# The Multi-Media Impacts of Cannabis Production in Metro Vancouver

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August 2019

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

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## Executive Summary

Indoor cannabis cultivation is a resource-intensive process. The benefit of indoor cultivation to producers includes production consistency and controlled ambient conditions. The main costs to producers are the energy expenses whereas the cost to society is in the form of environmental damages, such as: air emissions, water use and discharge, energy demand, and solid waste generation.

The purpose of this report is to assess the multi-media environmental impacts of cannabis cultivation in Metro Vancouver. The objective is to calculate a reliable, evidence-based projection of annual impacts by synthesizing high-quality information sources.

Previous studies have been hampered by a lack of data availability and are typically based on practices prevalent in illicit grow operations. This report fills this gap using a two-step methodology. First, a comprehensive literature review, primarily from regions that have legalized cannabis, is conducted to identify environmental impacts on a per gram (of final product) basis. Second, these figures are extrapolated to estimate annual environmental impacts using evidence about plant yield and density, total potential cultivation area, and number of harvests per year.

Table ES-1 summarizes the main findings. Energy demand is arguably the most significant, making up 16% of provincial demand. Water use also requires attention, as crop conversion to cannabis cultivation can use up to 24 times more water than vegetables and fruits.

Table ES-1: Projected Multi-media Impacts of Cannabis Cultivation in Metro Vancouver

| CATEGORY | ANNUAL ENVIRONMENTAL IMPACT |
|---|---|
| Local Air Quality | 1,745 tonnes VOC |
| Water Demand | 18,520 million litres |
| Energy Demand | 12.6 terawatt-hours |
| Carbon Emissions | 0.16 megatonnes |
| Solid Waste Generation | 9,098 tonnes |
| Wastewater Generation | 161 million litres |

## Introduction

On October 17, 2018, Canada legalized the non-medical use of cannabis nationwide. The expanded industry is expected to generate $CAD 4 billion in legal sales in 2019, equivalent to the average annual revenue of the entire National Hockey League over the last five years (Deloitte, 2018; Statista, 2018). Despite the significant economic boost, the associated land use changes and resource-intensive cultivation practices could have significant environmental impacts.

As of August 8th, 2019, there are 47 licensed cannabis cultivation facilities (CCFs) in British Columbia (B.C.). Twelve of these are in Metro Vancouver, with an additional 9 facilities announced but not licensed (Wan, 2019, Personal Communication). The existing and planned facilities are primarily indoor or greenhouses, which produce significantly more environmental impacts than their outdoor counterparts (Arnold, 2013). Controlling the indoor growing environment is highly resource-intensive, with potential increases in direct and indirect air emissions, water use and discharge, energy demand, and solid waste generation.

Previous studies have been hindered by the lack of reliable data due to the illicit nature of the industry. This report attempts to fill this gap by synthesizing information from other jurisdictions—many of which have legalized recreational cannabis—and applying the findings to Metro Vancouver

The purpose of this report is to assess the multi-media environmental impacts of cannabis production in Metro Vancouver on:

- Air quality
- Water use
- Energy use
- Solid waste generation
- Wastewater generation

## Research Approach

The multi-media environmental impacts of cannabis cultivation in Metro Vancouver were estimated in two steps. First, a detailed literature search was conducted to identify the environmental impact per gram of final product for each impact category. Second, these values were extrapolated to project annual environmental impacts using current information, personal communication with cultivators, and literature evidence about common cannabis cultivation practices.

A common way to describe environmental impacts is with an environmental impact factor (EIF). An EIF relates the quantity of environmental impact to the output associated with an activity. As such, the EIF for cannabis cultivation is expressed as environmental impact per gram of final consumable product, also known as dried matter (DM). Table 1 describes the five types of EIFs identified in this report.

Table 1: Environmental Impact Factors

| EDF TYPE | DESCRIPTION |
|---|---|
| Air Emissions Factor (AEF) | Air emissions (micrograms) per gram DM |
| Water Use Factor (WUF) | Water demand (litres) per gram DM |
| Energy Use Factor (EUF) | Energy use (kilowatt-hours) per gram DM |
| Waste Generation Factor (WGF) | Solid waste (grams) per gram DM |
| Wastewater Generation Factor (WWF) | Wastewater (litres) per gram DM |

### Literature Search

A mixed-method literature review of qualitative and quantitative research was conducted to identify environmental impacts per gram of final, saleable product. First, the peer-reviewed, academic literature from reputable environmental science journals was surveyed for each topic to identify EIFs. Second, non-peer reviewed literature was reviewed, including government reports, consultant reports, graduate theses, and news media. Lastly, CCFs were contacted through personal communication as an additional source of information.

Table 2 describes the distribution of information sources by environmental impact category. 17 sources containing EIFs were used for projecting environmental impacts in Metro Vancouver, the majority of which were non-peer reviewed reports. Many more literature sources were used for building context (see full reference list).

Table 2: Information Sources by Environmental Impact Category

| CATEGORY | PEER-REVIEWED | NON PEER-REVIEWED | PERS. COMM. | TOTAL |
|---|---|---|---|---|
| Air EIFs* | 1 | 0 | 2 | 4 |
| Air Production** | 2 | 4 | 2 | 8 |
| Water Demand | 0 | 6 | 0 | 6 |
| Energy Demand | 1 | 4 | 0 | 5 |
| Solid Waste | 0 | 1 | 0 | 1 |
| Wastewater | 0 | 0 | 2 | 2 |
| Total | 3 | 11 | 4 | 17 |

* sources where emission factors are provided or can be calculated using other production data

** sources that provide production information such as yield, plant density, canopy fraction, CCF fraction, and number of harvests

## Environmental Impact Estimation

The estimation of annual environmental impacts involved scaling EIFs using evidence from the literature as well as personal communication about cultivation conditions including: plant yield per harvest, number of harvests per year, planting density and the total area of CCFs in Metro Vancouver.

Figures for plant density and yield are based on cultivation conditions in indoor facilities in other regions where cannabis is legal. A planting density of 5 plants/$m^2$ is assumed, based on personal communication with the Spokane Clean Air Agency (SPCAA, 2017), which monitored four licensed indoor CCFs. Plant yield (grams of final product per plant) is based on a consulting report for the Colorado government, which conducted audits in three indoor CCFs in Colorado (Cannabis Conservancy, 2018 p. 73). Table 3 summarizes the results.

Table 3: Cannabis Plant Yield per Harvest

| CCF NAME | TYPE | YIELD (g/plant) |
|---|---|---|
| The Clinic | Indoor | 181 |
| Midwest Ranch | Greenhouse + Indoor | 222 |
| Anonymous | Indoor | 245 |
| | Mean | 216 |

Four harvests per year are assumed, which is typical for legal indoor operations (Caulkins, 2010). Lastly, the total potential CCF area in Metro Vancouver is assumed to be 1.35 million $m^2$ (Wan, 2019, Personal Communication). This includes all licensed CCFs and their announced expansion plans; 9 announced, unlicensed CCFs with announced sizes; and several announced CCFs with unreleased sizes. Approximately 67% of this total area is assumed to be plant cover, and the rest used for walkways or equipment storage (O'Hare et. al., 2013). Table 4 summarizes the cultivation conditions used in this report to extrapolate environmental impacts.

### Table 4: Cannabis Cultivation Conditions

| CONDITION | VALUE |
|---|---|
| Plant yield | 216 g/plant |
| Plant density | 5 plants/$m^2$ |
| Total Metro Vancouver CCF area | 1.35 million $m^2$ |
| Fraction of CCF under canopy | 67% |
| Number of harvests per year | 4 |

Although the above cultivation conditions were identified from the best available information sources, there are at least three limitations. First, plant yield estimates from the Colorado audits are based on unknown seed types and may differ from the type of cannabis grown in B.C. Furthermore, plant yield additionally depends on temperature, light intensity, and plant density (Vanhove et al. 2011, 2012), which vary between B.C. and Colorado. Second, although the evidence suggests that lower plant density increases yields (Vanhove et al. 2011, 2012), the optimal density is unclear. The 5 plants/$m^2$ figure used in this report is based on real data from Washington and resembles anecdotal evidence from B.C. Third, literature estimates on the number of harvests per year vary from 4 to 6 depending on the time that plants spend in vegetative and flowering stages (Caulkins, 2010). None of the information sources in this report state the number of harvests, so 4 harvests/year is assumed in order to be consistent with the bulk of the literature.

Despite these limitations, the conditions in Table 4 are applied to emissions factors to project annual impacts. For example, annual water demand based on a WUF of 4.7 litres/g DM/harvest is:

$$\text{Water Demand} = 4.7 \text{ litres/g DM/harvest} \times 216 \text{ g/plant} \times 5 \text{ plants/m}^2 \times 1.35 \text{ million m}^2 \times 0.67 \times 4 \text{ harvests/year}$$

$$= \mathbf{18{,}365 \text{ million litres/year}}$$

# Findings

## Local Air Quality

I. Emissions Factors

Previous studies from indoor CCFs have identified high levels of terpenes (Rice and Koziel, 2015; Wiebelhaus et al., 2016), a class of photoreactive volatile organic compounds (VOCs) that combine with sunlight and nitrogen dioxide to produce ozone and secondary organic aerosols. The limited literature on cannabis VOCs focuses on identifying hundreds of these VOC species rather than quantifying their amounts. Two methods are typically used:

- *Headspace sampling* profiles VOCs in a small area above the plant
- *Leaf enclosure sampling* profiles VOCs inside a bag secured around the plant

Table A-1 in the appendix summarizes the main VOC species found through each method. Some VOCs have low enough sunlight reactivity to have minimal local air quality impacts. Section 51 (Title 40) in the U.S. EPA Code of Regulations lists 70 such VOCs and excludes them from regulation (Table A-2 in the appendix). None of these are found in cannabis VOC emissions. Furthermore, the California Air Resources Board (CARB) lists the maximum incremental reactivity (MIR) in terms of potential ozone per gram of organic compound emissions. Terpenes are on the order of 4 whereas most unregulated alkenes and alkanes listed in the EPA code range from 0.01-2.5. Taken together, this implies that the VOCs released from CCFs in Metro Vancouver are photoreactive and therefore have the potential to impact regional air quality.

Despite the value of a cannabis VOC profile, the abundance of each compound is more important for understanding air quality impacts. Three sources of directly measured AEFs were found. First, in the only peer-reviewed paper, Wang et al. (2019) used the leaf enclosure method on four cannabis strains and found a maximum VOC emission rate of 8.7 µg/g DM/hr after harvest in Colorado. Second, the Air Quality Division of Washoe County, Nevada (2016) used headspace sampling in one facility and found a VOC emission rate of 30,983 µg/plant/hr. This equates to 143 µg/g DM/hr, under the 216 g/plant assumption, but the stage of growth was not stated for this sampling event. Third, the Spokane Clean Air Agency (SCAA, 2017) also used headspace sampling in one facility at the end of the growth cycle (when emissions are at their peak) and found a VOC AEF of 0.83 µg/ft$^3$/plant. The facility had a 10,000 ft$^3$ grow room and a 2000 ft$^3$/min exhaust to outside. Plant yield was not reported, however, under the 216 g/plant assumption this equates to 461 µg/g DM/hr.

There could be many reasons for the discrepancies in VOC emission rates between the headspace sampling and leaf enclosure studies, including differences in seed variety, growth stage, and lighting. Seed type is not stated in the headspace studies whereas the leaf enclosure study uses four strains: Critical Mass, Lemon Wheel, Elephant Purple, and Rockstar Kush. Furthermore, the former study collects air samples during a peak emissions period (within 14 days before harvest) whereas the latter study samples after harvest when emissions are lower (SCAA, 2017).

### II. Projected Impact on Local Air Quality

Table 5 reports projected annual VOC emissions from Metro Vancouver CCFs under the three AEF scenarios from the literature. For context, VOC emissions in Metro Vancouver were 45,000 tonnes in 2015 (Metro Vancouver, 2018), of which 7800 tonnes were from natural sources not including agriculture (Cumming, 2019, Personal Communication). Based on the highest emissions rate from SCAA (2017), annual cannabis VOC emissions would make up 9% of the Metro Vancouver total. As it is not clear whether leaf enclosure or headspace sampling is more accurate, the mean of 1,745 tonnes across the three studies may be a more reliable projection. This is equivalent to 4% of the annual Metro Vancouver total and 22% of the natural VOC emissions.

VOCs are a precursor to ground-level ozone, which has the potential to cause harmful human health impacts. Therefore, a comprehensive assessment of local air quality impacts must include the ozone formation potential of cannabis cultivation.  This report uses the ozone factor of 41 µg $O_3$/g DM/hr calculated in Wang et al. (2019), which was derived by multiplying the emissions rate of each VOC species by its ozone potential (grams ozone per gram VOC) from the California Air Resources Board (CARB, 2010).

Table 5: Projected Annual Emissions from Metro Vancouver Cannabis Cultivation

| STUDY | AEF | VOC (TONNES) | OZONE (TONNES) |
|---|---|---|---|
| Wang et al. (2019) | 8.7 µg/g DM/hr | 74 | 350 |
| Washoe County (2016) | 143 µg/g DM/hr | 1225 | - |
| SCAA (2017) | 461 µg/g DM/hr | 3936 | - |

## Water Demand

### I. Water Use Factors

Cannabis is a water-thirsty crop (Bustic and Brenner, 2016). The rule of thumb among cannabis cultivators is that a successful crop requires 22.7 litres/plant/day, about twice as much as grapes (Humboldt Grower Association, 2010; Williams, 2001). Four non-academic sources form our current understanding of cannabis water demand. Three of these are from outdoor CCFs in California, making it difficult to apply lessons since almost all Metro Vancouver CCFs are indoors or greenhouses.

First, WUFs in the California news media range from 2.8-56.8 litres/plant/day. The former is from an interview with a California Sheriff (Mallery, 2011) and the latter with a prominent marijuana attorney (Van Hook, 2012). Second, the 22.7 litres/plant/day rule-of-thumb was calculated by the Humboldt Grower Association (HGA), assuming a density of 2.3 $m^2$/plant, and standard sprinkler system with a 3.8 litres/hr flow rate, and 30 minutes of watering every other day. Third, the Cal NORML non-profit interviewed 11 outdoor CCFs to verify the HGA figure with real-world data and found a substantially lower figure of 8.7 litres/plant/day (Cal NORML, 2015).

One post-legalization study from Colorado (Cannabis Conservancy, 2018) conducted water audits in five indoor CCFs and found a median WUF of 4.7 litres/g DM. This equates to 11 litres/plant/day[1], assuming a year-round grow cycle and a 216 g/plant yield.

## II. Projected Impact on Water Demand

Figure 1 shows projected annual water demand from Metro Vancouver CCFs. Each bar shows projected water demand from each study or media piece using the corresponding WUF in the cell below. Mean annual water demand from indoor and outdoor CCFs is 18,520 and 37,885 million litres. The large discrepancy is due to the significantly lower water requirements in indoor facilities. Since Metro Vancouver uses mostly indoor CCFs, the former number is the best projection of annual water demand.

For context, the average daily per capita water consumption in Metro Vancouver was 448 litres in 2018 (Metro Vancouver, 2018). Using the 2018 Metro Vancouver population figure of 2.4 million, the 18,520 million litres of annual water demand from cannabis is equivalent to 21 litres/capita/day, or, 4.7% of the per capita total demand.

Another way to contextualize the cannabis water demand projection is to compare it with that of other crops. Fruits and vegetables grown in the Lower Fraser Valley have a water demand of 214.5 litres/$m^2$ (Statistics Canada, 2012). If these crops occupied the same land area as cannabis, water demand would be 776 million litres/year[2]. In other words, annual water demand from Metro Vancouver cannabis cultivation is projected to be 24 times higher than if fruits and vegetables were grown instead.

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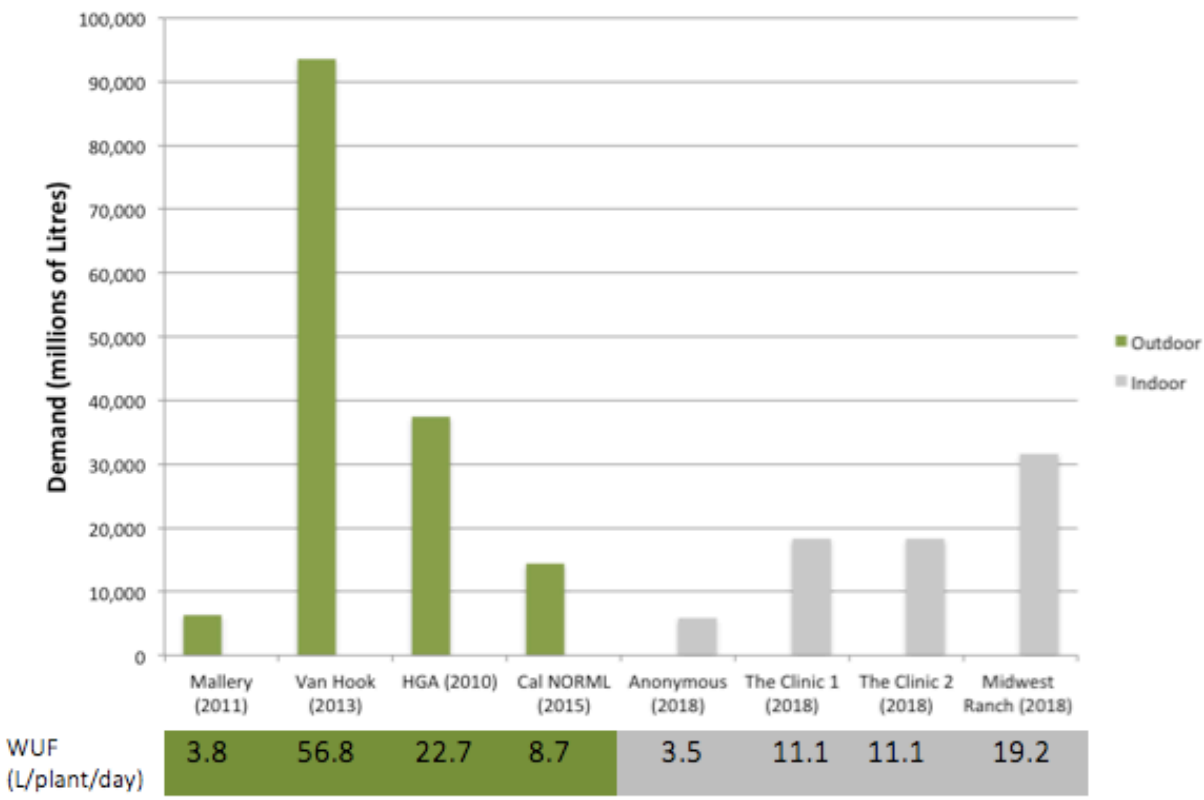
[1] 4.7 L/g DM/harvest x 216 g DM/plant x 4 harvest/year x 1 year/365 days = 11 L/plant/day

[2] 214.5 litres/$m^2$/harvest x 1.35 million $m^2$ total CCF area x 0.67 space used x 4 harvests/year = 776 million litres/year (Statistics Canada, 2012)

Figure 1: Annual Water Demand from Metro Vancouver Cannabis Cultivation




## Energy Demand

### I. Energy Intensity Factors

Energy demand is the greatest contributor to the environmental footprint of indoor cannabis production (DDPHE, 2018). In the only peer-reviewed paper on this topic, Mills (2012) estimates that US energy demand from cannabis production is 1% of national electricity consumption, equivalent to that of 2 million average homes.

There is disagreement in the literature about the distribution of energy use from cannabis production. Jourabchi (2014) found that lighting makes up 80% of energy demand whereas Mills (2012) argues that this number is 38%, with the remainder going to ventilation, space heating/cooling, and pre-heating irrigation water. The former conducted 13 interviews with CCFs whereas the latter used equipment manufacturer data, likely explaining the discrepancy.

Regardless of the breakdown, indoor CCFs present a burden on electricity infrastructure. In one media piece, Oldham (2015) found that electricity demand increased by 3% in Seattle and that CCFs made up 50% of new electricity demand in Colorado following legalization in each state.

There are two non peer-reviewed studies that directly measure cannabis EUFs. First, the Cannabis Conservancy (2018) analyzed daily electricity meter data from all equipment sources in five indoor Colorado CCFs and found a median EUF of 2.6 kWh/g DM. Second, in her masters thesis, Arnold (2013) conducted energy audits of lights, fans, dehumidifiers, heating/cooling systems, and pumps in three indoor California CCFs and found a mean EUF of 4.4 kWh/g DM. Facilities were not randomly selected in either study, limiting the generalizability of the EUFs. However, both studies are from indoor facilities, similar to Metro Vancouver.

Three other studies report cannabis EUFs without energy audits. Mills (2012) used equipment manufacturer data and found an EUF of 6 kWh/g DM for the US. The Northwest Power and Conservation Council (NWPCC) (2014) conducted 90 phone interviews with Oregon and Washington indoor growers and found a mean EUF of 1507 kWh/$m^2$. This equates to 1.4 kWh/g DM under the assumed plant yield and density in Table 4. In another graduate thesis, Sweet (2016) used data from a 2015 NWPCC survey of seven CCFs and found a mean EUF of 1905 kWh/$m^2$, or, 1.8 kWh/g DM.

## II. Projected Impact on Energy Demand and Carbon Emissions

Table 6 summarizes the cannabis EUFs identified in the literature and projects annual energy demand under the standard assumptions. Metro Vancouver CCFs are projected to consume an average of 12.6 TWh of energy per year, equivalent to 16% of provincial electricity consumption (National Energy Board, 2019)[3].

### Table 6: Projected Annual Energy Demand from Metro Vancouver Cannabis Cultivation

| SOURCE | EUF (kWh/g DM) | ENERGY DEMAND (TWh) |
|---|---|---|
| Arnold (2013) | 4.4 | 17.1 |
| Conservancy (2018) | 2.6 | 10.1 |
| Mills (2012) | 6 | 23.4 |
| NWPCC (2014) | 1.4 | 5.4 |
| Sweet (2016)* | 1.8 | 6.9 |
| Mean | - | 12.6 |

*All values based on electricity consumption from grow lights only

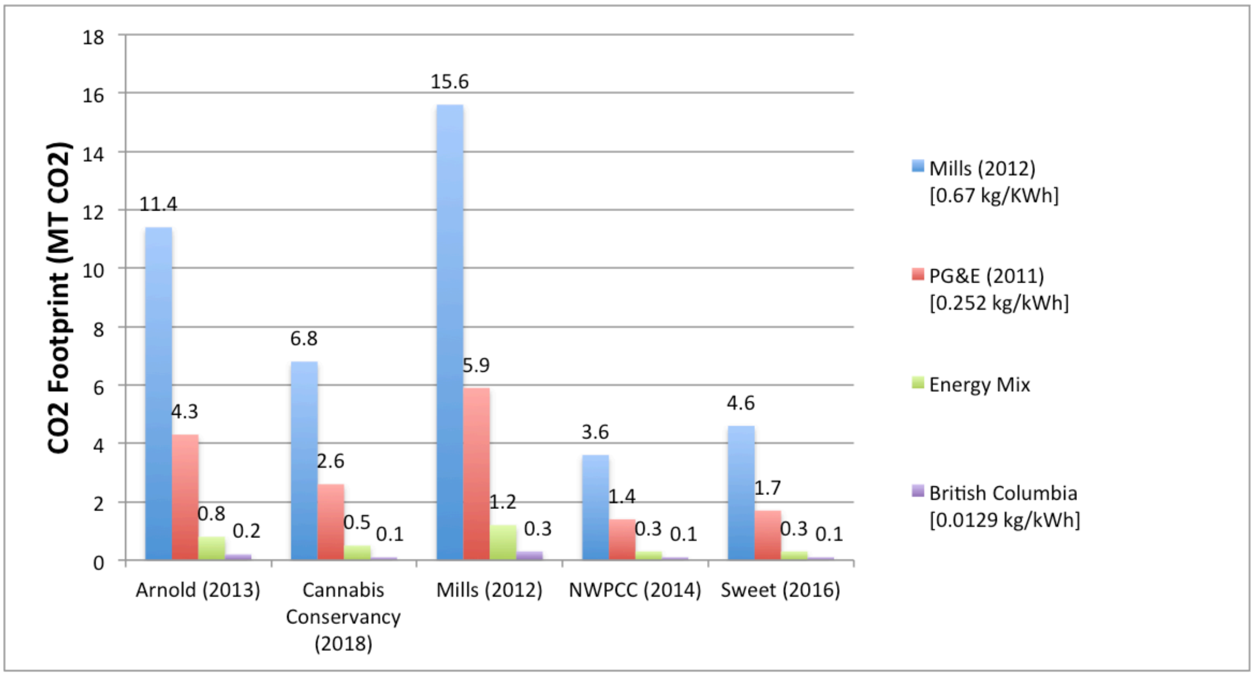
Generating 12.6 TWh of electricity can have a large carbon footprint, depending on the fuel mix. This report estimates the carbon footprint of cannabis cultivation by multiplying energy demand under each scenario in Table 6 with a carbon emissions factor (CEF) (kg $CO_2$ per kWh). There are four available sources of CEFs. First, Mills (2012) used a value of 0.67 kg $CO_2$/kWh for the US.

[3] B.C. generated 76.4 TWh of electricity in 2017 (NEB, 2019)

Second, Pacific Gas and Electric (2011) reported a CEF of 0.252 kg $CO_2$/kWh for Washington and Oregon. Third, Environment and Climate Change Canada (2014) reported a CEF of 0.0129 kg $CO_2$/kWh for B.C., which is substantially lower due to B.C.'s reliance on hydroelectricity. Lastly, ECCC (2014) also reported CEFs by fuel type. Table A-3 in the appendix shows the Canadian energy mix and fuel-specific CEFs.

Figure 2 shows projected carbon emissions from each study in Table 6 and for each CEF scenario. For the energy mix scenario, annual energy demand is split according to the shares in Table A-3 and the corresponding CEF applied (e.g. the coal CEF is applied to the 9.3% of total energy that is coal-generated, the natural gas CEF is applied to 9.6% of total energy demand, and so on)[4].

Figure 2: Projected Carbon Footprint (Mt $CO_2$) from Metro Vancouver Cannabis Cultivation




In a scenario where all Metro Vancouver CCFs are connected to the local grid and all electricity is generated in-province, the carbon footprint based on the 0.0129 kg/kWh CEF would be 0.16 MT, or 41 kg $CO_2$/kg DM[5]. This is the same footprint as driving across B.C. in a 44-mpg car (based on calculations in Mills (2012)).

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[4] The full calculation is: Annual Emissions = Annual Electricity Demand [0.02 x 0.0165 + 0.096 x 0.180 + 0.005 x 0.269 + 0.093 x 0.327]

[5] Total production = 1.35 million $m^2$ total facility area x 0.67 x 5 plants/$m^2$ x 216 g/plant x 4 harvests/year x 0.001kg/g = 3,907,440 kg DM/year

However, not all of the CCFs exclusively use power from the B.C. grid. Two have installed auxiliary power plants using natural gas as fuel and two others use biomass-fired boilers for auxiliary heat. Therefore, the average carbon footprint of cannabis production falls somewhat higher than 0.16 MT. Perhaps a more useful comparison is that the total amount of energy required for cannabis production listed in Table 6 is equal to almost 3 new Site C power projects (B.C. Hydro, 2017).

## Solid Waste Generation

### I. Waste Generation Factors

Solid waste from cannabis cultivation mostly includes stalks, stems, root balls, and spillage. There are no current estimates of cannabis waste from B.C., but its southern neighbor, Washington State, reported hauling approximately 770,000 kg of solid waste from cannabis clients since legalization in 2014 (Black, 2017). Using Washington's latest population figure of 7.5 million (US Census Bureau, 2018), this amounts to 0.03 kg/capita/year, equivalent to 0.03% of Metro Vancouver's 2018 per capita weekly compostable organic waste disposed[6].

In the absence of specific data on waste disposal from CCFs, this report uses a new approach to fill in the gap. The fraction of dry plant biomass ending up as final product (buds) is identified and the remainder is assumed to be waste. The Netherlands Office of Medical Cannabis identified this fraction in a 2006 study of plant weight and waste at different stages of growth (Leggett, 2006). Saleable product is 30% of dry weight and the residual is lost to twigs, stems, seeds, and spillage.

### II. Projected Impact on Solid Waste Generation

This report follows Leggett (2006) and assumes that final product weight is 30% of dry weight. Assuming the remainder is waste, back-calculations can estimate the WGF. For example, the assumed final product weight of 216 g/plant implies the dry harvest weight was 216/0.3=720 g/plant and 720 – 216 = 504 g/plant was disposed as seeds, stems, and spillage.

Using this method, Table 7 reports WGFs during the drying stage (after harvesting wet biomass) and curing stage (picking buds from dry biomass) for the yield scenarios in the three indoor CCF audits in Colorado (see Table 3). Annual solid waste generation is calculated by applying the conditions from Table 4 on the estimated WGFs.

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[6] Compostable organic waste in 2018 was 91 kg/capita (TRI, 2018). This includes household yard waste.

Table 7: Plant yield, WGFs, and Annual Solid Waste from Metro Vancouver Cannabis Cultivation

| FACILITY | YIELD (g/plant) | WGF (g/plant) | WASTE (tonnes) |
|---|---|---|---|
| The Clinic | 181 | 422 | 7624 |
| Midwest Ranch | 222 | 518 | 9350 |
| Anonymous | 245 | 572 | 10,319 |

Mean annual solid waste generation from cannabis is 9098 tonnes. For context, this is 2% of yard and food waste (i.e. compostable organic waste) in Metro Vancouver in 2017 (Metro Vancouver, 2017b)[7]. Note that some CCFs treat solid waste on-site, so this estimate represents an upper bound.

## Waste Water Generation

### I. Wastewater Generation Factors

Wastewater generation is arguably the least studied topic among the environmental impacts of cannabis cultivation. This is likely because facilities were not historically testing their wastewater for hazardous contents or, at least, not reporting this data publicly. After legalization in Canada, CCFs that discharge wastewater into city sewage infrastructure must first treat it to the minimum quality threshold. Based on personal communication with a Metro Vancouver Liquid Waste Services officer, unconnected CCFs either request Metro Vancouver or a third-party service to truck wastewater to a treatment plant, in which case the minimum quality threshold must still be met.

CCFs rarely report wastewater discharge rates, making it difficult to directly calculate a WWF. Two estimates have been quoted through personal communication with CCFs. One Metro Vancouver CCF reported a WWF of 5 mL/plant/day. Another CCF quoted a WWF of 190 mL/plant/day and an additional 225 litres from clean-up after each harvest.

Metro Vancouver (2017) states compostable organic waste equaled 91 kg/capita. Using current population of 2.463 million this amounts to 224,133 tonnes.

## II. Projected Impact on Annual Wastewater Generation

Table 8 shows projected annual wastewater discharge based on the two WWFs received through personal communication. Mean annual discharge is 161 million litres. For context, 450 billion litres of wastewater was treated in Metro Vancouver in 2017 (Metro Vancouver, 2017a). In relation, the amount contributed by CCFs is less than 0.04%.

### Table 8: Projected Annual Wastewater Discharge from Metro Vancouver Cannabis Cultivation

| SOURCE | WWF | ANNUAL DISCHARGE (MILLIONS OF LITRES) |
|---|---|---|
| B.C. CCF 1 | 5 mL/plant/day | 8 |
| B.C. CCF 2 | 190 mL/plant/day | 313 |

## Conclusion

The purpose of this report was to assess the multi-media environmental impacts of cannabis production in Metro Vancouver on:

- Air quality
- Water use
- Energy use
- Solid waste generation
- Wastewater generation

17 peer-reviewed and non-peer reviewed literature sources were consulted to identify environmental damages on a per-gram (of final product) basis. These figures were extrapolated to project annual environmental damages based on evidence about plant yield and density, number of harvests, and total area of cultivation facilities.

The results are tabulated below. Overall, the environmental impacts of cannabis cultivation are variable. Energy demand has the largest impact, making up 16% of B.C. electricity consumption. Local air quality impacts also require attention, with cannabis VOC emissions making up 4% of the Metro Vancouver total. On the other hand, additional wastewater is virtually zero in relation to total Metro Vancouver discharge.

| CATEGORY | ANNUAL ENVIRONMENTAL IMPACT |
|---|---|
| Local Air Quality | 1,745 tonnes VOC |
| Water Demand | 18,520 million litres |
| Energy Demand | 12.6 terawatt-hours |
| Carbon Emissions | 0.16 megatonnes |
| Solid Waste Generation | 9,098 tonnes |
| Wastewater Generation | 161 million litres |

The above values are based on publicly available information with some personal communication with regulatory officers from Metro Vancouver and other jurisdictions. The summary above provides impact estimates based on best judgment using very limited and often highly variable information. Despite the contribution of this report, more rigorous research is needed to aid relevant regulatory bodies in assessing the environmental impact of cannabis cultivation and identifying opportunities for mitigation.

## References


Arnold, Jessica. (2013). “Energy consumption and environmental impacts associated with cannabis cultivation”. (Thesis). Humboldt State University. Retrieved from http://humboldtdspace.calstate.edu

BC Hydro. (2017),  Site C Clean Energy Project, Retrieved from: https://www.sitecproject.com/about-site-c/project-overview

Black, Lester. (2017). “Washington's Weed Industry Has a Million-Pound Waste Problem”. *The Stranger*. Retrieved from https://www.thestranger.com/weed/2017/07/26/25307388/washingtons-weed-industry-has-a-million-pound-waste-problem

Bustic, Van and Jacob Brenner. (2016). “Cannabis (*Cannabis sativa or C. indica*) agriculture and the environment: a systematic, spatially-explicit survey and potential impacts.” *PLoS One. 11(4).*

California Public Utilities Commission Policy and Planning Division. (2017). “Energy Impacts of Cannabis Cultivation: Workshop Report and Staff Recommendations”. Retrieved from: https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/PPD%20-%20Prop%2064%20Workshop%20Report%20FINAL.pdf

Cal NORML (2015). “Cal NORML Challenges Fish & Wildlife Figures on Marijuana Water Consumption”. Retrieved from: https://www.canorml.org/cal-norml-challenges-fish-wildlife-figures-on-marijuana-water-consumption/

Caulkins, Johnathan. (2010). “Estimated Cost of Production for Legalized Cannabis.” *RAND Working Paper Series No. WR-764-RC.*

Cannabis Conservancy. (2018). “Energy Use in the Colorado Cannabis Industry:  Fall 2018 Report” Retrieved from: *https://www.colorado.gov/pacific/energyoffice/atom/134686*

CARB, California Air Resources Board, (2010). Regulation order tables of maximum incremental reactivity (MIR) values. Retrieved from: https://www.arb.ca.gov/consprod/regs/2012/4mirtable50411.pdf.

Cumming, Sheryl. (2019). Metro Vancouver AQCC. Personal Communication about break-up of 2015 VOC emissions inventory.

Deloitte. (2018). "2018 Cannabis Reports". Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/consulting/ca-cannabis-2018-report-en.PDF

Denver Department of Public Health and Environment. (2018). "Cannabis Environmental Best Management Practices Guide". Retrieved from: https://www.denvergov.org/content/dam/denvergov/Portals/771/documents/EQ/MJ%20Sustainability/Cannabis_BestManagementPracticesGuide_FINAL.pdf

Environment and Climate Change Canada. (2014). "Canada's emission trends 2014: annex 2. Table A.6. Retrieved from: https://www.canada.ca/en/environment-climate-change/services/climate-change/publications/emission-trends-2014/annex-2.html

Environmental Protection Agency. Title 40: Protection of the Environment. Part 51, Subpart F: Procedural Requirements. Electronic Code of Federal Regulations. Retrieved from: https://www.ecfr.gov/cgi-bin/text-idx?rgn=div8&node=40:2.0.1.1.2.3.8.1

Humboldt Growers Association.(2010). "Humboldt County Outdoor Medical Cannabis Ordinance Draft". Retrieved from: http://library.humboldt.edu/humco/holdings/HGA2.pdf

Jourabchi, M. (2014). "Electrical load impacts of indoor commercial cannabis production". Retrieved from: https://www.nwcouncil.org/media/7130334/p7.pdf

Leggett, T. (2006). "Review of the World Cannabis Situation." *Bulletin on Narcotics, United Nations Office on Drugs and Crime Volume LVIII, No 1 and 2.*

Mallery M. (2011). "Marijuana National Forest: Encroachment on California Public Lands for Cannabis Cultivation". *Berkeley Undergrad Journal.* 23(2)

Metro Vancouver (2017a). "The 2017 Greater Vancouver Sewerage and Drainage District Environmental Management and Quality Control: Annual Report". Retrieved from: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/2017GVSDD-EMQCAnnualReport.pdf

Metro Vancouver. (2017b). "Recycling and Solid Waste Management - 2017 Report". Retrived from http://www.metrovancouver.org/services/solid-waste/SolidWastePublications/2017SolidWasteManagementAnnualSummary.pdf

Metro Vancouver (2018). "2015 Lower Fraser Valley Emissions Inventory and Forecast: Final Report and Summarized Results. Retrieved from: http://www.metrovancouver.org/services/air-quality/AirQualityPublications/2015LowerFraserValleyAirEmissionsInventory.pdf

Metro Vancouver. (2018). “2017 Water Consumption Statistics Report”. Retrieved from: http://www.metrovancouver.org/services/water/WaterPublications/2017_Water_Consumption_Statistics_Report.pdf”

Mills, Evan. (2012). The carbon footprint of indoor Cannabis production. Energy Policy. 46 pp. 58-67

National Energy Board. (2019). “Provincial and Territorial Energy Profiles – Canada”. Government of Canada. Retrieved from: https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/cda-eng.html”

Northwest Power and Conservation Council. (2014). “Electricity Consumption from Northwest Cannabis Production”.

O’Hare, Micahel., Sanchez, D., Alstone, P. (2013). Environmental Risks and Opportunities in Cannabis Cultivation. *BOTEC Analysis Corporation White Paper.*

Oldham, Jennifer. (2015). “As Pot-Growing Expands, Electricity Demands Tax U.S. Grids”. Retrieved from: http://www.bloomberg.com/news/articles/2015-12-21/as-pot-growing-expands-power-demands-tax-u-s-electricity-grids

Pacific Gas and Electric. (2011). “Greenhouse Gas Emission Factors Info Sheet”. Retrieved from http://www.pge.com/includes/docs/pdfs/shared/environment/calculator/pge_ghg_emission_factor_info_sheet.pdf

Rice, S., Koziel, J.A., (2015). “Characterizing the smell of marijuana by odor impact of volatile compounds: an application of simultaneous chemical and sensory analysis”. *PloS One*. 10(12): pp. 17

Spokane Clean Air Agency. (2017). Personal Communication about raw data from VOC sampling.

Statista. (2018). “National Hockey League – total league revenue from 2005/06 to 2017/18”. Retrieved from https://www.statista.com/statistics/193468/total-league-revenue-of-the-nhl-since-2006/

Statistics Canada. (2012). “Agricultural Water Use in Canada”. Retrieved from: https://www150.statcan.gc.ca/n1/pub/16-402-x/16-402-x2013001-eng.pdf

Sweet, Sarah. (2016). “THE ENERGY INTENSITY OF LIGHTING USED FOR THE PRODUCTION OF RECREATIONAL CANNABIS IN WASHINGTON STATE AND IMPLICATIONS FOR ENERGY EFFICIENCY”. (Thesis). Evergreen State College

Toonen, M., Ribot, S., Thissen, J. (2005). “Yield of illicit indoor cannabis cultivation in The Netherlands”. *Journal of Forensic Science.* 51 (2006): pp 1050–1054.

TRI Environmental Consulting. (2018). “2018 Waste Composition Monitoring Program – Metro Vancouver”. Retrieved from http://www.metrovancouver.org/services/solid-waste/SolidWastePublications/Solid_WasteComposition_Study_2018.pdf

United States Census Bureau. (2012). “Quick Facts: Washington”. Retrieved from: https://www.census.gov/quickfacts/fact/table/WA/PST045218

Vanhove, Wouter & Van Damme, Patrick & Meert, Natalie. (2011). “Factors determining yield and quality of illicit indoor cannabis (Cannabis spp.) production.” *Forensic science international*. Vol. 212 pp. 158-63.

Vanhove, Wouter & Surmont, Tim & Van Damme, Patrick & De Ruyver, Brice. (2012). “Yield and turnover of illicit indoor cannabis (Cannabis spp.) plantations in Belgium.” *Forensic science international*. Vol. 220. 265-70

Van Hook, Curtis. (2012). “Leading California Marijuana Attorney Says Growers Must Focus on Water Conservation”. *PRWEB*. Retrieved from: www.prweb.com/releases/marijuanaattorney/california/prweb9316223.htm

Wan, Curtis. (2019). Project Engineer, Environmental Regulation and Enforcement. Personal communication about cannabis cultivation licenses and facility sizes in Metro Vancouver.

Wang, Chi-Tsan & Wiedinmyer, Christine & Ashworth, Kirsti & Harley, Peter & Ortega, John & Vizuete, William. (2019). “Leaf enclosure measurements for determining volatile organic compound emission capacity from Cannabis spp.” *Atmospheric Environment*. Vol. 199 pp. 80-87

Washoe County Air Quality Division. (2016). Personal Communication about raw data from VOC sampling.

Wiebelhaus, Nancy & Hamblin, D'Nisha & M. Kreitals, Natasha & Almirall, Jose. (2016). “Differentiation of Marijuana Headspace Volatiles from other Plants and Hemp Products using Capillary Microextraction of Volatiles (CMV) coupled to Gas-Chromatography-Mass Spectrometry (GC-MS)”. *Forensic Chemistry*. 2.

Williams, L.E. (2001). “Irrigation of winegrapes in California”. *Practical Winery and Vineyard Journal*

# Appendices

Table A-1: VOC profile of cannabis plants

| HEADSPACE (RICE AND KOZIEL, 2015) | LEAF ENCLOSURE (WANG ET AL. 2019) |
|---|---|
| α-pinene | α-pinene |
| β-pinene | β-pinene |
| β-myrcene | β-myrcene |
| limonene | limonene |
| hashishene | caryophyllene |
| caryophyllene | thujene |
| humulene | camphene |
| β-ocimene | sabinene |
| α-phellandrene | α-phellandrene |
| 3-carene | α-terpinene |
| α-terpinene | p-cymene |
| Terpinolene | cis-β-ocimene |
| Linalool | γ-terpinene |
| α-cadinene | terpinolene |
| | eucalyptol |

*Grey indicates VOC species found across multiple studies/methods

Table A-2: EPA Policy: 40 CFR Section 51 – Definitions

| VOC INCLUDES ANY SUCH ORGANIC COMPOUND OTHER THAN THE FOLLOWING, WHICH HAVE BEEN DETERMINED TO HAVE NEGLIGIBLE PHOTOCHEMICAL REACTIVITY: | |
|---|---|
| Methane | 1,1,1,2,3-pentafluoropropane (HFC-245eb) |
| ethane | 1,1,1,3,3-pentafluoropropane (HFC-245fa) |
| methylene chloride (dichloromethane) | 1,1,1,2,3,3-hexafluoropropane (HFC-236ea) |
| 1,1,1-trichloroethane (methyl chloroform) | 1,1,1,3,3-pentafluorobutane (HFC-365mfc) |
| 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113) | chlorofluoromethane (HCFC-31) |
| trichlorofluoromethane (CFC-11) | 1 chloro-1-fluoroethane (HCFC-151a) |
| dichlorodifluoromethane (CFC-12) | 1,2-dichloro-1,1,2-trifluoroethane (HCFC-123a) |
| chlorodifluoromethane (HCFC-22) | 1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-butane (C4F9OCH3 or HFE-7100) |
| trifluoromethane (HFC-23) | 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3- |

| | |
|---|---|
| | heptafluoropropane ((CF3)2CFCF2OCH3) |
| 1,2-dichloro 1,1,2,2-tetrafluoroethane (CFC-114) | 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluorobutane (C4F9OC2H5 or HFE-7200) |
| chloropentafluoroethane (CFC-115) | 2-(ethoxydifluoromethyl)-1,1,1,2,3,3,3-heptafluoropropane ((CF3)2CFCF2OC2H5) |
| 1,1,1-trifluoro 2,2-dichloroethane (HCFC-123) | methyl acetate |
| 1,1,1,2-tetrafluoroethane (HFC-134a) | 1,1,1,2,2,3,3-heptafluoro-3-methoxy-propane (n-C3F7OCH3, HFE-7000) |
| 1,1-dichloro 1-fluoroethane (HCFC-141b) | 3-ethoxy- 1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl) hexane (HFE-7500) |
| 1-chloro 1,1-difluoroethane (HCFC-142b) | 1,1,1,2,3,3,3-heptafluoropropane (HFC 227ea) |
| 2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124) | methyl formate (HCOOCH3) |
| pentafluoroethane (HFC-125) | 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-trifluoromethyl-pentane (HFE-7300) |
| 1,1,2,2-tetrafluoroethane (HFC-134) | propylene carbonate |
| 1,1,1-trifluoroethane (HFC-143a) | dimethyl carbonate |
| 1,1-difluoroethane (HFC-152a) | *trans*-1,3,3,3-tetrafluoropropene |
| parachlorobenzotrifluoride (PCBTF) | HCF2OCF2H (HFE-134) |
| cyclic, branched, or linear completely methylated siloxanes | HCF2OCF2OCF2H (HFE-236cal2) |
| acetone | HCF2OCF2CF2OCF2H (HFE-338pcc13) |
| perchloroethylene (tetrachloroethylene) | HCF2OCF2OCF2CF2OCF2H (H-Galden 1040x or H-Galden ZT 130 (or 150 or 180)) |
| 3,3-dichloro-1,1,1,2,2-pentafluoropropane (HCFC-225ca) | *trans* 1-chloro-3,3,3-trifluoroprop-1-ene |
| 1,3-dichloro-1,1,2,2,3-pentafluoropropane (HCFC-225cb) | 2,3,3,3-tetrafluoropropene |
| 1,1,1,2,3,4,4,5,5,5-decafluoropentane (HFC 43-10mee) | 2-amino-2-methyl-1-propanol |
| difluoromethane (HFC-32) | t-butyl acetate 1,1,2,2- Tetrafluoro -1-(2,2,2-trifluoroethoxy) ethane |
| ethylfluoride (HFC-161) | *cis*-1,1,1,4,4,4-hexafluorobut-2-ene (HFO-1336mzz-Z) |
| 1,1,1,3,3,3-hexafluoropropane (HFC-236fa) | perfluorocarbon compounds which fall into these classes: |
| 1,1,2,2,3-pentafluoropropane (HFC-245ca) | **(i)** Cyclic, branched, or linear, completely fluorinated alkanes |

| | |
|---|---|
| 1,1,2,3,3-pentafluoropropane (HFC-245ea) | **(ii)** Cyclic, branched, or linear, completely fluorinated ethers with no unsaturations |
| | **(iii)** Cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations and |
| | (iv) Sulfur containing perfluorocarbons with no unsaturations and with sulfur bonds only to carbon and fluorine |

### Table A-3: Canadian Energy Mix and Fuel-Wise Emissions Factors

| FUEL TYPE | % OF TOTAL GENERATION | EMISSIONS FACTOR (KG $CO_2$/KWH) |
|---|---|---|
| Solar | 0.5 | 0 |
| Wind | 4.7 | 0 |
| Hydro | 58.8 | 0 |
| Nuclear | 14.6 | 0 |
| Biomass | 2.0 | 0.0165 |
| Natural Gas | 9.6 | 0.180 |
| Oil and Diesel | 0.5 | 0.269 |
| Coal | 9.3 | 0.327 |