DEVELOPMENT SERVICES DEPARTMENT
ENVIRONMENTAL COORDINATOR
450 110th Ave NE
BELLEVUE, WA 98009-9012

# DETERMINATION OF NON-SIGNIFICANCE

**PROPONENT:** City of Bellevue, Development Services Department

**LOCATION OF PROPOSAL:** City-wide

**DESCRIPTION OF PROPOSAL:** Land Use Code Amendment establishing permanent regulations regulating recreational marijuana producers, processors, and retailers. The permanent regulations will replace interim regulations adopted by Ordinance No. 6133 B-1 and extended and amended by Ordinance No. 6156. File No. 14-130927-AD.

**FILE NUMBERS:** 14-130927-AD **PLANNER:** Catherine Drews, Legal Planner

The Environmental Coordinator of the City of Bellevue has determined that this proposal does not have a probable significant adverse impact upon the environment. An Environmental Impact Statement (EIS) is not required under RCW 43.21C.030(2)(C). This decision was made after the Bellevue Environmental Coordinator reviewed the completed environmental checklist and information filed with the Land Use Division of the Development Services Department. This information is available to the public on request.

☒ This DNS is issued after using the optional DNS process in WAC 197-11-355. There is no further comment period on the DNS. The public and agency comment period was provided with the notice of application.

☐ This DNS is issued under WAC 197-11-340(2) and is subject to a 14-day comment period from the date below. Comments must be submitted by 5 p.m. on _____. This DNS is also subject to appeal. A written appeal must be filed in the City Clerk's Office by 5:00 p.m. on _____.

Any appeal of the SEPA threshold determination on a Process IV action shall be filed together with an appeal of the underlying Process IV action. The appeal shall be by petition to the Growth Management Hearings Board and shall be filed with the 60-day time period set forth in RCW 36.70A.290.

This DNS may be withdrawn at any time if the proposal is modified so that it is likely to have significant adverse environmental impacts; if there is significant new information indicating, or on, a proposals probable significant adverse environmental impacts (unless a non-exempt license has been issued if the proposal is a private project or if the DNS was procured by misrepresentation or lack of material disclosure.

Environmental Coordinator — 7/10/2014 Date

OTHERS TO RECEIVE THIS DOCUMENT:
☐ State Department of Fish and Wildlife / Stewart.Reinbold@dfw.gov; Christa.Heller@dfw.wa.gov;
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**CITY OF BELLEVUE**
**ENVIRONMENTAL CHECKLIST**
**(Integrated SEPA/GMA Process)**

## A. BACKGROUND INFORMATION

| | |
|---|---|
| **PROPOSAL TITLE:** | Land Use Code Amendment establishing permanent regulations regulating recreational marijuana producers, processors, and retailers. The permanent regulations will replace interim regulations adopted by Ordinance No. 6133 B-1 and extended and amended by Ordinance No. 6156. File No. 14-130927-AD. |
| **PROPERTY OWNERS' NAME:** | N/A; applies City-wide |
| **PROPOSAL LOCATION:** | City-wide |
| **PROPONENT'S NAME:** | City of Bellevue, Development Services Department |
| **CONTACT PERSON'S NAME:** | Catherine A. Drews, Legal Planner |
| **CONTACT PERSON'S ADDRESS:** | Development Services Department<br>City of Bellevue<br>P.O. Box 90012<br>Bellevue, WA 98009-9012 |
| **CONTACT PERSON'S PHONE:** | 425-452-6134 |

**BRIEF DESCRIPTION OF THE PROPOSAL'S SCOPE AND NATURE:**

1. **General description:** Land Use Code Amendment (LUCA) to establish permanent regulations regulating recreational marijuana producers, processors, and retailers as allowed under Initiative 502 passed by Washington voters in November 2012. The permanent regulations will replace interim regulations adopted by Ordinance No. 6133 B-1 and extended and amended by Ordinance No. 6156. The amendment will establish appropriate land use districts to locate recreational marijuana producers, processors, and retailers. The amendment will also include performance standards intended to mitigate the impacts related to recreational marijuana operations. The proposal will add a new section to the general development requirements applicable to recreational marijuana uses, create new general development requirements for "those uses, including specific definitions, and repeal Ordinance No. 6133 B-1 (adopting the interim regulations) and Ordinance No. 6156 (extending and amending Ordinance No. 6133 B-1). The interim regulations will provide the starting point for the proposed permanent regulations.

Planning Commission will be considering 2 draft proposals
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7/8/2014

2. **Site acreage:** Applies city-wide.

3. **Number of dwelling units/buildings to be demolished:** N/A

4. **Number of dwelling units/buildings to be constructed:** N/A

5. **Square footage of buildings to be demolished:** N/A

6. **Square footage of buildings to be constructed:** N/A

7. **Quantity of earth movement (in cubic yards):** N/A

8. **Proposed land use:** This LUCA will regulate recreational marijuana producers, processors, and retailers as allowed uses appropriate land use districts. Recreational marijuana uses will be prohibited in residential land use districts

9. **Design features, including building height, number of stories and proposed exterior materials:** The proposal will not change any Land Use Code requirements pertaining to building size, height, design, appearance, location on property, or other regulation affecting observable physical attributes of existing or proposed structures. The LUCA will include screening for security purposes when loading/unloading marijuana shipments and separation requirements beyond those in Chapter 314-55 Washington Administrative Code to protect neighborhood character.

10. **Other:** N/A

**Proposed timing or schedule (including phasing, if applicable):** Final action on the LUCA by the City Council is expected to occur in fall of 2014.

**Do you have any plans for future additions, expansion, or further activity related to or connected with this proposal? If yes, explain.** Yes. It is expected that recreational marijuana producers, processors, and retailers will apply for tenant improvement permits to build-out their operations and begin operations shortly after the Washington State Liquor Control Board (WSLCB) begins issuing recreational marijuana licenses.

**List any environmental information you know about that has been prepared, or will be prepared, directly related to this proposal.** The Washington State Liquor Control Board has prepared an environmental checklist and issued a determination of non-significance for recreational marijuana program. The following documents are incorporated by reference and copies are provided with this checklist:

1. Washington State Liquor Control Board: Environmental Checklist for Proposed rulemaking for WAC 314-55, Marijuana Licenses, Application process, Requirements, and Reporting (June 3, 2013).

2. Michael O'Hare, et. al., BOTEC Analysis, University of California, Berkeley: *Environmental Risks and Opportunities in Cannabis Cultivation*, (BOTEC Analysis Corp., 1-502 Project #430-5d, Final (June 28, 2013).
3. Washington State Liquor Control Board: Determination of Nonsignificance (July 12, 2013).
4. Michael O'Hare, et. al., BOTEC Analysis, University of California, Berkeley: *Environmental Risks and Opportunities in Cannabis Cultivation*, (BOTEC Analysis Corp., Final Revised (September 7, 2103).
5. Revised SEPA Determination of Nonsignificance (DNS) and Addendum to Environmental Checklist (September 26, 2013).

**Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain. List dates applied for and file numbers, if known.** No known applications are pending.

| Applicant/Permit Name | I-502 Type | Permit #/Application Date |
|---|---|---|
| Ceres/Saturn | producer/processor | 14-128054-BY (Mar. 26, 2014) |
| RedSpark | producer/processor | 14-127822-BY (March 21, 2014) |
| Par 4 | retail | 14-130922-BZ (May 16, 2014) |
| 30th St. Enterprises | producer/processor | 14-133095-BW (May 23, 2014) |
| Novel Tree | retail | 14-134623-BZ (June 20, 2014) |

Added newest application MAS 7/8/2014

**List any government approvals or permits that will be needed for your proposal, if known. If permits have been applied for, list application date and file numbers, if known.** The City Council will consider the Planning Commission's recommendation and adopt an ordinance implementing the new LUCA. The Council-adopted ordinance will be subject to the disapproval jurisdiction of the East Bellevue Community Council.

## B. ENVIRONMENTAL ELEMENTS

No discussion of the individual Environmental Elements is required for GMA actions per WAC 197-11-235.3.b.

## C. SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS (do not use this sheet for project actions)

### SUMMARY

Project Summary: This Land Use Code Amendment will establish permanent regulations regulating recreational marijuana producers, processors, and retailers. The permanent regulations will replace interim regulations adopted by Ordinance No. 6133 B-1 and extended and amended by Ordinance No. 6156.

**Environmental Summary per WAC 197-11-235(3)(b):**



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State the proposal's objectives: The objective of the proposal is to establish regulations establishing appropriate land use districts to locate and operate recreational marijuana production, processing, and retail outlets. The LUCA will include performance standards supplemental to those in Chapter 314-55 WAC that are intended to address the impacts related to the operation of recreational marijuana uses. The LUCA is also intended to implement the Council's guiding principles for this work.

Specify the purpose and need to which the proposal is responding: At the November 6, 2012, General Election, Washington voters approved Initiative 502 (I-502) legalizing the possession of limited amounts of marijuana. I-502 became effective on December 6, 2012, and is codified into Chapter 69.50 RCW, the state Uniformed Controlled Substances Act.

In general I-502:

- Legalizes the use of marijuana by people 21 years and older. Adults may possess up to 1 ounce of marijuana, 16 ounces of marijuana-infused product in solid form, and 72 ounces of marijuana-infused product in liquid form;
- Specifies that only state-licensed marijuana production, processing, and sale of marijuana are permitted;
- Requires licensed facilities to be at least 1,000 feet from schools, public playgrounds, recreation centers, state-licensed day cares, public parks, public transit centers, libraries, and arcades1; and
- Limits signage to a maximum of one that is no larger than 11 square feet in area.

I-502 did not repeal or amend the Medical Cannabis Act, Chapter 69.51A RCW.

Ordinance No. 6133 B-1 (October 21, 2014) implemented an emergency interim zoning control regulating the location of recreational marijuana uses and providing performance standards intended to address impacts related to the operation of recreational marijuana uses. The interim regulation:

1. Defines key terms and incorporates definitions from WAC 314-55-010;
2. Incorporates the state separation requirements and imposes separation requirements between recreational marijuana uses and medical cannabis collective gardens and between recreational marijuana outlets;
3. Provides zoning for recreational marijuana uses;
4. Prohibits recreational marijuana in residential land use districts;
5. Requires conformance with design review standards where applicable
6. Imposes additional security requirements; and
7. Requires odor control.

Council adopted planning principles on December 2, 2012 to guide development of the LUCA:

[1] These facilities are defined at WAC 314-55-010. The separation distance is measured as the shortest line between the property lines of the proposed recreational marijuana use and the uses listed in the LCB rules. WAC 314-55-050(10).



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1. Bellevue Appropriate. Bellevue will establish appropriate land use zones for recreational marijuana producers, processors, and retailers ("recreational marijuana uses"). To the extent permitted, Bellevue will establish performance standards consistent with applicable provisions of Chapter 69.50 RCW and Chapter 314-55 WAC, now or as hereafter amended, that ensure these business represent the community values and goals set forth in the City's Comprehensive Plan.

2. Neighborhood Character is Protected. Recreational marijuana uses shall not be located in residential land use districts. Recreational marijuana uses shall be separated by 1,000 feet from elementary or secondary schools (public or private), playgrounds, recreation center or facility; child care center; pubic park; public transit center; library; and game arcade where admission is not restricted to persons age twenty-one or older, or a medical cannabis collective garden. Recreational marijuana use shall use appropriate ventilation to ensure abutting uses or properties are not impacted by odor.

3. Security Measures are Required. Recreational marijuana uses must have sufficient security measures to protect the public. Recreational marijuana uses must conform to state requirements for security and secure usable marijuana consistent with state pharmacy requirements for securing controlled substances.

4. Regulations are Specific and Understandable. The permanent regulations should be specific about the requirements to locate and operate recreational marijuana uses so that qualified licensees understand what is expected under the regulation.

5. Administration and Enforcement is Straightforward. Ensure regulations are capable of being administered and enforced. Development Services and the Bellevue police department should collaborate in matters of approval of license applications and renewals and where appropriate, enforcement.

6. The Outcome is in Conformance with Applicable Law. The establishment and operation of recreational marijuana uses must conform with, and not frustrate, the purpose of state law. Recreational marijuana uses must conform to the applicable requirements of Chapter 69.50 RCW and Chapter 314-55 WAC, now or as hereafter amended.

7. Processing of the Amendment is Inclusive. The code amendment process for recreational marijuana uses should seek and include input from a wide range of stakeholders.

Council amended the interim regulations to require that recreational marijuana retail outlets be separated by at least 1,000 feet with adoption of Ordinance No. 6156. The proposal is intended to respond to the concerns raised by citizens, consistent with the above Council-provided principles.



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State the major conclusions, significant areas of controversy and uncertainty: The City has received several comments to date regarding recreational marijuana uses in Bellevue. Comments range from supporting banning marijuana, opposing banning marijuana, the risks associated with marijuana use, and concerns about the locations of recreational marijuana businesses. The major area of concern will be the location of recreational marijuana uses. Allowed land use districts were established in the interim regulations (Ord. No. 6133 B-1). Proposal details may evolve as a result of public input and Planning Commission deliberation, to ensure that the proposal achieves its objectives.

State the issues to be resolved, including the environmental choices to be made among alternative courses of action: Issues to be resolved include development of a Bellevue appropriate approach to the regulation of recreational marijuana uses. Alternative courses of action include: not amending the LUC to regulate recreational marijuana uses and relying solely on WSLCB regulations. In terms of environmental impacts, not amending the LUC may result in increased environmental impacts related to waste disposal, energy consumption, and disposal of waste water. By adopting the proposed amendment, recreational marijuana uses must comply with adopted performance amendments. These uses must also comply with the Washington State Liquor Control Board's rules that include provisions for liquid and solid waste disposal (WAC 314-55-097); limits on soil types, fertilizers, pesticides, and other crop production aids (WAC 314-55-084) . Marijuana recreational uses must also comply with applicable City codes, including those intended to protect the environment, including but not limited to the City's Storm and Surface Water Utility Code, Chapter 24.06 BCC; the City's Building and energy codes (Title 23); and the City's nuisance codes (Titles 9 and 9A).

State the impacts of the proposal, including any significant adverse impacts that cannot be mitigated: The proposal is a nonproject action to allow recreational marijuana producers, processors, and retailers in limited land use districts. There are no significant adverse impacts resulting from that action. The Washington State Liquor Control Board's implementing regulations and the City Code will fill any gaps and adequately mitigate expected environmental impacts. Consequently, no significant adverse environmental impacts are anticipated.

Describe any proposed mitigation measures and their effectiveness: No specific development is being approved with this proposal. No significant environmental impacts have been identified, therefore no mitigation measures, beyond those required in the state rules and the City Code are proposed.

1. **How would the proposal be likely to increase discharge to water; emissions to air; production, storage, or release of toxic or hazardous substances; or production of noise?** .

   **Discharge to water**: Indoor cultivation often employs pesticides and herbicides. Hydroponic pollution is also a concern for indoor cultivation. Hydroponic systems use more water and produce more nutrient pollution than other growing methods. According to WSLCB's consultant, water used for indoor cultivation is high in nitrogen and



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phosphorous and if disposed in storm drains (which is illegal in Bellevue), it contributes to water body eutrophication and in sewers the water imposes an additional treatment load. **Discharge to air:** See response to paragraph 3 below.

**Production, storage, or release of toxic or hazardous substances:** According to WSLCB's consultant: "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 neuro-toxin, 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)." *Environmental Risks and Opportunities,* Revised Final at 18. The report further states that many other industrial and municipal lighting applications generate used lamps the require management outside the municipal waste stream and that existing recycling/disposal system could serve well for cannabis lighting waste." *Id.*, at 18-19. HID light bulbs and all mercury containing bulbs are now required to be recycled under RCW 70.275.080.

**Production of noise:** Adoption of the proposed amendment will not result in increased noise.

**Proposed measures to avoid or reduce such increases are:** Recreational marijuana uses must comply with the Washington State Liquor Control Board's rules that include provisions for liquid and solid waste disposal (WAC 314-55-097); limits on soil types, fertilizers, pesticides, and other crop production aids (WAC 314-55-084). Marijuana recreational uses must also comply with applicable City codes, including those intended to protect the environment, including but not limited to the City's Storm and Surface Water Utility Code, Chapter 24.06 BCC; the City's Building and energy codes (Title 23); and the City's nuisance codes (Titles 9 and 9A)

2. **How would the proposal be likely to affect plants, animals, fish or marine life?** Under the interim regulations (Ordinance No. 6133 B-1 and Ordinance No. 6156), the outdoor cultivation of marijuana is prohibited. Because the interim regulations will form the starting point for development of the permanent regulations, adoption of the proposed code amendment will not increase the potential impacts to plants and animals.

**Proposed measures to protect or conserve plants, animals, fish or marine life are:** N/A

3. **How would the proposal be likely to deplete energy or natural resources?** Growing plants indoors requires energy and water. According to an article in the Seattle Times, studies indicate that growing 2.2 pounds of cannabis indoors produces 4,600 kilograms of carbon dioxide, which is considered a greenhouse gas. *Pot Grows Leave Huge Carbon Footprint*, Seattle Times, May 12, 2013. The Washington State Department of Ecology requires reporting of greenhouse gases when new emissions are expected to average 10,000 metric tons or more of carbon dioxide per year. *Guidance for Ecology*

*Including Greenhouse Gas in SEPA Reviews*, June 3, 2011. According to WSCLB's consultant, 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. *Environmental Risks and Opportunities,* Revised Final at 9. The interim regulations limit indoor marijuana cultivation to the Light Industrial Land Use district. It is unlikely the limited number of producers will trigger the threshold to report greenhouse gas emissions. Three producers currently have applied for building permits. Two tier 3 (10,000 – 30,000 square feet of canopy) and one Tier 1 (less than 2,000 square feet of canopy).

**Proposed measures to project or conserve energy and natural resources are:** N/A

4. **How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection; such as parks, wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains, or prime farmlands?** Adoption of the proposed code amendment will not affect environmentally sensitive areas or areas designated or eligible for governmental protection.

   **Proposed measures to protect such resources or to avoid or reduce impacts are:** N/A

5. **How would the proposal be likely to affect land and shoreline use, including whether it would allow or encourage land or shoreline uses incompatible with existing plans?** Adoption of the proposed amendment will not affect any shoreline areas.

   **Proposed measures to avoid or reduce shoreline and land use impacts are:** N/A

6. **How would the proposal be likely to increase demands on transportation or public services and utilities?** The proposed Land Use Code Amendment is not likely to increase demands on these services and utilities. Recreational marijuana uses are consistent with uses allowed in the proposed land use districts; therefore traffic demand should be similar.

   **Proposed measures to reduce or respond to such demand(s) are:** N/A

7. **Identify, if possible, whether the proposal may conflict with local, state, or federal laws or requirements for the protection of the environment.**
   Marijuana is a classified as a Schedule 1 drug under the federal Controlled Substance Act. Under federal law, the production, processing, and dispensing of marijuana is illegal.[2] On August 29, 2013, however, the United States Department of Justice, Office of the Attorney General, (DOJ) released updated guidance regarding

[2] 21 U.S.C. 801 et. seq.

marijuana enforcement. According to DOJ, the guidance was updated in response to state ballot initiatives, such as I-502, which legalize the possession of small amounts of marijuana and regulate the production, processing, and sale of marijuana. The guidance reiterates that DOJ is committed to using its investigative and prosecutorial resources to address the most significant threats to public safety related to marijuana crimes in "the most effective, consistent, and rational way." The guidance directs federal prosecutors to review potential marijuana-related charges in cases to determine whether the conduct at issue implicates one or more of the eight stated federal enforcement priorities set forth in the guidance. The DOJ guidance rests on expectations that state and local governments implement a strong and effective regulatory system.

**D. The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.**

**Signature** Catherine Drews **Date Submitted:** 05-29-14



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7/8/2014

Washington State
Liquor Control Board

Proposed Rulemaking for WAC 314-55 Marijuana Licenses, Application Process, Requirements and Reporting

## Revised

### SEPA Determination of Nonsignificance (DNS) and Addendum to Environmental Checklist

September 26, 2013

The Washington State Liquor Control Board (WSLCB) conducted a SEPA nonproject review and filed an Environmental checklist (checklist) and Determination of nonsignificance (DNS) on June 3, 2013. This is an addendum to that checklist and DNS. The proposal is a rule establishing a system to license and regulate marijuana production, distribution and possession for persons over 21 years of age imposed by the passage of Initiative-502 (I-502).

I-502 requires a tightly controlled and regulated marijuana market including strict controls to prevent diversion, illegal sales and sales to minors while providing reasonable access to products to mitigate the illicit market. The requirements in the proposal are designed to comply with the initiative's mandate. These rules will reduce adverse environmental impacts caused by current unregulated marijuana grows on public and private lands and facilities.

On July 3, 2013, the WSLCB filed proposed rules with the state code reviser (CR 102). The Board held five public hearings across the state and solicited public input on its proposed rules. Based on public comments, the Board chose to revise its rules. The Board filed revised rules on September 4, 2013 (Supplemental CR 102).

The WSLCB contracted with BOTEC Analysis Corporation to provide technical expertise. BOTEC submitted a white paper on the environmental risks and opportunities in marijuana cultivation. The final report was submitted June 28, 2013 and a final revised report was submitted September 7, 2013. The final revised report is attached and some of the information is summarized in the addendum below.

<u>Addendum to existing checklist analysis:</u>

The original checklist in Part D, Supplemental Sheet for Nonproject Actions (1) did not address Water Quantity as it relates to outdoor cultivation of cannabis. Water use and fertilizer runoff to streams or groundwater is also a concern for outdoor cultivation as for any crop. Illegal growing has had damaging effects when water is illegally diverted through PVC pipes to nearby grow operations, with negative effect on pH, stream flow, water temperature and nutrient content. This is an environmental cost that a legal regime may avoid. Outdoor cultivators will need to follow state and local water resource laws and requirements.

The original checklist in Part D, Supplemental Sheet for Nonproject Actions (1) under Toxic Waste erroneously stated that high-intensity discharge (HID) bulbs are not recyclable. HID light bulbs and all mercury containing bulbs are now required to be recycled under RCW 70.275.080.

The original checklist in Part D, Supplemental Sheet for Nonproject Actions (2) did not address how outdoor cultivation of marijuana could affect wildlife. Endangered species candidates like the fisher, which populate the Pacific Northwest, can be harmed by rodenticides that are used for marijuana cultivation.

Research has linked rat poisons used during illegal marijuana cultivation to fisher deaths near illegal cannabis cultivation sites. Rodenticides such as brodifacoum may also affect owls, martens and foxes. The proposed regulations restricting pesticide types and regulating their use would lessen this environmental impact.

<u>Addendum to checklist based on new and revised language:</u>

Below are the substantial revisions that the LCB has made to the rules based on public input and continued research and discussion.

**Production Limits**

- Added language that limits the total amount of useable marijuana to be produced to 40 metric tons
- Added language that sets the maximum amount of space for marijuana production at two million square feet

**Effect of proposed measures:**

The production limits will lessen the environmental impact by controlling the amount of marijuana that can be legally produced.

**Production Tiers**

- Added language that creates three production tiers based on square footage. Applicants are limited by the size category of their production premises and the amount of actual square footage in their premises that will be designated as plant canopy. There are three categories:
    - Tier 1 – less than 2000 square feet
    - Tier 2 – 2000 to 10,000 square feet
    - Tier 3 – 10,000 to 30,000 square feet

**Effect of proposed measures:**

The three production tiers limit the amount of marijuana production to two million square feet in the state. This will lessen the environmental impact by controlling the amount of marijuana that can be legally grown and produced.

**Market Control Limits**

- Limits any entity and/or principals within any entity to three producer or processor licenses.
- Limits any principal and or entity to no more than three retail licenses with no multiple location licensee allowed more than 33 percent of the allowed licenses in any county or city

**Effect of proposed measures:**

The proposed rule directly affects the environment as it relates to water, air, aesthetics, plants, animals, marine life, energy or natural resources, transportation or public services and utilities by controlling the amount of marijuana that can be cultivated by an entity and/or principals in the state.

**On-Site Product Limits**

- Established the maximum amount of marijuana allowed on a licensee's premises at any time based on the type of grow operation (indoor, outdoor, greenhouse).
    - Producer License
        - Outdoor or greenhouse: 125 percent of year's harvest
        - Indoor: Six months of its annual harvest
    - Processor License
        - Six months of their average useable marijuana (plant material); and
        - Six months average of their total production (finished product)
    - Retailer License
        - Four months of their average inventory

**Effect of proposed measures:**

The proposed rule directly affects the environment as it relates to water, air, aesthetics, plants, animals, marine life, energy or natural resources, transportation or public services and utilities by controlling the amount of marijuana that can be cultivated and stored on a licensee's premises.

**Retail Stores**

- A maximum of 334 retail stores will be allowed in the system
- Stores locations are allocated based on population and consumption data

**Effect of proposed measures:**

The proposed rule directly affects the environment as it relates to water, air, aesthetics, plants, animals, marine life, energy or natural resources, transportation or public services and utilities by controlling the amount of recreational marijuana stores and inventory in the state.

**Tightened Definitions**

- Added a definition for “plant canopy” to clarify what area is considered in the square footage calculation for marijuana producers”
- Revised the definition of “Public Park” to include parks owned or managed by a metropolitan park district. Clarified that trails are not included in the definition of “Public Park”
- Revised the definition of “recreation center or facility.” Added the language “owned and/or managed by a charitable non-profit organization, city, county, state, or federal government”

**Effect of proposed measures:**

The proposed rule directly affects the environment as it relates to water, air, aesthetics, plants, animals, marine life, energy or natural resources, transportation or public services and utilities by controlling the area where recreational marijuana can be produced, processed and sold at retail stores.

BOTEC
Analysis Corporation

# Environmental Risks and Opportunities in Cannabis Cultivation

Michael O'Hare, BOTEC, UC Berkeley
Peter Alstone, UC Berkeley
Daniel L. Sanchez, UC Berkeley

Final Revised
Sept. 7, 2013

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-

[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.

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[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 kg$CO_2$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 $CO_2$e, 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 ener-

gy 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.

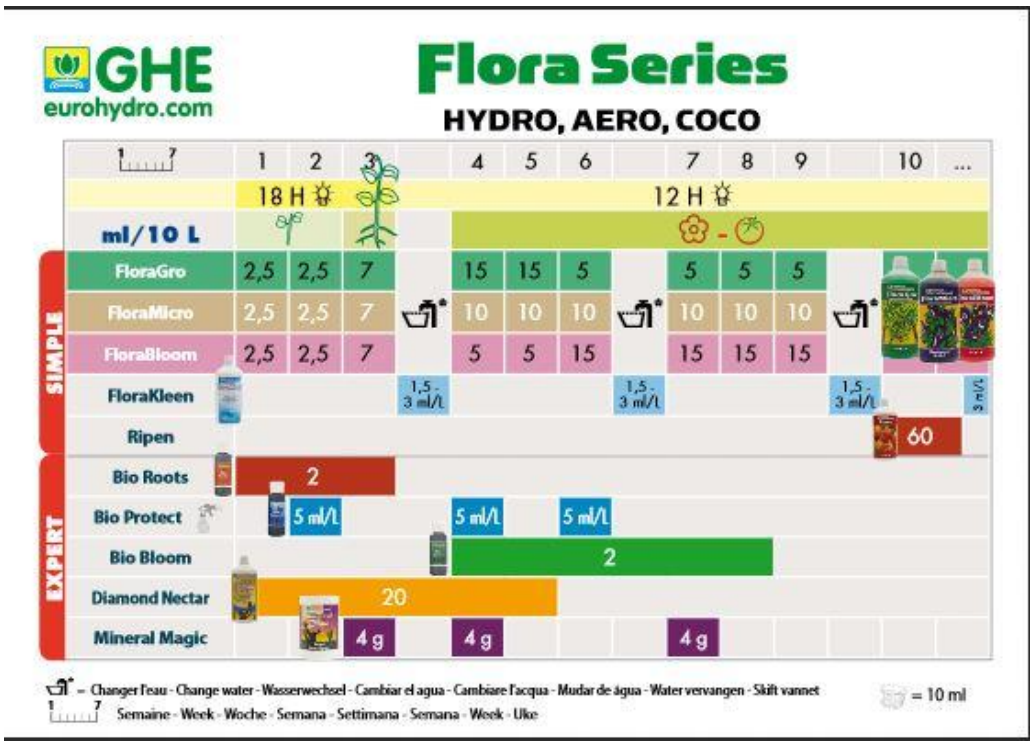



**Figure 2: Fertilization recommendations (current version of GHE chart reproduced in (Cervantes 2006), at [http://www.eurohydro.com/publications/publications/APPLICATION%20CHARTS/GB/CHART-FLORA-SERIES-GB.pdf](http://www.eurohydro.com/publications/publications/APPLICATION%20CHARTS/GB/CHART-FLORA-SERIES-GB.pdf)**

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.

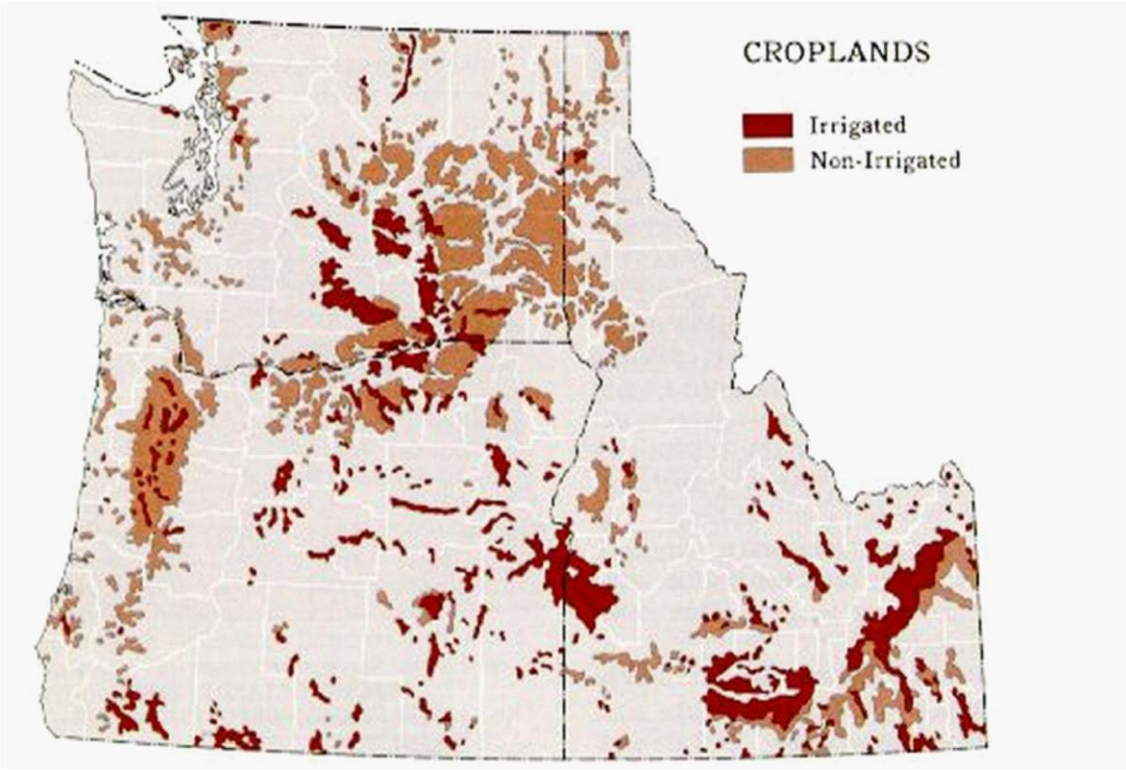



**Figure 3: Distribution of irrigated and non-irrigated cropland in the PNW from (Jackson and Kimmerling, 1993)**

**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.

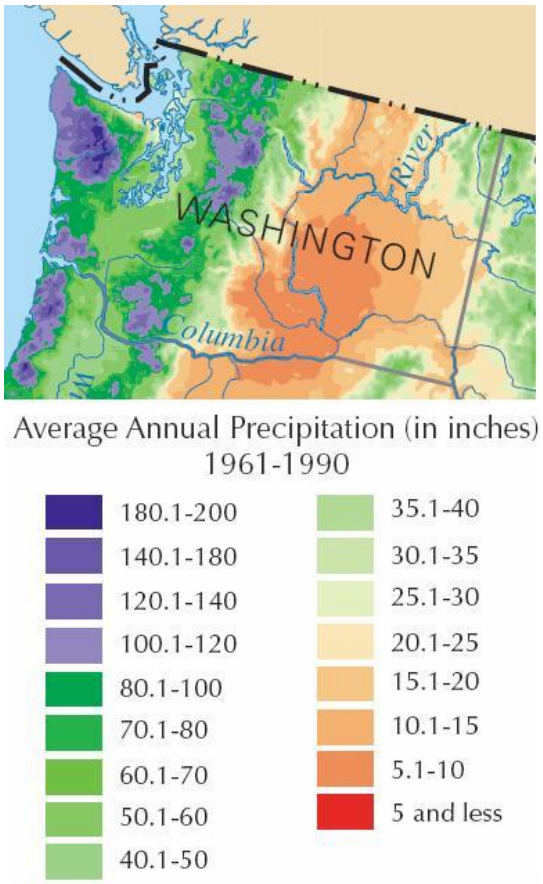



**Figure 4: Rainfall in Washington**

## 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 photodeprivation and other advanced growing techniques. (Sanford 2010a; Sanford 2010)

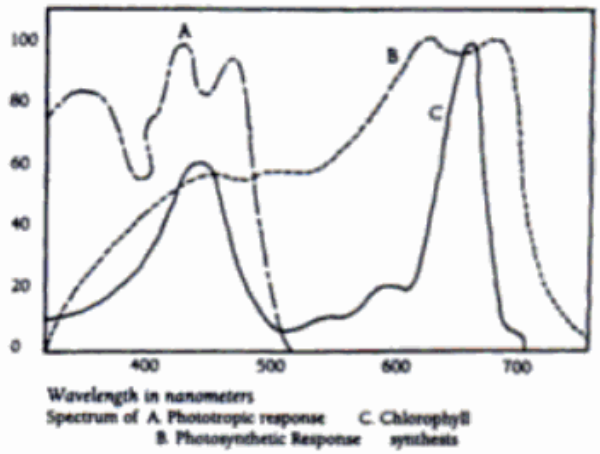
Indoor operations occur in buildings covered by existing Washington building regulations and conventional energy conservation practices such as insulation. The most important opportunities for environmental benefit lie in more efficient lighting equipment and timing to avoid peak use periods.

### *LEDs for indoor cultivation*

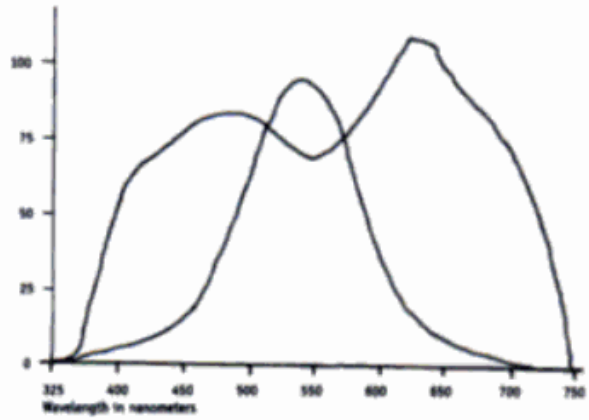
Light-emitting diodes (LEDs) have several advantages over high intensity discharge (HID) or high pressure sodium (HPS) lighting: lifetimes in excess of 100,000h, small size, specific wavelength, adjustable light intensity and quality, and high conversion efficiency (with low thermal losses) (Yeh and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

mercial 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

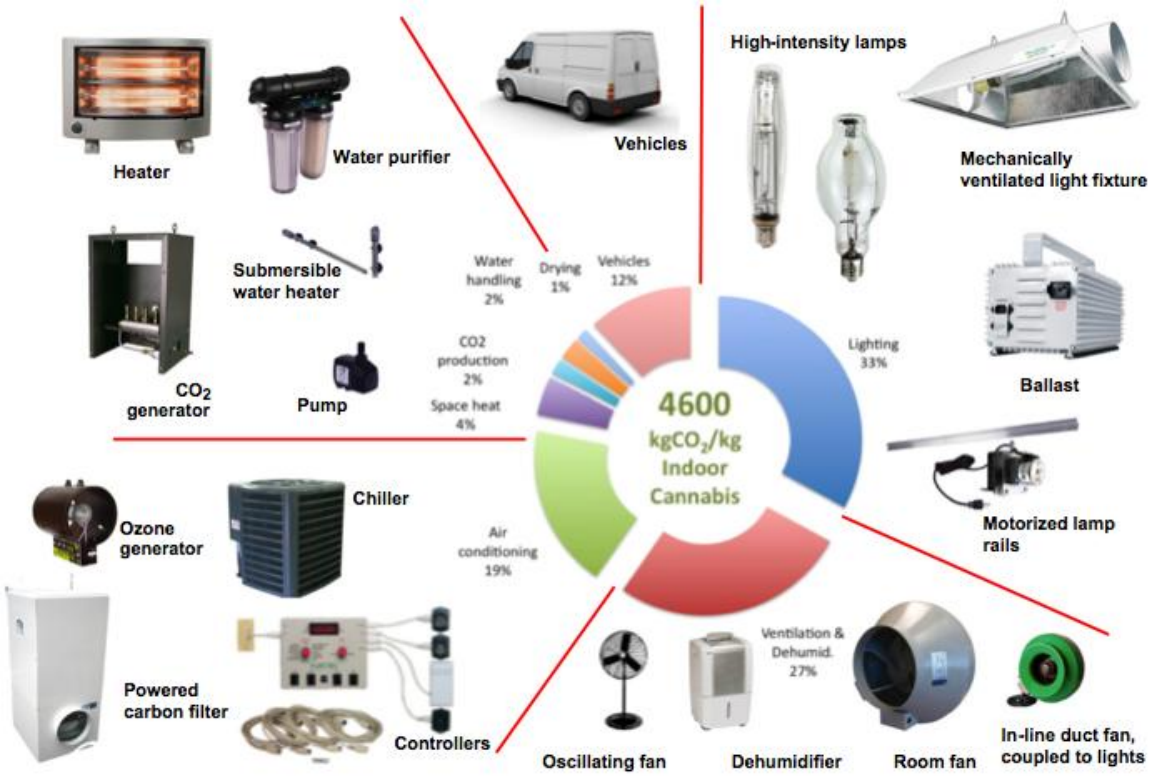



**Fig. A1 - Relative contribution of energy-consuming appliances to overall $CO_2$ emissions for indoor production of cannabis.**

**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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# 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 be energy 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. Though electricity in the Pacific Northwest is some of the lowest-GHG-intensity in the US, it still has a significant "carbon footprint."

Marginal electricity demand is much more carbon-intensive than average demand, since daily peaks are usually met with natural-gas fired generation rather than less GHG-intensive "baseload" hydropower generation. Increased cannabis cultivation indoors can be a noticeable fraction (single-digit percentages) of the state's total electricity consumption. Indoor cultivation that concentrates lighting periods at night will have a much smaller climate effect than if lighting is provided during high-electric use times. Greenhouse production requires much less energy, and open cultivation an insignificant fraction of production costs.

Other environmental effects of cannabis are 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 greenhouse effects are much less important than some other risks (and benefits) of a legal cannabis market. But 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 about cannabis cultivation include adjusting the excise tax on indoor-cultivated marijuana to reflect about 9c per gram worth of global warming effect, labeling low-GHG marijuana as such, encouraging 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.

## 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, for indoor production, 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 they 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 warm-temperate to subtropical annuals, grown 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 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 basis[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 level 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, marijuana 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

[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/

and fungal agents. Indoor growing allows high profits from the typically high-grade product that is produced under controlled conditions and is perceived 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).

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', 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 [3] 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.

### *Greenhouse*

Greenhouse cultivation demands significantly less energy than indoor cultivation practices, 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.

Belgian greenhouses have an energy intensity 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

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

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 hydro-electric and nuclear with only about 17% fossil-fueled, mostly natural gas http://www.eia.gov/electricity/state/Washington/ table 4. The average greenhouse-gas intensity of electricity produced in the state is 135 kg $CO_2$/MWh. The state is also intertied with the Western USA Grid however, which has a higher carbon intensity. Furthermore, 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 kg$CO_2$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 $CO_2$e, 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 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.

## 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.

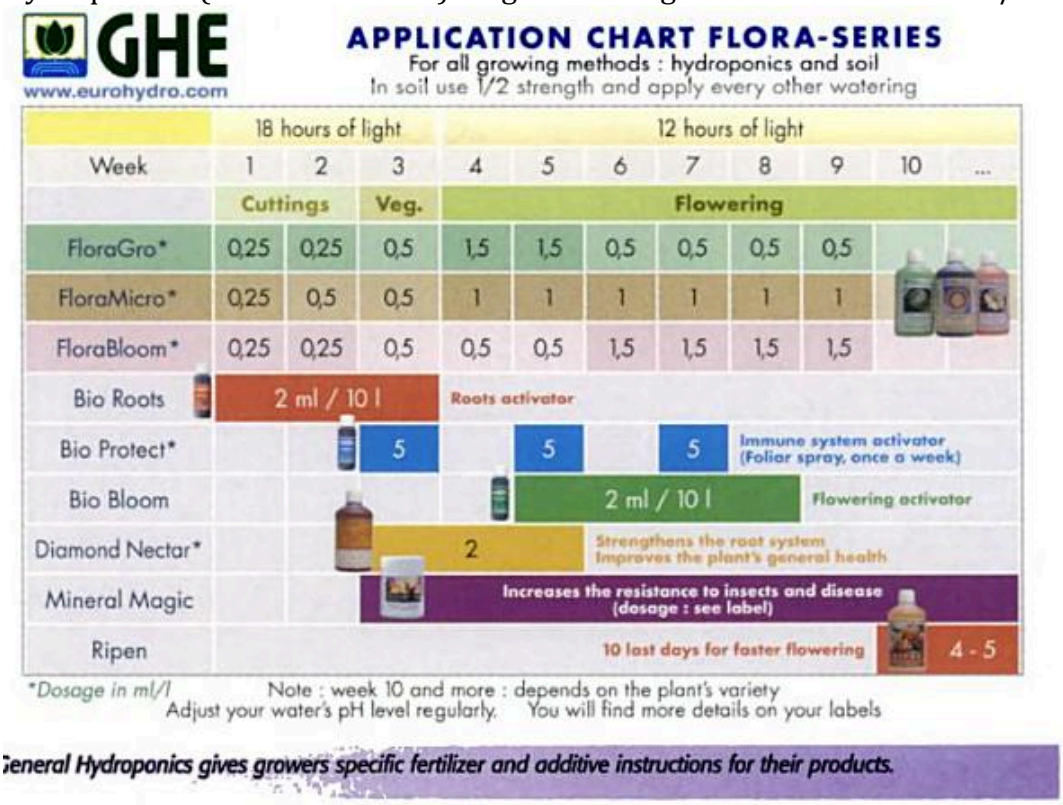



**Figure 2: Fertilization recommendations (from (Cervantes 2006)**

Soil-grown cannabis requires fewer fertilizer inputs than hydroponic cannabis. Notably, General Hydroponics recommends one-quarter the hydroponic application rate 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. 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 than traditional soil-grown water application.

Hydroponic pollution is also a concern for indoor cultivation. In addition to higher water demand, hydroponic systems produce more nutrient pollution than other growing methods. In Northern California, water used for indoor cultivation contributes to pollution in local streams. Water is often illegally diverted through PVC pipes to nearby grow operations, with negative effect on pH, stream flow, water temperature, and nutrient content (Shafer 2012).

### *Hop cultivation*

To understand the water consumption of outdoor cannabis cultivation, we will infer from two other crop: 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." They also note 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.

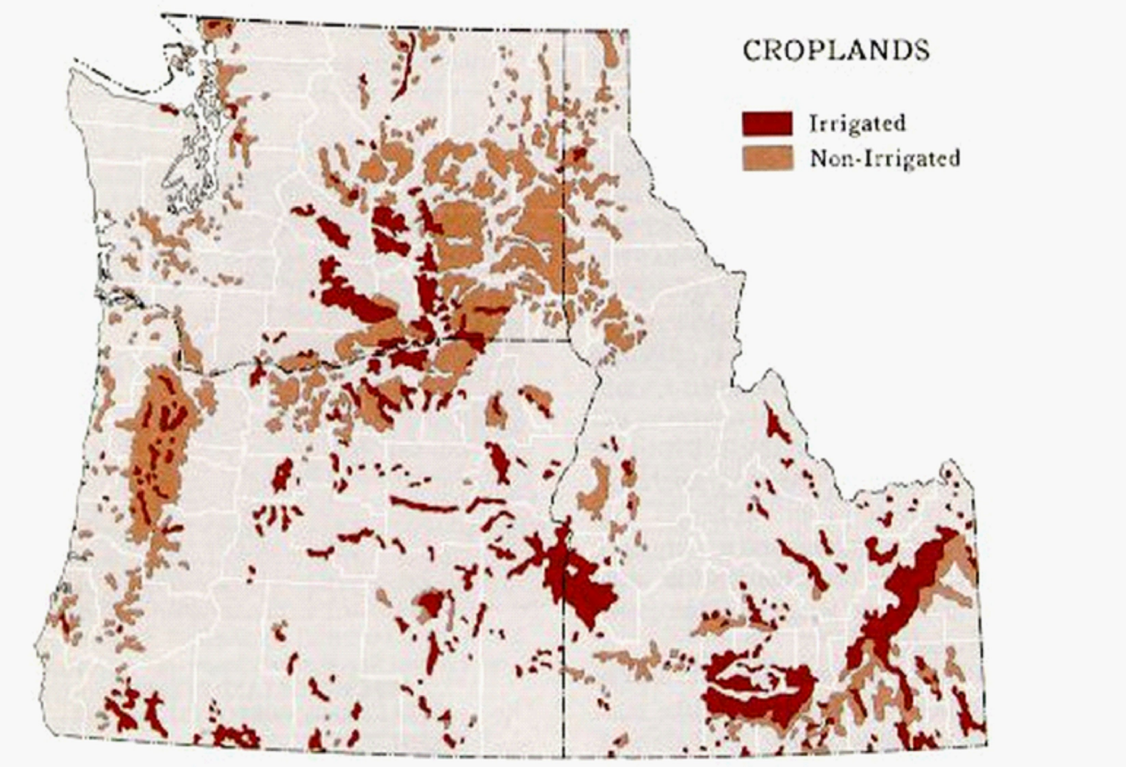



**Figure 3: Distribution of irrigated and non-irrigated cropland in the PNW from (Jackson and Kimmerling, 1993)**

**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 rainfed 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.

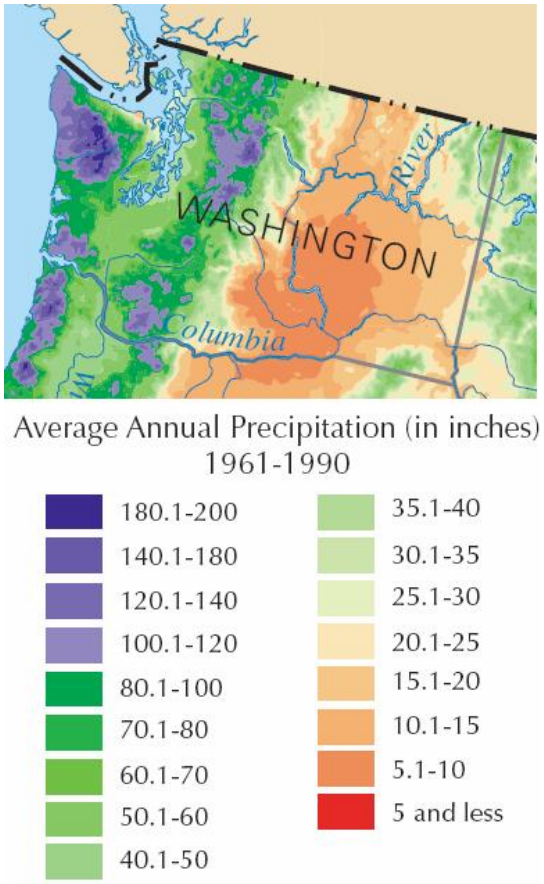



**Figure 4: Rainfall in Washington**

## 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 often employs 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).

### *Hemp cultivation*

No pesticides or herbicides are registered for hemp or cannabis. BCMAF notes that hemp is freer of pests than other crops, while weeds can be reduced to virtually zero under a dense hemp canopy (Food 1999). OSU concurs: 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 are not recyclable; 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, other lighting applications generate waste lamps that need management outside the standard municipal waste stream and this 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 overdrafted 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 criminals 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 photodeprivation and other advanced growing techniques. (Sanford 2010; Sanford 2010)

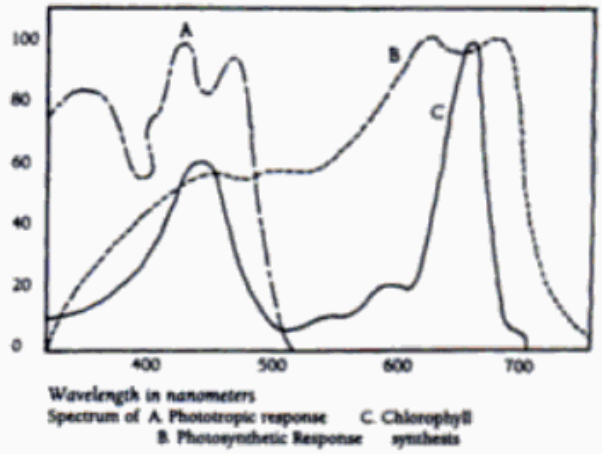
Indoor operations occur in buildings covered by existing Washington building regulations and conventional energy conservation practices such as insulation. The most important opportunities for environmental benefit lie in more efficient lighting equipment and timing to avoid peak use periods.

### *LEDs for indoor cultivation*

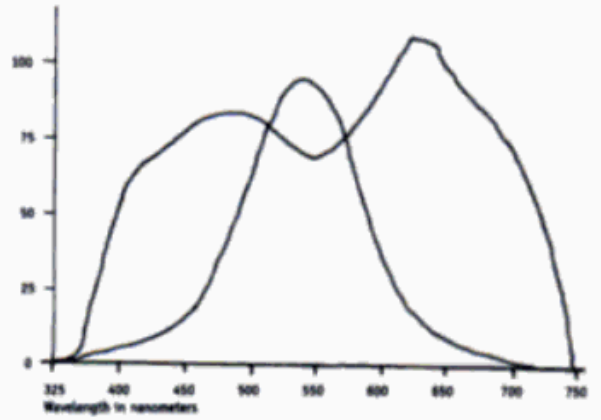
Light-emitting diodes (LEDs) have several advantages over high intensity discharge (HID) or high pressure sodium (HPS) lighting: lifetimes in excess of 100,000h, small size, specific wavelength, adjustable light intensity and quality, and high conversion efficiency (with low thermal losses) (Yeh and 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 2009, 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 substitute would create some offsetting environmental benefits/ 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)). This means that 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.

In general, policy analysts favor these practices in the reverse of the foregoing order, with incentive methods most preferred. 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.**

The LCB should consider allowing outdoor growing as either promises significant environmental advantages and 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. 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. Such a study should employ publicly available energy model software, such as EnergyPlus, to accurately model the effect of building material, glazing, orientation, layout, heating systems, and shading on energy consumption in targeted cultivation areas. 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. Smart meters and 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.

**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 branding 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 establish lighting disposal regulations*

Given the high potential for mercury release from HID bulbs, LCB should ensure proper disposal of bulbs used for cannabis production. As HID bulbs are not recyclable, LCB could mandate a separate lighting disposal stream to ensure that bulbs do not cause air or water contamination.

Appendix 1: Figures from Mills 2012

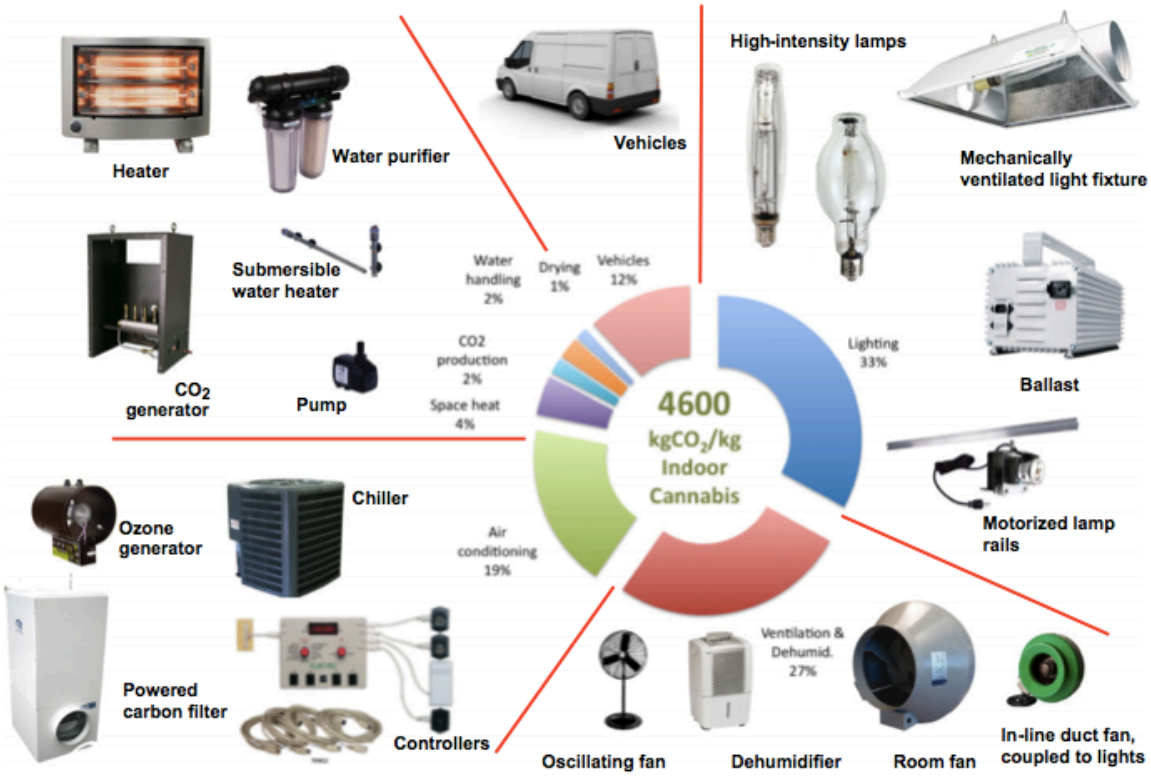



**Fig. A1 - Relative contribution of energy-consuming appliances to overall $CO_2$ emissions for indoor production of cannabis.**

**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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