Alberta oil-sands and climate: Warming from well-to-wheel emissions

N.C. Swart[1] and A.J. Weaver[1]

[1] *School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada, V8W 3V6.*

1 Well-to-wheel emissions

- **See calculations of bitumen carbon content (1.32×10^5gC / bbl bitumen) in the supplementary material of Swart and Weaver (online at Nature Climate Change).**
- **There is debate over the WTW figures below. They WERE NOT part of the peer-review Nature Climate Change commentary**

In a ”wells to wheels” (WTW) approach, emissions incurred during extracting, refining and transporting of bitumen are added to the emissions associated with ultimate use in an internal combustion engine. Bitumen can either be extracted by surface mining (about 20% of the reserve is thought to be accessible this way[1]) or a more energy intensive in-situ process (which applies to 80% of the reserve). For in situ extraction, the bitumen is heated and diluted underground before being pumped to the surface. We call the surface mining and upgrading path SM&UP, and the in-situ and upgrading path IS&UP. After extraction, most bitumen is subsequently upgraded to form synthetic crude oil (SCO), and eventually primarily refined into gasoline and diesel[2]. The majority of the additional energy invested for the extraction and upgrading processes is currently provided by natural gas. Part of the required energy may be supplied by heavier oil sands feedstock [2,3], and this may be increasingly true in the future as natural gas supplies become limiting[4].

Charpentier et al.[2], reviewed 13 previous studies of emissions associated with the Alberta oil sands. The Charpentier et al. data include emissions from greenhouse gasses (CH_4, N_2O) other than carbon dioxide, converted to CO_2 equivalents. The emissions are assigned to different stages in the process, for example, wells-to-refinery gate (WTR) emissions include emissions due to extraction and upgrading to SCO; wells-to-tank (WTT) emissions also include those associated with the refining and distribution; tank-to wheels (TTW) emissions are those resulting from the final combustion of the fuel in a vehicle. It is worth noting that TTW emissions for a given vehicle are the same, regardless of the original source of the fuel, and in addition they account for 60–80% of total emissions associated with the life-cycle of the fuel. Thus, differences in emissions intensities amongst fuels occur in the wells-to-tank stage. Therefore, comparison of fuel types on a WTT basis always exhibit a greater variability than comparisons on a WTW basis, since most of the emissions occur in the final combustion phase[5].

Charpentier et al. find that the studies they analyze differ in their boundaries for the inclusion of emissions categories, for example whether venting, flaring and fugitive emissions from tailings ponds are included. Also, extraction processes vary from site-to-site, as does the quality of bitumen, thus requiring differing levels of upgrading. These factors all lead to differences or uncertainties amongst studies as to the actual emissions associated with bitumen production. On a WTW basis, Charpentier et al. give emissions of 260–320 and 320–350 gCO_2eq/km for SM&UP and IS&UP respectively, relative to 250–280 gCO_2eq/km for conventional crude. From these results we may see that oil-sands production is associated with higher emissions than conventional crude on WTW basis. A similar conclusion has been reached by other recent studies[5,6].

We use the WTW data provided by Charpentier et al.[2] in their table S2. They report emissions in gCO_2eq/km, where a spark ignition internal combustion engine with a fuel consumption of 9.6 l/100 km is assumed, and we convert this into emissions per barrel of bitumen, using the conversion factors below.

1. Surface mining and upgrading: The wells to wheels emissions estimates range from 263 – 322 gCO_2eq/km[2], yielding a carbon content per barrel range of:

$$263\,\frac{\text{g}}{\text{km}} \times \frac{1}{0.096}\,\frac{\text{km}}{1} \times \frac{12}{44} \times 159\,\frac{1}{\text{bbl}} = 1.19 \times 10^5 \text{ g / bbl} \tag{1}$$

to

$$322\,\frac{\text{g}}{\text{km}} \times \frac{1}{0.096}\,\frac{\text{km}}{1} \times \frac{12}{44} \times 159\,\frac{1}{\text{bbl}} = 1.45 \times 10^5 \text{ g / bbl} \tag{2}$$

Here we have converted from CO_2 to C by multiplying by 12/44, and converted from liters to barrels using 1 bbl = 159 l.

2. In situ and upgrading (and in situ without upgrading): The wells to wheels emissions estimates range from 269 – 353 gCO_2eq/km[2], yielding a carbon content range:

$$269\,\frac{\text{g}}{\text{km}} \times \frac{1}{0.096}\,\frac{\text{km}}{1} \times \frac{12}{44} \times 159\,\frac{1}{\text{bbl}} = 1.22 \times 10^5 \text{ g / bbl} \tag{3}$$

to

$$353\,\frac{\text{g}}{\text{km}} \times \frac{1}{0.096}\,\frac{\text{km}}{1} \times \frac{12}{44} \times 159\,\frac{1}{\text{bbl}} = 1.59 \times 10^5 \text{ g / bbl} \tag{4}$$

The Charpentier et al. emissions results are based on reformulated gasoline being combusted in the engine. We assume a bitumen to gasoline volume conversion of 1:1, in order to apply these results to the oil sands reserve (This method has been questioned; Also, products other than gasoline are also refined from bitumen, which will have an impact on the numbers). Quoted volume yields of bitumen to SCO are typically between 80 and 100% or more[1], therefore by using a ratio of 1:1 we achieve a plausible upper bound. Surprisingly, the lower bound estimates of carbon content from the WTW approach are lower than our initial estimate (1.32×10^5 g/bbl bitumen), based on the properties of bitumen. This implies that either carbon ”removal” occurs at some point in the WTW process, or that the estimates are incorrect and too low. Stockpiling of the petroleum coke by-product from the upgrading process may lead to a carbon removal. Based on Table 3 of Furimsky[3], we estimate that this could account for up to 0.147×10^5 g/bbl bitumen, thereby increasing the lower WTW estimates of carbon content at least to above our baseline value. Since the petroleum coke could be burnt in the future, it is not correct to assume this carbon has been ”sequestered”. Rather it has been temporarily removed (A. Brandt, pers. comm., 2011).

For our total WTW estimate of carbon emissions associated with the Alberta oil sands reserve we apply the SM&UP figure (1.45×10^5 g / bbl) to 20% of the reserve, and the IS&UP figure (1.59×10^5 g / bbl) to 80% of the reserve. Applying this scaling leads to a value of 1.59×10^5 g / bbl which can be multiplied by the reserve size in barrels to get the WTW emissions (see table below).

2 Well-to-wheel warming

Based on the carbon-climate response methodology described in the paper (CCR $= \frac{1.5^oC}{1\times10^{18}gC}$), we can calculate the warming associated with the WTW emissions. We can see that the central estimate of warming has increased by about 17%, to 0.42°C relative to the basic calculation (see table). Please note however the large uncertainties in the WTW estimates, and in the conversion back to emissions per barrel of bitumen.

Table S1: **Well-to-wheel potential carbon emissions and warming**

	Amount $\times 10^{12}$ bbl	carbon density $\times 10^{5}$ gC/bbl	Total carbon $\times 10^{17}$gC	Δ T (mean) $^{\circ}$C	δ T (5%) $^{\circ}$C	Δ T (95%) $^{\circ}$C
Bitumen in place	1.8	1.56	2.81	0.42	0.28	0.59
Proven reserve	0.169	1.56	0.264	0.04	0.03	0.06
Active development	0.026	1.56	0.041	0.01	0.00	0.01

References

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