ	NA	bbls	547,202	199,728,730	994,521	363,000,000	2,207,720	805,817,800	2,802,830	1,023,032,950
Production		Mining	NA	bbls	977,580	356,816,700	931,507	340,000,000	1,603,899	585,423,135	2,433,000	888,045,000
Production		Total	NA	bbls	1,524,782	556,545,430	1,926,027	703,000,000	3,811,619	1,391,240,935	5,235,830	1,911,077,950
Greenhouse Gases (CO_2e)		In situ	0.082	tonnes/bbl	44,749	16,333,428	81,330	29,685,436	180,543	65,898,218	229,210	83,661,652
Greenhouse Gases (CO_2e)		Mining	0.073	tonnes/bbl	71,176	25,979,077	67,821	24,754,689	116,777	42,623,434	177,142	64,656,698
Greenhouse Gases (CO_2e)		Total	NA	tonnes/bbl	115,925	42,312,506	149,151	54,440,125	297,320	108,521,651	406,352	148,318,350
Water Use	Fresh Water	In situ	0.45	bbl/bbl	248,522	90,710,527	451,680	164,863,219	1,002,677	365,977,180	1,272,958	464,629,490
Water Use	Fresh Water	Mining	2.41	bbl/bbl	2,351,894	858,441,150	2,241,049	817,982,989	3,858,712	1,408,429,900	5,853,390	2,136,487,364
Water Use	Fresh Water	Total	NA	bbl/bbl	2,600,416	949,151,677	2,692,729	982,846,208	4,861,389	1,774,407,079	7,126,348	2,601,116,854
Water Use	Brackish Water	In situ	0.39	bbl/bbl	215,238	78,561,985	391,188	142,783,668	868,392	316,963,144	1,102,475	402,403,297
Water Use	Brackish Water	Mining	NA	bbl/bbl	NA	NA	NA	NA	NA	NA	NA	NA
Water Use	Brackish Water	Total	NA	bbl/bbl	215,238	78,561,985	391,188	142,783,668	868,392	316,963,144	1,102,475	402,403,297
Air Emissions	NO_2	In situ	61.57	g/bbl	34	12,297	61	22,350	136	49,613	173	62,987
Air Emissions	NO_2	Mining	81.32	g/bbl	79	29,016	76	27,649	130	47,607	198	72,216
Air Emissions	NO_2	Total	NA	g/bbl	113	41,313	137	49,998	266	97,220	370	135,203
Air Emissions	SO_2	In situ	41.40	g/bbl	23	8,270	41	15,030	91	33,364	116	42,357
Air Emissions	SO_2	Mining	449.37	g/bbl	439	160,343	419	152,786	721	263,071	1,093	399,061
Air Emissions	SO_2	Total	NA	g/bbl	462	168,612	460	167,815	812	296,435	1,209	441,418
Air Emissions	$PM_{2.5}$	In situ	1.54	g/bbl	0.84	307	1.53	558	3.40	1,239	4.31	1,573
Air Emissions	$PM_{2.5}$	Mining	4.42	g/bbl	4.32	1,578	4.12	1,504	7.09	2,590	10.76	3,928
Air Emissions	$PM_{2.5}$	Total	NA	g/bbl	5.17	1,885.54	5.65	2,062.26	10.49	3,828.92	15.07	5,501.62
Tailings (MFT)		In situ	NA	bbl/bbl	NA	NA	NA	NA	NA	NA	NA	NA
Tailings (MFT)		Mining	1.5	bbl/bbl	1,466,370	535,225,050	1,397,260	510,000,000	2,405,849	878,134,703	3,649,500	1,332,067,500
Tailings (MFT)		Total	NA	bbl/bbl	1,466,370	535,225,050	1,397,260	510,000,000	2,405,849	878,134,703	3,649,500	1,332,067,500
Land		In situ	1.60×10^{-6}	ha/bbl	0.9	320	1.6	581	3.5	1,289	4.5	1,637
Land		Mining	9.40×10^{-6}	ha/bbl	9.2	3,354	8.8	3,196	15.1	5,503	22.9	8,348
Land		Total	NA	ha/bbl	10.1	3,674	10.3	3,777	18.6	6,792	27.4	9,984

METHODS

Summary

We report the average upstream oilsands production impact intensities (per barrel of bitumen or SCO produced) for air emissions, greenhouse gas emissions, water use, and tailings production using publicly available historical data from 2009 onwards.

- Intensity calculations used project-specific data from publicly available sources including: the Oilsands Information Portal (OSIP), Canadian Association of Petroleum Producers (CAPP), National Pollution Release Inventory (NPRI), the Government of Alberta's Greenhouse Gas Reporting Program, the Energy Resources Conservation Board, and academic papers.
- Project-specific annual emissions data and project-specific annual production volumes (bitumen or synthetic crude oil) were combined for each project and year with data. We weighted intensity averages by the production volumes of the projects included in the calculations for each average. This excludes projects that have already begun operations, but have not yet produced oil (e.g. Imperial Oil's Kearl mine was excluded (production began in end of March 2013) because it was an outlier that skews the water consumption data upwards considerably. In addition, Nexen's Long Lake in situ facility was excluded because no other operator has announced plans to replicate this technology approach).
- We used the production volume data reported in the Alberta Oil Sands Information Portal (OSIP) as the denominators for all impact intensity calculations.
- To the best of our knowledge, neither project-specific nor year-specific tailings production volume data is publicly available. Although OSIP reports the area of each tailings lake, this data does not lend itself to quantifying the production volume intensity. The tailings production volume intensity we report is taken from a peer-reviewed academic study.
- Where available, we compared the intensities that we calculated to those that we calculated using industry-wide (i.e., not project-specific) historical impact and production history reported by the Canadian Association of Petroleum Producers (CAPP).
- We used the intensities calculated to extrapolate absolute daily and annual oilsands production impacts associated with 2010 and 2012 actual production, 2022 ERCB production forecasts, and the total production capacity of all oilsands projects that had received regulatory approval as of November 2, 2012 (includes all operating, under-construction, and approved projects).

Additional Methodological Details

Exclusion of Nexen Long Lake In Situ Project

We considered Nexen's Long Lake in situ project to be an outlier and excluded it from our calculations of the intensity averages. Sensitivity analyses indicated that inclusion of this project raised the average in situ intensity for all types of impacts with the exception of brackish water use. For brackish water use the inclusion of Long Lake resulted in a slight [3.2%] decrease in the average intensity. To the best of our knowledge, no other planned in situ projects intend to use Nexen's proprietary OrCrude technology, hydrocracking, and gasification upgrading process to produce Premium Synthetic Crude; thus, extrapolating future absolute impacts from current average impact intensities that include Long Lake would likely result in an upward bias. We therefore excluded Long Lake's contributions to average impact intensities in order to provide more realistic and/or conservative estimates of future cumulative impacts.

Uncertainty

The impact intensities that we report should be considered averages based on recent industry performance history, not precise forecasts of future impact intensities. Intensities may decrease in the future due to stricter regulations, innovation and implementation of new technologies or increased efficiencies (e.g., increased use of power co-generation or increased recycle-water availability). Conversely, impact intensities may increase in the future as remaining resource deposits become more and more marginal (i.e., requiring more energy and effort to extract a lower-quality resource). It is difficult to quantify whether improvements in performance will outweigh the effect of increasingly marginal resources on the oilsands industry's environmental performance, especially since unknown future policy and economic scenarios are also likely to be influential variables in this relationship. As such, while the impact intensities we report here are relatively accurate reflections of recent performance history, they are a projection of future impacts based on the assumptions described herein.

Data availability

At the time of writing this report, there was no publicly available historical data for oilsands greenhouse gas emissions or air emissions (NO_2, SO_2, and $PM_{2.5}$) for the year 2011 or later, and data on the annual volume of tailings produced was not available for any year. Thus, the tailings production intensity we report is taken from another study, and the greenhouse gas and air emission intensities we report are derived from 2009-2010 production and emission data. Oilsands historical water use (fresh and brackish) data was available for the year 2011; the water use intensities we report are derived from 2009-2011 production and water use data in order to reflect the most recent oilsands water use trends.

Greenhouse gas emissions associated with cogeneration of electricity

Some oilsands projects use a combined process to generate steam and electricity on site, whereas other projects purchase electricity from the Alberta electricity grid and utilize on-site boilers for steam. The combined process is known as cogeneration or combined heat and power. Facilities that employ cogeneration typically produce more electricity than they need and sell the surplus into the grid for use elsewhere. The inclusion of cogeneration emissions therefore overestimates the average GHG emission intensities associated with oilsands production in those facilities. Conversely, excluding the GHG grid emissions emitted by external providers of electricity to oilsands projects that do not employ cogeneration (instead having standalone boilers and purchasing power from Alberta's grid) results in an underestimation of GHG emission intensities associated with oilsands production from non-cogeneration facilities. Because of this complexity, we chose to use full facility emissions for all projects in our analyses of GHG and air emissions. Thus, we neither credited projects for cogeneration contributions to the grid nor penalized projects for electricity consumed from the grid.

Full data tables are available upon request.

Endnotes

1 Energy Resource Conservation Board, *Alberta's Energy Reserves 2012 and Supply/Demand Outlook 2013-2022* (2013), 10. http://www.aer.ca/documents/sts/ST98/ST98-2013.pdf

2 *Alberta's Energy Reserves 2012 and Supply/Demand Outlook 2013-2022*, 10.

3 Canadian Association of Petroleum Producers, *Crude Oil: Forecast, Markets and Transportation* (2013), 6. http://www.capp.ca/forecast/Pages/default.aspx

4 Oil Sands Environmental Coalition, *Submission to Joint Review Panel for the Shell Jackpine Mine Expansion Project,* October 1, 2012, 26. http://pubs.pembina.org/reports/osec-submission-jackpine-expansion-oct-2012-corrected.pdf

5 Oilsands Review, "Statistics: Oilsands Production." http://www.oilsandsreview.com/statistics/production.asp

6 Oilsands Review, "Statistics: Oilsands Production."

7 The RCE 2010 progress report notes that about 0.6 barrels of fresh water was used to produce each barrel of oil produced from conventional oil operations in Alberta in 2010. Responsible Canadian Energy, *2010 Progress Report*. http://www.rce2010.ca/western-canada/water/water-usage/

8 Alberta Environment and Sustainable Resource Development, "Oil Sands Information Portal: Oil Sands Operators' Water Use History," http://environment.alberta.ca/apps/OSIPDL/Dataset/Details/56 (accessed April 19, 2013). Water use volumes are reported in m^3, therefore converted to barrels as needed (1 m^3 = 6.29 barrels).

9 Federation Internationale de Natation specifications for Olympic swimming pool are 25 meters wide, 50 meters long and 2 metres deep, for a volume of 2,500 m^3. Dimensions Info, "Olympic Swimming Pool Dimensions." http://www.dimensionsinfo.com/olympic-swimming-pool-dimensions/.

10 A typical bathtub contains approximately 160 litres of water.

11 In a comparison of production emissions only, the per-barrel greenhouse gas emissions associated with oilsands extraction and upgrading are estimated to be 3.2 to 4.5 times as high as than conventional crude oil produced in Canada or the United States. National Energy Technology Laboratory, *Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels*, DOE/NETL-2009/1346 (2008), 12. http://www.netl.doe.gov/energy-analyses/pubs/NETL LCA Petroleum-Based Fuels Nov 2008.pdf

12 Alberta Environment and Sustainable Resource Development, "Greenhouse Gas Reporting Program," http://environment.alberta.ca/02166.html, 2009 and 2010 Greenhouse Gas Summary Reports (datasets) (accessed April 19, 2013). Emission totals used in intensity calculations include emissions from co-generation but do not include grid emissions from electricity consumption by oilsands projects that do not employ co-generation.

13 Projected 2022 annual GHG emissions is 108,521,651 tonnes. The average U.S. passenger vehicle emissions in 2010 was 4.8 tonnes CO_2e per year. U.S. Environmental Protection Agency, "Calculations and References." http://www.epa.gov/cleanenergy/energy-resourc"es/refs.html

14 Environment Canada, "National Pollution Release Inventory (NPRI) Downloadable Datasets: Facility Data", http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98-, 2009 and 2010 datasets (accessed April 19, 2013).

15 S. M. Rowland,C. E. Prescott, S. J. Grayston, S. A. Quideau and G. E. Bradfield, "Recreating a Functioning Forest Soil in Reclaimed Oil Sands in Northern Alberta: An Approach for Measuring Success in Ecological Restoration," *Journal of Environmental Quality* 48 (2009). https://www.agronomy.org/publications/jeq/abstracts/38/4/1580 ; Simon Dyer, Jennifer Grant, Marc Huot, Nathan Lemphers, Beneath the Surface: A review of key facts in the oilsands debate (Pembina Institute, 2013), 42. http://www.pembina.org/pub/2404

16 Mining tailings production intensity refers to what's known as "mature fine tailings". The sand particles in tailings settle to form a stable deposit fairly quickly, while the finer clay particles take decades to settle (these are known as fluid fine tailings). In three to five years, the fluid fine tailings will concentrate to about 30 or 35 per cent solids at which time they are referred to as mature fine tailings (MFT). Because these mature tailings don't settle out and cannot be reclaimed without substantial processing, more and larger tailings ponds have been required over the years as production has increased.

17 R.J. Mikula, "Advances in oil sands tailings handling: building the base for reclamation," In Restoration and Reclamation of Boreal Ecosystems: Attaining Sustainable Development, D.H. Vitt and J.H. Bhatti, editors (Cambridge University Press, 2012).

18 Alberta Environment and Sustainable Resource Development, "Oil Sands Information Portal."

19 The City of Vancouver is 114.9 km^2 in size or 114,900,000 m^2. The volume of tailings (m^3) was divided by the surface area to find a depth of 7 metres.

20 This value is approved oilsands production only. However, should industry and government projections be accurate, production levels of this magnitude may be realized by 2025. Oilsands Review, "Statistics: Oilsands Production."

21 Mikula, "Advances in oil sands tailings handling."

22 2.4 million barrels of mineable production/day x 1.57 bbl of MFT/bbl of bitumen = 3.77 million barrels of MFT/day. 3.77 million barrels of MFT per day is equivalent to 1.4 billion barrels of MFT per year.

23 Area of New York's Central Park is 339 ha, or 3,339,000 m^2. Daily production of tailings in 2022 is projected to be 2,405,849 barrels or 382,500 m^3, which gives a covering of 0.115 m per day or 3.45 metres (11.3 feet) per month.

24 Simon Dyer and Richard Schneider, *Death by a Thousand Cuts: The Impacts of In Situ Oilsands Development on Alberta's Boreal Forest* (Pembina Institute, 2006), 10. http://www.pembina.org/pub/1262

25 Simon Dyer, Jeremy Moorhouse and Marc Huot, *Drilling Deeper: the In Situ Oil Sands Report Card* (Pembina Institute, 2010), 30. http://www.pembina.org/pub/1981

26 Sarah Jordaan, David W. Keith and Brad Stelfox, "Quantifying land use of oil sands production: a life cycle perspective," *Environmental Research Letters* 4 (2009).

27 In situ land intensity average value of 0.115 m^2/m^3 SCO (from Jordaan et al.) is equivalent to 0.0000018 ha per barrel. According to CAPP, in situ production in 2011 is 833,000 barrels per day. 833,000 barrels per day*0.0000018 ha per barrel results in 1.5 ha of land disturbance per day. This is approximately equal to 3 football fields per day.

28 Shell Canada Limited, "Application for Approval of the Jackpine Mine Expansion Project - Environmental Impact Assessment." Vol. 1, Project Description, 2007, 19-6. http://www.shell.ca/en/aboutshell/our-business-tpkg1/upstream0/oil-sands/jackpine-mine-expansion.html

29 Bob Dunbar, *Existing and Proposed Canadian Commercial Oil Sands Projects* (Strategy West Inc., 2008). http://www.strategywest.com/downloads/StratWest_OSProjects.pdf

30 "Application for Approval of the Jackpine Mine Expansion Project," Vol. 1, P-iii.

31 Area of an American football field = 120 x 53.3 yards = 6,396 sq yards = 0.54 hectares. http://en.wikipedia.org/wiki/American_football