BOTEC
Analysis Corporation

Environmental Risks and Opportunities in Cannabis Cultivation

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BACK OF THE ENVELOPE CALCULATIONS

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Executive Summary

The most important environmental cost of marijuana production (cultivation of cannabis) in the legal Washington market is likely to stem from energy consumption for indoor, and to a lesser extent, greenhouse, growing. Nearly all of this energy is electricity used for lighting and ventilating, and the energy bill can amount to 1/3 of production costs. While the price of electricity provides growers a market signal for efficient production, it does not reflect the climate effect of greenhouse gas released by electricity production nor other "externalities"—the value of environmental and other harms that are not included in the price of goods.

Though electricity in the Pacific Northwest is some of the lowest-GHG-intensity in the US, growing cannabis could still have a significant "carbon footprint." Marginal electricity consumption (in addition to current levels) is much more carbon-intensive than average consumption in the region, since daily peaks are usually met with natural-gas fired generation rather than less GHG-intensive "baseload" hydro-power generation. Increased cannabis cultivation indoors will likely be a noticeable fraction (single-digit percentages) of the state's total electricity consumption. Indoor cultivation that concentrates lighting in off-peak electricity periods at night will have a much smaller climate effect than if lighting is provided during peak electric use times. Greenhouse production requires much less energy, and for outdoor cultivation energy is an insignificant fraction of production costs.

Other environmental effects of cannabis are also worth attention, including water use, fertilizer greenhouse-gas emissions, and chemical releases, but are typical of similar horticultural and agricultural operations and should not be primary concerns of the Liquor Control Board (LCB). Even the climate effects are much less important than some other risks (and benefits) of a legal cannabis market. They should be mitigated *when that can be done without substantial sacrifice of other goals*, as appears to be the case.

Policies available to the LCB to respond to environmental concerns include adjusting the excise tax on indoor-cultivated marijuana to reflect about 9c per gram worth of global warming impact, labeling low-GHG marijuana as such, encouraging efficient LED lighting development and use, allowing outdoor cultivation, making energy-efficient production a condition of licensing, and leading other state agencies in the development of better technologies and diffusion of best practices to growers. If legal cannabis production moves toward national acceptance, the importance of developing environmentally sound production practices will grow, and policies made now in Washington and Colorado, the early adopters, may shape practices in the new industry nationwide and, develop in-state capacity to meet the equipment and expertise needs of the national industry.

Introduction

This memo reviews the main environmental effects of cannabis cultivation (we do not analyze processing or distribution), emphasizing energy and climate issues with a briefer review of other considerations (water use, chemicals, etc.). We find that the predominant environmental concern in marijuana production is energy use for indoor production (less importantly for greenhouse production) and in particular the climate effects of this energy use. We then turn to the main opportunities for growers to reduce these environmental consequences, finding that the most important is substituting greenhouse and outdoor production for indoor operations, and managing indoor production for reduction of electricity use and especially electricity use during the day. We also sketch some ways the Liquor Control Board (LCB) can encourage better environmental practice in this industry.

Indoor cannabis production is very energy-intensive compared to other products on a per-pound basis, less so per unit value. However, environmental risks from cannabis production are nowhere near as salient a part of the overall policy framework for marijuana as (for example) the explosive and toxic hazards of methamphetamine, or the environmental costs of large-scale agriculture, mining, metallurgy, and other industries. Nor should legal cannabis production, licensed and inspected, generate the variety or degree of environmental damage inflicted by illegal production (Barringer 2013). Our bottom line is that environmental considerations should not be a major component of marijuana policy, but are worth explicit attention and policy design.

Cannabis culture

This section briefly discusses the main methods of cannabis production, in particular growing the plants from which marijuana and other psychoactive materials are derived.

The cannabis varieties of psychoactive interest are dioecious annuals adapted to climates in the warm-temperate to subtropical range and grown primarily for the flowers of the female plant. Cultivation requirements are determined by these properties and the plant's flowering response to a prolonged diurnal dark period.

Cannabis can be grown from seed, with male and female plants separated after germination, or from cuttings (clones). Rooting clones assures an all-female stand of plants and preserves the respective use properties of the many varieties that have been developed.

The seedlings are grown to the desired size and maturity in a *vegetative phase* and induced or allowed to flower. When unfertilized flowers reach the desired size, they are harvested for further processing. Growing can be hydroponic (in water with dissolved nutrients), in soil (usually outdoors), or in an irrigated artificial growing medium for mechanical support.

Light is provided by the sun outdoors or in a greenhouse, or with electric lighting indoors or sometimes in a greenhouse. Indoor growing requires ventilation, sometimes filtered to reduce odor, to remove heat and humidity. CO_2 may be provided to accelerate growth, usually by venting a propane or natural gas flame into the plants' enclosure

Weeds may be controlled with herbicides outdoors; pests including insects, disease, and fungus may be controlled with chemicals or mitigated with design and management of growing chambers. Cannabis can be grown organically, without chemical fertilizers or pesticides, but at higher cost and usually lower yield.

The high specific value of cannabis flowers, and the desire of illegal growers to minimize and hide the area used for cultivation, has nurtured a labor-intensive, space-concentrated practice for indoor production analogous in some ways to horticulture of orchids and other delicate and exotic plants. This practice may change significantly in a legal operating environment.

Environmental consequences of cannabis production

Energy

The most significant environmental effect of cannabis production, and the one that varies most with different production practices, is energy consumption, especially fossil energy use with climate effects from release of greenhouse gas. Indoor-grown marijuana is an energy-intensive product by weight, using on the order of 2000 kWh per pound of product (for comparison, aluminum requires only about 7 kWh per pound). However, the high unit value of marijuana (approximately $2,000/lb. at wholesale[1]) compared to aluminum (~$0.90/lb)[2] means energy is a much smaller fraction of product cost: accounting for the value of the products, it takes 8,000 kWh to make $1,000 worth of aluminum vs. 1,000 kWh for $1,000 of marijuana. Glass is considered an energy-intensive product, but energy costs represent only about a sixth of glass-production costs, about half the energy-intensity of indoor-grown cannabis.

Total current marijuana consumption in Washington is estimated at about 160 metric tons per year; if this quantity were to be grown indoors with typical practices, marijuana cultivation would increase the state's electricity demand by about 0.8% (using 2010 as a baseline year). Mills estimates that California indoor cultivation currently uses 3% of all electricity in the state (note that California has higher electricity prices than Washington and lacks the electric-intensive industry cluster of the northwest) (Mills 2012). While precise estimates are impossible, ma-

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[1] The wholesale price of marijuana is highly uncertain and currently subject to significant market distortion from the illegal nature of the product. The price in a legal-market framework is likely to be lower.

[2] Based on Aluminum futures prices on the London Metals Exchange http://www.lme.com/metals/non-ferrous/aluminium/

rijuana cultivation will be a non-trivial though small component of Washington energy consumption: significant enough to be worth reducing where possible without offsetting losses on other dimensions of value.

Indoor growing

Growing marijuana indoors requires careful and energy-intensive replication of ideal outdoor conditions, including provision of light, fresh air ventilation, cooling (required due to the energy density of lighting and ventilation) and control of pests and fungal agents. Indoor growing allows high profits from the typically high-grade product that is produced under controlled conditions and is also perceived by many growers as more secure and stealthy. Indoor cultivation can also achieve multiple harvests per year; growing marijuana with electricity divorces the process from the constraints of seasonal growing and typical harvest cycles.

Figure 1: Indoor Cannabis culture

An extensive peer-reviewed study details the energy consumption of present day indoor production facilities. Lighting levels are elevated 500 times greater than (for example) recommended for reading, while ventilation occurs at 60 times the rate in a modern home. Power densities are about 2000 W/m^2 of growing area (Mills 2012)[3].

A "grow house," or residential building converted to support cannabis cultivation, can contain 50 – 100 kW of installed lighting. Mills estimates that lighting alone has a power density of approximately 400 W/m^2. Lighting often contains a mixture of metal halide (MH) and high-pressure sodium (HPS) lamps, which must be replaced every 3-4 growing cycles.

CO_2 generators, fueled by natural gas or propane, are often used to raise indoor CO_2 levels and boost plant productivity. Concentrations of CO_2 are often raised to four times natural levels, or ~1600 ppm(v). Mills estimates that CO_2 generators are responsible for 2% of the overall carbon footprint of indoor cultivation. However, given the beneficial effect of heightened CO2 concentration on plant yield, this practice may decrease overall environmental impact per unit of product.

Illegal indoor production often entails off-grid diesel or gasoline fuel generators. Per unit greenhouse gas (GHG) emissions from these generators are often 3-4 times greater than the relatively low-carbon electricity available in the Pacific Northwest or California. Spills of diesel fuel can pollute local water sources and harm aquatic life.(Gurnon 2005) We expect that legal production will avoid nearly all use of off-grid generation.

The energy costs of indoor cultivation can account for over 1/3 of total costs for representative production systems depending on a range of factors, including the yield of the growing operation and the cost of electricity (growers in private residences pay much higher prices for electricity than those with commercial or even industrial accounts that would be typical in a legal market framework)(Arnold 2013). Arnold also worked with several Northern California dispensaries with indoor production facilities to determine their energy and carbon intensity. She found that each of three dispensaries had an energy intensity of 2,000 kWh / lb. product, and carbon intensity of 1,000 lb. $C0_2$/ lb. based on the average grid mix for the area. These figures are lower than Mills's, and probably represent energy savings from economies of scale in larger production operations.

Other estimates of lighting intensity are in similar range: (Caulkins 2010) estimates lighting intensity of 430 W/ m^2, while typical lighting systems [4] are sold at intensity of ~650 W/m^2. As the layout and spacing of each production facility will differ, these figures will vary. Energy required for ventilation varies more widely; Arnold finds that 9-15% is used for ventilation in a large facility, while Mills estimates that 27% of indoor production energy is for ventilation.

[3] While most of the calculations in Mills have strong face validity, some of its underlying assumption about total marijuana production in the country have been questioned (e.g., Kilmer et al., 2011; Caulkins et al., 2012). We have used this study mainly for per-unit estimation.

[4] A typical lighting system can use 1000W of lighting power for 16 ft^2 of production area.

Greenhouse

Greenhouse cultivation demands significantly less energy than does indoor cultivation, though actual energy intensities vary widely. As sunlight is used for plant photosynthesis, most greenhouse energy consumption is due to heating, though a well-designed greenhouse with built-in thermal inertia can keep itself warm most of the time by sunlight alone. Lighting can be augmented with lamps and may be needed to match the yields from fully indoor growing, particularly in the winter months.

As a point of reference, Belgian greenhouses have an energy intensity for a growing cycle of approximately 1000 MJ/m^2, which Mills notes is about 1% of his estimate for indoor production (De Cock and Van Lierde 1999). Winter heating in a double plastic greenhouse in Serbia requires 9-14 MJ / m^2 (Djevic and Dimitrijevic 2009). The greenhouse was held between 53-59 °F, while daily temperatures in the region average ~30-40 °F in winter months (Unsigned). This is similar to the climate in much of Washington State.

Several factors affect energy consumption in greenhouses, including greenhouse shape, construction material, as well as heating, shading, and lighting practices. It is unclear whether cannabis growers will choose to heat greenhouses during winter months to increase production, but the high value of cannabis will make it more attractive to do so for that crop than it is for other agricultural products.

A greenhouse for horticulture can include a wide range of design and operational features at correspondingly varying capital and operating costs. The enclosure itself can be plastic film, in one or two layers, over a frame, or glass (single or double pane) in a metal or wood construction. Ventilation is usually by gravity where panes in the roof can be opened, and mechanical shades, automated or manual, can provide photoperiod control and limit heat gain. Growing media include soil, media, or hydroponic tanks. Greenhouse operation has benefited from years of experience growing high-value crops like flowers and out-of-season vegetables and the technology should be easily adopted for cannabis.

Outdoor

Field production of psychoactive cannabis is environmentally similar to growing hemp (non-psychoactive cultivars of cannabis) or other nitrogen-hungry field or row crops. Environmental climate effects include small fossil energy inputs per unit of product, mostly diesel fuel for cultivation, indirect energy use for fertilizer production, and fertilizer N_2O release. We have not estimated the full energy implications of field production in the current draft except to note that they are (i) *very* small compared to greenhouse or indoor production (ii) variable in response to agronomic practices like crop rotation and no-till cultivation that have been developed for other crops. In any case, the small acreage required for Washington MJ production would probably otherwise be used for other row or specialty crops with similar energy requirements.

Greenhouse gas and climate

The energy required for indoor growing (and the smaller amounts used for other methods) almost always leads to greenhouse gas (GHG) pollution that increases global warming. We discuss GHG intensity (climate effect) separately from total energy for two reasons: first, because optimizing indoor production can greatly affect the GHG intensity of cannabis cultivation independently of total energy intensity (see below); second, because climate effects are the major unregulated and unpriced environmental consequences of this industry (and many other industries). Growers pay for electricity and all other fuels, and hence see a built-in incentive to reduce their use to an *efficient* level, but using a more- rather than less-GHG-intensive form of energy does not cost the grower any more, and this distortion of efficient incentives–what economists call a *market failure*–is a standard justification for government action. Charging an additional fee for the GHG from electricity consumption for indoor growers (for example) would fix the market failure and provide the correct incentives for innovation. While the climate impact of cannabis production in Washington will be modest, choices made in Washington now will help shape the development of production technology nationwide and perhaps worldwide, if the movement toward allowing legal production and sale continues.

The Washington electric grid is unusually "low-carbon", mostly hydroelectric and nuclear with only about 17% fossil-fueled, mostly natural gas http://www.eia.gov/environment/emissions/state/analysis/pdf/stateanalysis.pdf (table 4). The average GHG intensity of electricity produced in the state is 135 kg CO_2/MWh. However, the state is inter-tied with the Western USA Grid however, which has a higher carbon intensity, and additional loads anywhere on the Western Grid have an impact "on the margin" that is different from the average of the whole grid. The average marginal climate effect of additional electricity demand in the Western Electricity Coordination Council (WECC) region is 486 kg CO_2 / MWh (Siler-Evans, Azevedo et al. 2012), three times the average for the State. The real impact of additional electricity use from cannabis will be close to the marginal factor for WECC, and there is good reason to use marginal costs as indicators of value in cases like this because the consumer's decision to use more electricity rather than less is intrinsically marginal.

Overall, Mills estimates that carbon dioxide emissions are approximately 4600 kg CO_2 / kg indoor cannabis produced but this is based on average national electric GHG-intensity; the figure for Washington production will be much less for the average grid mix (but similar if one takes the marginal WECC emissions factor as discussed above). Using figures derived from (Mills 2012), the Okanogan Cannabis Association estimates that the indoor production of 186 thousand pounds of cannabis, one estimate of state production, would release about 0.4 million metric tons of CO_2(Moberg and Mazzetti 2013), just under one-half of one percent of the total for the state as of 2008.

Indoor production variations could lead to a significant amount of GHG reduction from these average estimates, in particular by concentrating the light periods during the nighttime when demand is low and almost entirely supplied by the low-GHG Northwest baseload plants. This timing also reduces cooling costs from lower outdoor temperatures and the ability to use fresh outside air for cooling.

One set of estimates for the relative contribution of each process to greenhouse gas emissions of indoor cultivation, as well as other process assumptions, is shown in Appendix 1.

Comparison

Using values cited above, we are able to compare high and low estimated values for the energy and GHG intensity of indoor, greenhouse, and outdoor cultivation.

	Energy kWh/kg		**GHG kgCO$_2$eq/kg**	
	Low	High	Low	High
Outdoor	(minimal)	(minimal)	(minimal)	(minimal)
Greenhouse	6	580	1	282
Indoor	4400	6100	590	3000

Table 1 - On-site energy and climate intensity of different cultivation methods per kilogram of product (marijuana).

At $30/tonne CO_2e, a common assumed social cost of GHG emissions, these estimates imply climate damage worth between about 1c and 9c per gram of product for indoor growing, less than 1c for other methods. Even the highest figure represents a modest share (no more than a few percent) of the total cost of production: an issue worth thinking about, but not one large enough to require substantial sacrifices of other goals.

Other Environmental Considerations

Outdoor

Field production of cannabis is environmentally similar to growing hemp or other nitrogen-hungry field or row crops. Environmental effects include small fossil energy inputs per unit of product, mostly diesel fuel for cultivation; fertilizer runoff and N_2O release, water contamination, soil carbon sequestration, and release of toxic chemicals (herbicides, fungicides, and pesticides) are the other important environmental considerations and only fertilizer manufacturing energy, N_2O and soil carbon have important climate implications. We have not estimated the climate effects of field production except to note that they are (i) very small compared to greenhouse or indoor production (ii) variable in response to agronomic practices like crop rotation and no-till cultivation that have been developed for other crops.

Fertilizer

Cannabis requires a nitrogen-rich soil environment. Specific application rates, however, are described only in grey literature. Cervantes lists the following application schedule for hydroponic and soil growth, provided by General Hydroponics (Cervantes 2006). Figures are given in ml. fertilizer / l. water.

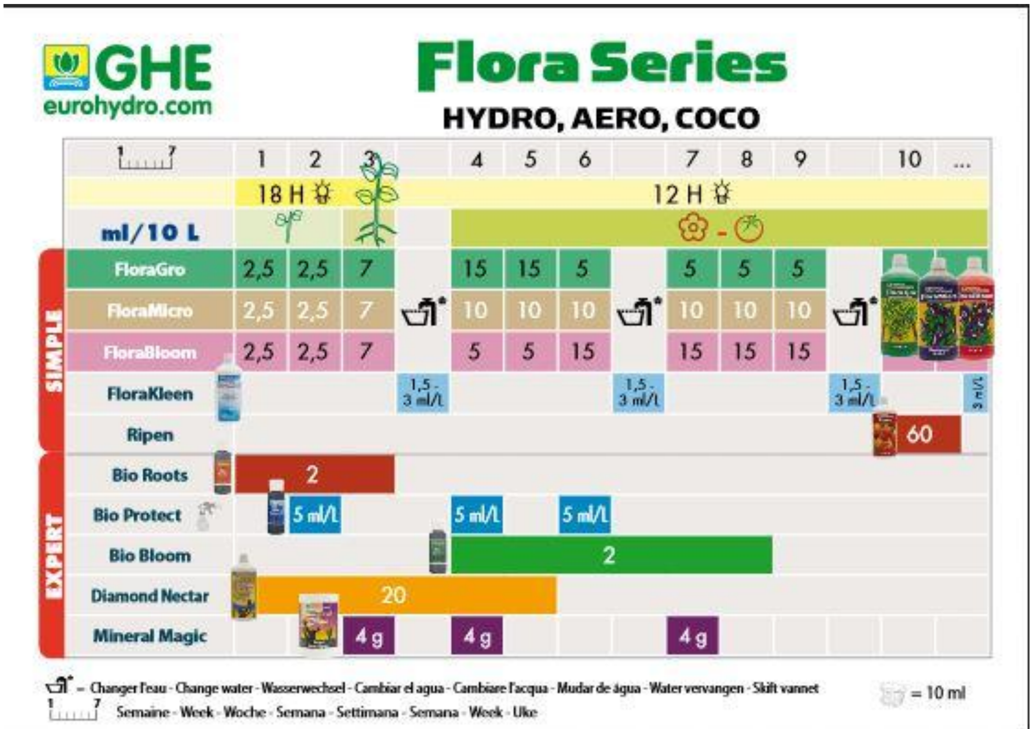


Figure 2: Fertilization recommendations (current version of GHE chart reproduced in (Cervantes 2006), at http://www.eurohydro.com/publications/publications/APPLICATION%20CHARTS/GB/CHART-FLORA-SERIES-GB.pdf

Soil-grown cannabis requires fewer fertilizer inputs than hydroponic cannabis. Notably, General Hydroponics recommends lower hydroponic fertilizer application rates for soil-grown cannabis.

Hemp

Much more information about fertilizer application is available for hemp, an industrial form of cannabis sativa used for industrial and foodstuff products. Hemp has similar nutrient requirements to corn, and requires nitrogen in particular. The British Columbia Ministry of Agriculture and Food (BCMAF) recommends the following maximum application amounts:

Nutrient	**Application Amount (kg/ha)**
Nitrogen (N)	120
Phosphorous (P)	100
Potassium (K)	160

Table 2: Fertilizer recommendations for hemp (from BCMAF)

Much of this nutrient draw returns to the soil. Consensus among agriculture researchers is that hemp requires a high level of nutrients compared to other crops.

Oregon State University has undertaken an extensive study of the feasibility of industrial hemp production in the Pacific Northwest , including Washington. They note that most research maintains that only soils in high state of fertility produced good crops of hemp. In particular, they recommend adequate application of nitrogen and phosphorus (practices that put streams and groundwater at risk of pollution). They provide the following summary of existing literature (Ehrensing 1998):

Country	Year	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
United States	1952	60	30	40
Spain	1955	60	100	70
Italy	1956	40-60	100	70
Netherlands	1957	100-200		
Rumania	1961	50-70	30-60	
Bulgaria	1964	120	90	60
Netherlands	1964	120	80	160-180
USSR	1965	150	90	120
Netherlands	1966	120	100	100
USSR	1966	120	90	90
Rumania	1966	50	100	
USSR	1968	120	90	90
South Korea	1968	100	60	80
USSR	1969	120	90	90
Italy	1975	75-150		
Denmark	1976	140		
France	1982	100-140	80-120	160-200
Poland	1995	90-120	70-100	150-180
United Kingdom	1995	120	100	160

Table 3: Hemp Fertilization Reports from (Ehrensing 1998)

In estimating the cost of hemp production in the Pacific Northwest, OSU applies a fertilization rate of 600 lb. / acre of 16-16-16 (16% each elemental N, phosphate (P_2O_5), and potash (K_2O)) fertilizer.

The Reason Foundation similarly reports application rates in Canada of 55-80 lb. / acre and 30-40 lb. / acre phosphate (Smith-Heister 2008).

Water

Indoor

Indoor cultivation of cannabis is water-intensive, particularly when it is hydroponic. Mills estimates that one cultivation room (22 m^2) requires 151 L / day (Mills 2012). This is equivalent to 2.5 m of water per year (98 in. / yr.) of application. This level of water application is much higher (per unit of growing area, not per volume of crop) than traditional soil-grown water application and higher than reported for other crop hydroponic culture (Bradley et al 2001, Wheeler et al 1999).

Growing water is not only lost through evapotranspiration in a warm growing room, but also becomes contaminated with algae and otherwise and needs occasional replacement. It is high in nitrogen and phosphorus and if disposed in storm drains when it contributes to water body eutrophication; in sewers it imposes an additional treatment load. This issue is recognized in the grey literature as a concern for growers, for example at http://boards.cannabis.com/hydroponics/156247-hydroponic-wastewater-disposal.html .

Water use and fertilizer runoff to streams or groundwater is also a concern for outdoor cultivation as for any crop (nitrogen runoff from the corn belt, for example, has caused the famous "dead zone" in the Gulf of Mexico). Illegal growing has had damaging effects as when water is illegally diverted through PVC pipes to nearby grow operations, with negative effect on pH, stream flow, water temperature, and nutrient content (Shafer 2012),. This is another environmental cost that a legal regime may avoid.

Hop cultivation

To understand the water consumption of outdoor cannabis cultivation, we will infer from two other crops: hops and hemp. Hemp is taxonomically the same species as psychoactive cannabis; hops is a different species of the family *Cannabinaceae*.

Research at Washington State University indicates that 300-450 gallons of water are needed to produce a pound of hops in the Yakima Valley of Washington. In 1992, all hop acreage in Washington was irrigated (Zepp and Smith 1995). Hops in the Yakima Valley generally consume about 28 inches of water per year, though annual application can exceed 50-60 inches (Extension). 75-80% of total annual water use occurs after mid-June, particularly in late July and early August, with maximum daily water uses of about .5 in / day. These numbers should only serve as guidance: soil type contributes to water holding capacity, while irrigation methods determine frequency and volume.

Hemp cultivation

BCMAF estimates that hemp grown in British Columbia requires 12-15 in. (30-40 cm) of water per growing season or rainfall equivalent (Food 1999). Hemp cultivation in the UK requires 20cm of precipitation per growing season (Cherrett, Barrett et al. 2005).

OSU discusses the water and irrigation requirements of hemp at length, finding that "hemp will almost certainly require irrigation to reliably maximize productivity in the region. The requirement for supplemental irrigation will place hemp in direct competition with the highest value crops in the PNW [Pacific Northwest], limiting available acreage." The OSU report also notes that hemp yield is strongly dependent on the amount of rainfall during June and July (Ehrensing 1998).

As large-scale hemp production has generally been centered in areas with significant rainfall, very little information is available about hemp irrigation. While 33% of cropland in the PNW is irrigated, only 20.5% of cropland in Washington was irrigated in 1992. The PNW faces water deficits, and new irrigation is unlikely.

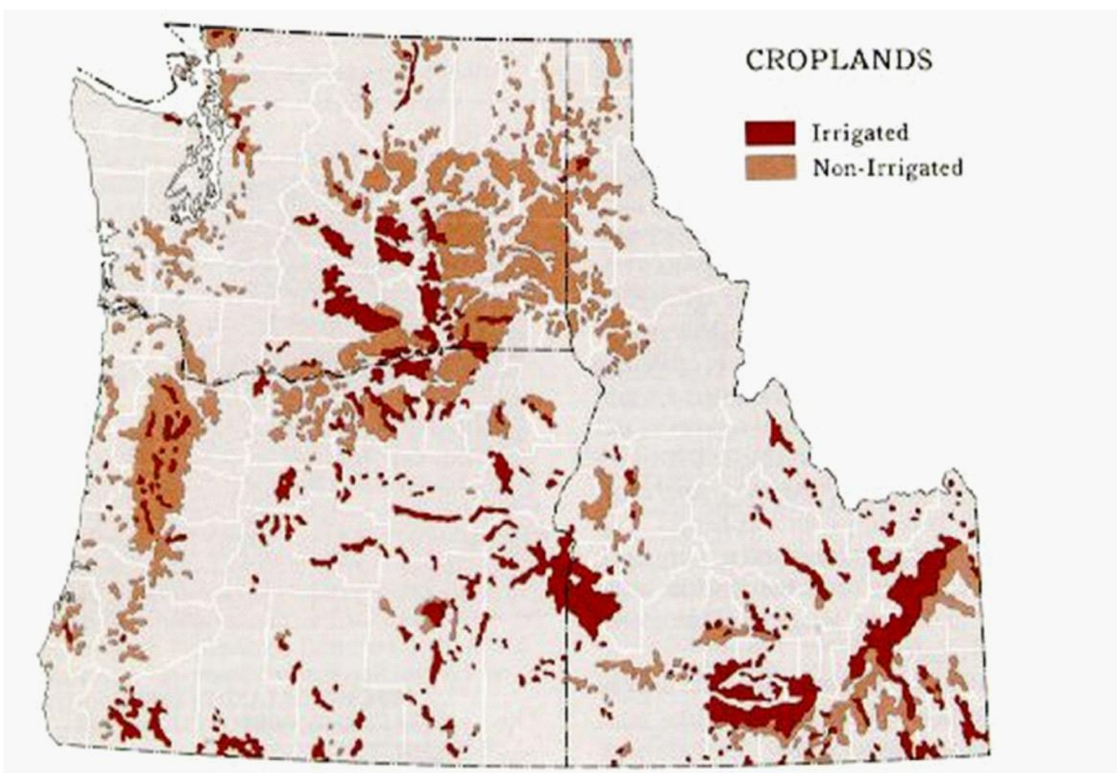


Figure 3: Distribution of irrigated and non-irrigated cropland in the PNW from (Jackson and Kimmerling, 1993)

Table 4. Cropland area in the Pacific Northwest in acres (1992 Census of Agriculture).

	Irrigated	Non-Irrigated	Total	% Irrigated
Idaho	3,260,006	3,041,856	6,301,862	51.7
Oregon	1,622,235	3,415,529	5,037,764	32.2
Washington	1,641,437	6,357,982	7,999,419	20.5
Total PNW	6,523,678	12,815,367	19,339,045	33.7

OSU believes that hemp cultivation will probably occur west of the Cascades because of water availability:

> With early spring planting, it may be possible to grow hemp using available soil moisture and rainfall in some areas west of the Cascades, much like spring cereal grains. Risks associated with such production will be high and yields may be quite variable from season to season … Reliable irrigation can, however, reduce weather risks associated with rain-fed production. Irrigation is not only an additional economic cost of production, but is also an environmental concern, especially considering recent controversies surrounding agricultural water use and increasing demand for in-stream water rights in the PNW (Ehrensing 1998).

Precipitation in Washington is very limited east of the Cascade Mountains. However, the state's extensive infrastructure of dams and irrigation in that region probably affords ample water for the small acreage that may be devoted to marijuana, and the climate is more suitable during the summer.

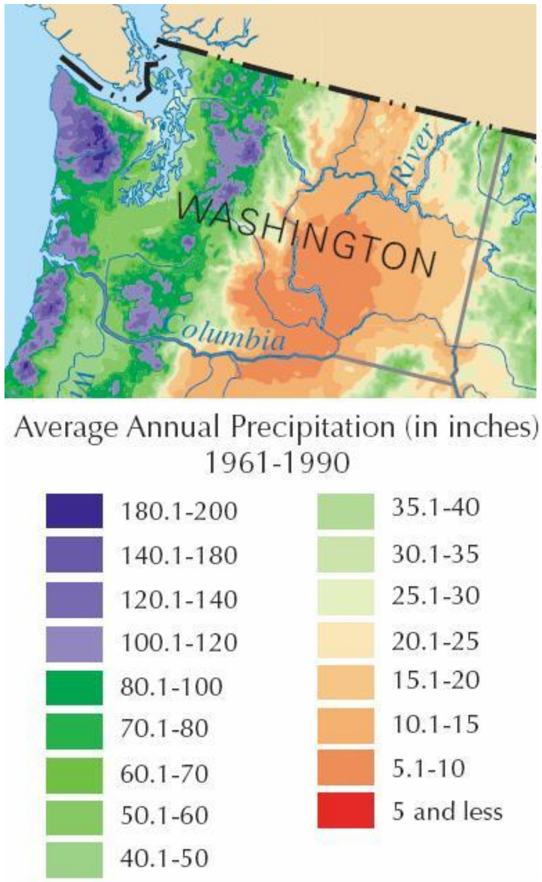


Figure 4: Rainfall in Washington

Pesticides/herbicides/fungicides

Under draft LCB regulation, all usable marijuana for sale in the State of Washington must carry a warning that discloses all pesticides, herbicides, and fungicides or other compounds used for pest control or plant disease in production or processing (2013). *Current indoor cultivation practices* in the illegal framework often employ pesticides and herbicides (Cervantes 2006). Control of chemical residues in cannabis products is considered in another report in this project; the environmental issues are only application drift and water (runoff and groundwater) pollution by agricultural chemicals (but see below regarding illegal vs. legal production general environmental issues).

Wildlife

Endangered species candidates like the fisher, which populate the Pacific Northwest, can be harmed by rodenticides used for marijuana cultivation. Research has linked rat poisons used for illegal marijuana cultivation to fisher death near illegal cannabis cultivation. Rodenticides such as brodifacoum may also affect owls, martens, and foxes (Gabriel et al 2012) We expect that legal culture and WDoE or LCB regulation addressing pesticide use would lessen this environmental impact.

Hemp cultivation

No pesticides or herbicides are registered for hemp or cannabis. BCMAF notes that hemp is less burdened by pests than are other crops, while weeds can be reduced to virtually zero under a dense hemp canopy (Food 1999). The OSU researchers concur: they find that herbicides and pesticides are not commonly used in hemp production, and significant crop losses from pests are not common. Because of these qualities, OSU believes that hemp can be used for weed suppression, noting "Weed suppression with minimal pesticide use is potentially one of the greatest agronomic and environmental benefits of growing hemp in rotation with other crops." Birds, however, feed voraciously on cannabis seeds and their feeding can lead to substantial crop losses (Ehrensing 1998).

OSU cautions that the introduction of new crops such as hemp to the PNW region can result in unforeseen pest problems: "High-density planting, increased fertilizer use, and irrigation have often increased incidence of pest problems in other crops, and such problems should be anticipated with intensive hemp production."

The following pests are commonly associated with hemp:

Pseudomonas syringae pv. cannabina (bacteriosis of hemp)

Xanthomonas campestris pv. cannabis (leaf spot of hemp)

Fusarium oxysporum f.sp. cannabis

Pseudoperonospora cannabina (downy mildew of hemp)

Orobanche spp. (broomrape) (Cherrett, Barrett et al. 2005)

Other Toxics

Heavy metal and toxins from lighting

Lighting materials used in indoor cannabis cultivation have environmental risks if not properly managed for disposal. High-intensity discharge (HID) bulbs cost about $5 each to recycle, so they present an incentive for improper (illegal) disposal. Each bulb contains approximately 30 mg of mercury and other toxins. Mercury is a neurotoxin, and is recognized as extremely toxic, particularly in gaseous form. The Okanogan Cannabis Association estimates that indoor cultivation of cannabis could produce 46,000 HID bulbs each year in Washington (Moberg and Mazzetti 2013).

Using productivity assumptions in Mills, we estimate that there is the potential for 30 mg of mercury pollution per kg of cannabis product if proper disposal is not practiced. However, many other industrial and municipal lighting applications generate used lamps that need management outside the standard municipal waste stream and the existing recycling/disposal system could serve as well for cannabis lighting waste.

Legal vs. illegal cultivation

Rapid expansion of illegal outdoor marijuana cultivation in northern California, including cultivation on public land, has become recognized as a source of serious environmental damage, from wildlife poisoned by pesticides to over-drafted and polluted rivers to deforestation and erosion (Shafer 2012; Barringer 2013). As mentioned previously, spills of diesel fuel often pollute local water sources. The *North Coast Journal* describes the diesel generators often employed for off-grid electricity production in Humboldt County:

> *The diesel generators supplying power for the 1,000-watt grow lights can be as big as a small pickup truck. They are sometimes buried underground, which can be a fire hazard, or rigged with plastic water tubing instead of proper fuel lines. They are often placed in dubious locations, such as right beside creek beds -- greatly increasing the potential for contaminated water -- because the depth and the surrounding trees help to muffle the machines' drone. Some growers even use water tanks to store the diesel fuel, officials said.(Gurnon 2005)*

An important environmental advantage of legal, licensed, cannabis production will be its displacement of environmentally damaging practices by criminal and unregulated parties. We are not able to quantify these benefits but believe them to be significant.

Options for Environmental Protection

This section highlights management practices that can reduce the environmental footprint of cannabis production.

Energy-Efficiency Measures

Outdoor cultivation of cannabis does not raise important energy issues different from other crops. Conventional good agronomic practice such as low-till/no-till, erosion and runoff control, careful control of nitrogen application and timing, integrated pest management, and the like all apply and expertise in these practices is available from county agents and extension services. It is unlikely that the LCB will want to develop this kind of expertise or micromanage outdoor growing for environmental effects.

Excellent guides exist for energy efficiency measures in greenhouses, for example (Bartok 2005). In particular, greenhouse design should consider the effects of glazing materials on heat loss and light transmission, ways to reduce infiltration and nighttime heating losses, greenhouse heating units, the effect of heat distribution on heating costs, ways to maximize space utilization, using efficient circulation and ventilation fans, and how supplemental lighting can reduce energy requirements (Sanford 2010). Energy consumption involves tradeoffs with plant yield and other agronomic needs. Given the high value of cannabis, growers face a strong incentive to use more energy to increase yields than growers of other products.

Efficient greenhouse design is strongly dependent on location and climate, but several themes for good design emerge. Sanford 2010 recommends high efficiency condensing heaters, effective space utilization, basket fans for air circulation, control systems, and energy audits to reduce consumption. In particular, curtain systems can dramatically reduce energy costs. Curtain systems also allow growers to tightly control the amount of light their plants receive, enabling photo-deprivation and other advanced growing techniques. (Sanford 2010a; Sanford 2010)

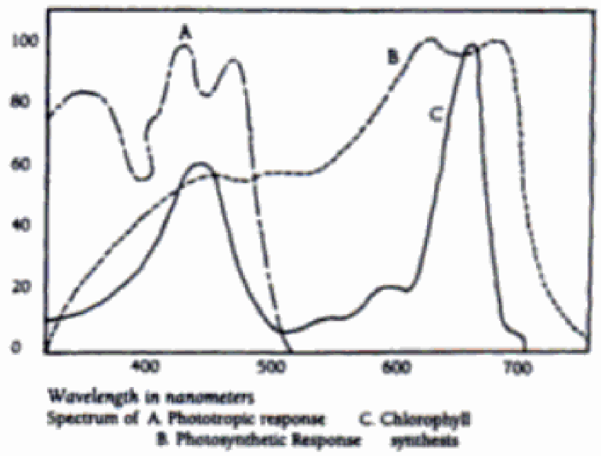
Indoor operations occur in buildings covered by existing Washington building regulations and conventional energy conservation practices such as insulation. The most important opportunities for environmental benefit lie in more efficient lighting equipment and timing to avoid peak use periods.

LEDs for indoor cultivation

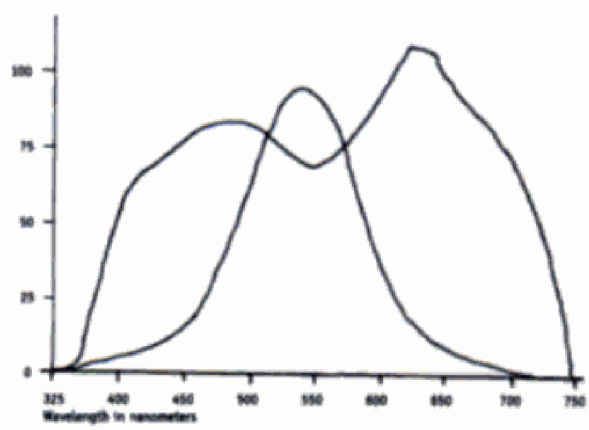
Light-emitting diodes (LEDs) have several advantages over high intensity discharge (HID) or high pressure sodium (HPS) lighting: lifetimes in excess of 100,000h, small size, specific wavelength, adjustable light intensity and quality, and high conversion efficiency (with low thermal losses) (Yeh and Chung 2009).

Plant growth depends specifically on the amount of photosynthetically active radiation (PAR) it receives. Plant varieties have specific PAR spectra, which differ from the sensitivity of the human eye. Chlorophyll molecules absorb red and blue wavelengths most efficiently. Green light, a major constituent of white light and the peak of the solar spectrum and human vision, is not as useful for plant growth. Because plants have different spectral preferences than people, the general lighting that is optimized for lumen output may not be ideal for plant growth. Agricultural lighting is a sub-field of the lighting industry and uses specially tuned light sources to match the PAR spectrum.

In general, the more energy that can be directed into wavelengths plants can use, the more product per kWh will be produced (and the lower the resulting GHG intensity of the product), and LEDs offer not only high overall light output-per-watt efficiency (horticultural LED arrays can provide three times more light output per watt of input power on an area-equivalent basis than HID lamps (Morrow 2008)) but also the potential to “tune” the emitted spectrum to plant needs.



This chart shows the exact level that A. Phototropic response, B. Photosynthetic response and C. Chlorophyll synthesis take place.



The single humped line in the center of the graph represents the visible light spectrum seen by the human eye. The dual humped line represents the spectrum cannabis needs to grow.

Fig. 5: The PAR for cannabis from (Cervantes 2006)

Unfortunately, commercially available LEDs are not yet optimized for plant growth. Yeh, however, argues that LEDs are the first light source to provide true spectral control, allowing wavelengths to match to plant photoreceptors to optimize production as well as to influence plant morphology and composition. In addition, LEDs are easily integrated into digital control systems and can be dimmed (Yeh and Chung 2009). This adaptability, along with lower waste heat production, means that LEDs have the potential for very large energy savings in comparison with existing lighting technologies.

While luminous efficacy is an imperfect measure of a lamp's ability to deliver PAR due to spectral mismatch, the following values are representative of overall efficiency of light production:

Lighting Type	Overall luminous efficacy (lm / W)
100 W tungsten incandescent (120V)	17.5
LED, theoretical limit	~400
Available 8.7 W LED (120V)	69-93
Metal halide lamp	65-115
High pressure sodium	85-150

Table 5: Lighting source comparison from (Luminous efficicacy: Retrieved May 29, 2013, from http://en.wikipedia.org/wiki/Luminous_efficacy#Lighting_efficiency.)

Substitution and Complementarity

Cannabis consumption also has indirect impacts on consumption of other goods; it is presumably a substitute for such synthetic cannabinoids as Spice and K2, and a complement to Doritos and unbaked chocolate-chip cookie dough. Whether it complements or substitutes for the consumption of various other psychoactives remains unknown, and the answer need not be the same for all drugs or all user types. (See Boyum *et al*. 2011 and references there.) If it were to turn out that cannabis substituted directly for alcohol (a point on which the research literature is divided and inconclusive) that substitution would create some offsetting environmental benefits because beer brewing also has energy demands (the energy requirements for one marijuana "joint" are approximately equal to those for 18 pints of beer (Mills 2012)). In that case, any environmental impacts from increased marijuana consumption in a legal market framework could be partially mitigated from substitution away from alcohol. The benefits of substituting cannabis for methamphetamine would be even greater. But since even the signs of the relevant cross-price elasticities are unknown, this analysis does not include this effect.

Recommendations

The following recommendations describe regulations, enforcement mechanisms, collaborations, and tax schemes that promote environmentally responsible cultivation of cannabis. LCB should consider feasibility, enforceability, and potential for market transformation when adopting a portfolio of environmental policies.

LCB's tools are primarily regulatory. Regulatory practice can be categorized into four distinctive approaches: process-specifying, product-specifying, outcome-specifying, and incentive-based. *Product* regulation allows and forbids products on an all-or-nothing basis; an example is the prohibition of wooden cutting boards in restaurants. *Process* regulation requires specific protocols, for example that restaurants wash dishes in a dishwasher using water above a certain temperature. *Outcome* regulation specifies properties of a product or process without requiring that they be achieved in any particular way; an outcome-based regulation for food could be a maximum allowed bacteria count for cutting boards, that the operator can meet by disinfectants, careful sanitation and management of contamination sources, or any other way. Finally, *incentive-based* regulation gives the producer consequential encouragement to provide more of a desired outcome but without (in principle) a minimum level of achievement. An example of this is the A,B,C hygiene ratings health departments award to restaurants in the expectation that an A rating will increase sales enough to make it worth it for most restaurants to achieve it, even though some restaurants' clientele may prefer the combination of price and risk resulting represented by a C score.

The advantages of the later-listed approaches is that they preserve incentives for innovation while focusing on the specific types of benefit the regulatory program is intended to obtain.

Despite the regulatory orientation of the LCB's marijuana program as currently conceived, we also include recommendations for non-coercive policies (advice, consulting, and research) that can improve the industry's environmental practice. Some of these may benefit from collaboration with other state agencies and non-profits.

Legal, licensed outdoor growing has the lowest environmental impact.

\ Outdoor growing promises significant environmental advantages and potentially lower production costs than indoor cultivation. Process regulations for security might lead to better overall results than outlawing field growing altogether.

Greenhouse cultivation promotes significant environmental protection relative to indoor growing

Greenhouse cultivation of cannabis entails lower energy consumption, GHG production, water consumption, wastewater production, fertilizer application, and toxic risks than indoor cultivation. LCB should promote greenhouse cultivation of cannabis, including cultivation in eastern Washington where the climate (hours of sunshine) is more favorable. Allowing production in standard greenhouses, rather than requiring new construction of high-security greenhouses, would encourage substitution away from environmentally problematic indoor growing.

Recognize the high GHG intensity of indoor growing with a differential tax

Energy efficiency and GHG reduction for indoor growing, where it matters most, can be pursued by outcome regulations such as (for example) licensing only operations meeting maximum electric consumption per growing area standards. Growers already have economic incentives for efficient use of electricity, but a main 'missing piece' of this framework regards GHG emissions, which as we have seen can vary significantly across production practices, are especially high for indoor operations, and are not reflected in electricity prices. A simple recognition of the distinctive climate effects of indoor growing would be to increase the producer tax on indoor marijuana by an amount that reflected (approximately) its respective carbon footprint. At $30/tonne of CO_2–a typical value in carbon markets–and assuming average Washington electricity GHG intensity and our "high" value for electric use per unit of product, this would be about 9c per gram of marijuana based on the marginal emission factor of Washington electricity. This amount would not ruin the competitiveness of indoor production but would provide a gentle incentive and have considerable symbolic value. The current cost of commercial electricity for cannabis production is about $400 per kilogram of finished product. This additional climate fee would amount to approximately a 20% surcharge on electricity use, about $90/kg. The status quo for indoor growing is on residential electricity accounts, with average rates that are 9% higher than the average commercial rate in Washington. Climate fees would essentially preserve (or slightly increase) the status quo incentives for energy efficiency.

Collaborate with the Washington State Energy Office, Utilities and Transportation Commission, and Washington State University, in the development and diffusion of lower-energy production practices.

Two technology areas for energy reduction and climate protection are especially promising: LED lighting for horticultural application, and energy efficiency measures for greenhouse heating. The Washington State Energy Office, located in the Department of Commerce, runs the State Energy Program that provides funding for energy technologies.

Develop LEDs for cannabis applications

LED developed for horticultural applications have the potential to significantly reduce lighting energy for both indoor and greenhouse applications. However, commercial development to date has focused on producing white light, rather than red/blue ("pink") LED arrays optimized for horticulture. LCB, the state universities' engineering and agriculture departments, and the Washington Department of Commerce could collaborate to advance commercialization of these technologies, serving as a critical link among LED consumers, academic researchers, and manufacturers.

Develop region-specific best practices for greenhouse energy efficiency

Cost-effective energy efficiency measures are driven in large part by regional climate. While University extension programs in Wisconsin and Connecticut have developed best practices for greenhouse efficiency, to our knowledge no similar effort has been performed in the Pacific Northwest. LCB should work with the State Energy Office or Washington State University to develop best practices suited to greenhouse cultivation of cannabis including building material, glazing, orientation, layout, heating systems, and shading on energy consumption in targeted cultivation areas. Case studies in the region on commercial greenhouse operations would also be a valuable input to the analysis and could provide important ground-truth. Attention should also be given to calculating a benefit-cost (B/C) ratio for efficiency measures. LCB should also seek industry input in developing these best practices.

Encourage time-of-use pricing with lower rates for night-time electric use

Off-peak electric usage in a system like Washington's, where baseload power is very low-carbon, has many benefits including reduced GHG emissions relative to daytime use. Time of use pricing and education on nighttime lighting in indoor growing facilities can encourage growers to move a significant amount of the electric usage to this environmentally favorable period.

Collaborate with Washington State University and other stakeholders to continue research on environmental impacts

Quantification of environmental impact in this report has relied on grey literature, craft-skill descriptions, and a small but growing set of academic and consulting reports. As the cannabis industry matures in Washington, academic and industry agricultural researchers should continue to measure the environmental impact of cannabis production methods. This research can be used to refine future regulation and drive environmentally friendly production methods. Researchers will need support to effectively transform the market including access to data on the environmental performance of facilities though federal law classifying marijuana as a Schedule 1 drug remains a serious potential obstacle to this research.

Consider labeling of "climate smart" or "environmentally friendly" cannabis for public sale in Washington

Draft LCB regulations entail labeling regulations for cannabis sold publicly. LCB should consider adding branding to cannabis that excels on environmental grounds, similar to the ENERGY STAR program administered for the U.S. Environmental Protection Agency for household appliances (2013). Such labeling programs, which affix a readily identifiable label among the most efficient products, can drive environmentally responsible purchasing and encourage a "race to the top" among producers. LCB could allow labeling for on energy/GHG consumption ("climate smart"), pesticide application ("environmentally friendly"), or a hybrid indicator.

Production enforcement mechanisms can promote environmental protection

Many of the most environmentally harmful practices in cannabis cultivation arise from a lack of information among regulators and the secret nature of cultivation. These include water diversion, water disposal, pesticide application, and electricity generation from on-site diesel generation. LCB should take advantage of the permitting process and information collection procedures to mitigate environmental damage.

Inspections of permitted facilities can ensure compliance with environmental regulation. In particular, LCB or other agencies should ensure that no illegal water diversion takes place, that only permitted pesticides, herbicides, or fungicides are being used for cultivation, and that diesel generation is properly permitted or installed. Inspections are supplemental to other environmental process regulation, and may overlap with other State agency jurisdiction.

While we cannot review the extensive literature on regulatory practice here, it's worth noting that "enforcement" regimes can vary widely in the underlying philosophy of their implementation, from strict defect-finding and punishment to a more complex regime in which inspectors see their job as not only police officers but 'production engineering consultants' providing information on best practices and opportunities to improve performance within the legal range.

Process Regulations can promote environmental protection

In addition to or in place of the tax differentials described above, a mechanism widely regarded as the most efficient generic approach to environmental regulation, LCB can use its permitting authority to enforce process regulations for cannabis cultivation. In particular, LCB should consider banning practices that promote toxic environmental releases, such as diesel generation, improper lighting disposal, and improper water disposal. Such regulations may overlap with or be redundant to other State or Federal regulations.

LCB should require all electricity be grid-connected

As diesel spills relating to on-site electricity generation can pollute waterways, LCB can require that all production facilities draw their electricity from the grid (with perhaps an exception for off-the-grid solar and other small-scale renewable sources). This would remove the incentive for producers to employ on-site fossil-fuel generation. It would also subject producers to Washington's increasing block rate structure electricity tariff, which increased the economic incentive to employ energy efficiency technology.

LCB can emphasize proper disposal of lamps

Given the high potential for mercury release from HID bulbs, LCB should ensure proper disposal of lamps used for cannabis production..

Appendix 1: Figures from Mills 2012

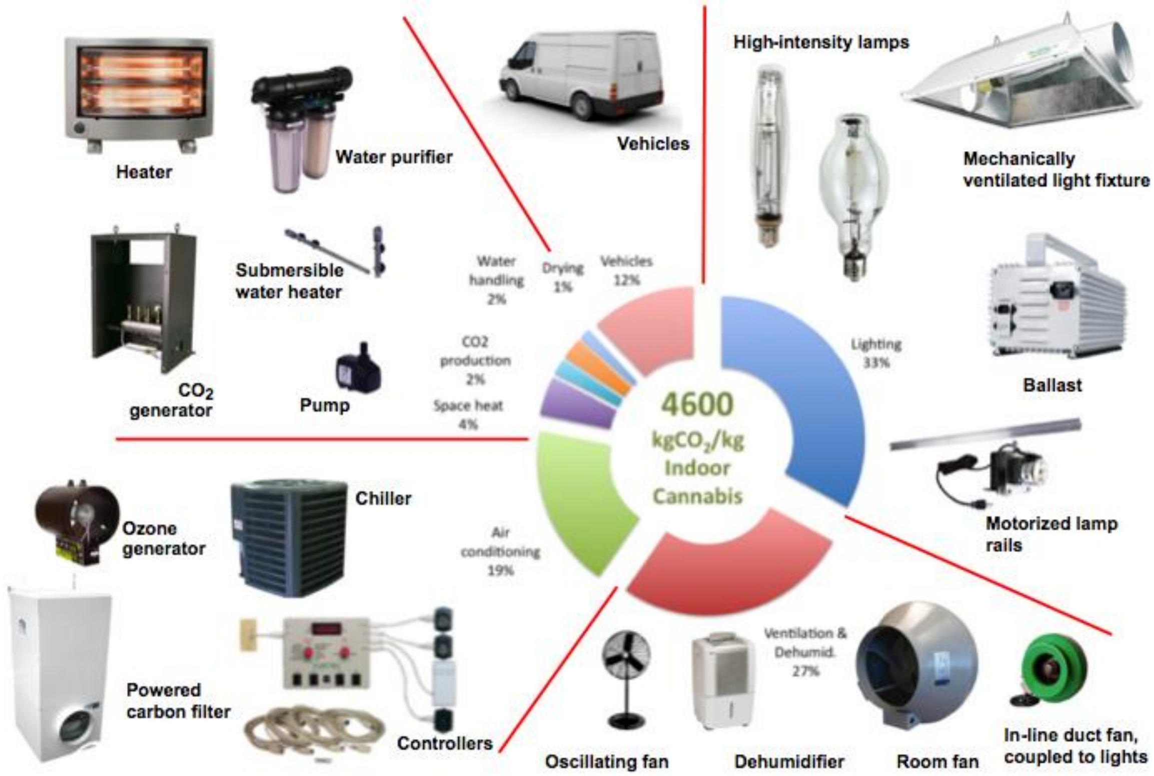


Fig. A1 - Relative contribution of energy-consuming appliances to overall CO_2 emissions for indoor production of cannabis.

Table A1
Configuration, environmental conditions, set-points.

Production parameters		
Growing module	1.5	m^2 (excl. walking area)
Number of modules in a room	10	
Area of room	22	m^2
Cycle duration	78	days
Production continuous throughout the year	4.7	cycles
Illumination	Leaf phase	Flowering phase
Illuminance	25 klux	100 klux
Lamp type	Metal halide	High-pressure sodium
Watts/lamp	600	1000
Ballast losses (mix of magnetic & digital)	13%	0.13
Lamps per growing module	1	1
Hours/day	18	12
Days/cycle	18	60
Daylighting	None	none
Ventilation		
Ducted luminaires with "sealed" lighting compartment	150	CFM/1000 W of light (free flow)
Room ventilation (supply and exhaust fans)	30	ACH
Filtration	Charcoal filters on exhaust; HEPA on supply	
Oscilating fans: per module, while lights on	1	
Water		
Application	151	liters/room-day
Heating	Electric submersible heaters	
Space conditioning		
Indoor setpoint — day	28	C
Indoor setpoint — night	20	C
AC efficiency	10	SEER
Dehumidification	7x24	hours
CO_2 production — target concentration (mostly natural gas combustion in space)	1500	ppm
Electric space heating	When lights off to maintain indoor setpoint	
Target indoor humidity conditions	40–50%	
Fraction of lighting system heat production removed by luminaire ventilation	30%	
Ballast location	Inside conditioned space	
Drying		
Space conditioning, oscillating fans, maintaining 50% RH, 70–80F	7	Days
Electricity supply		
grid	85%	
grid-independent generation (mix of diesel, propane, and gasoline)	15%	

Fig. A2 - Assumptions and inputs for process analysis of indoor cultivation.

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