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June 21, 2012

VIA PERSONAL DELIVERY

Council President Wesson and
Members of the Los Angeles City Council
City of Los Angeles
200 N. Sprint Street, Room 340
Los Angeles, CA 90012

Re: Council File 11-1737-S1 re Los Angeles Medical Marijuana Ordinance; Compliance with California Environmental Quality Act

Dear President Wesson and Council members:

This firm represents the Union of Medical Marijuana Patients ("UMMP") and Arts District Patients Collective, Inc. d/b/a Arts District Healing Center ("ADHC") with respect to the City of Los Angeles' ("City") proposed new medical marijuana ordinance ("Ordinance") banning so-called "medical marijuana businesses." On June 8, 2012, a detailed Analysis was filed with the City Clerk outlining the environmental effect of the proposed Ordinance. The Analysis concluded that the Ordinance was not exempt from the California Environmental Quality Act ("CEQA"). This letter outlines additional foreseeable environmental effects associated with the proposed Ordinance requiring review and mitigation under CEQA.

The Proposed Ordinance

In 2007, the City adopted Interim Control Ordinance ("ICO)" No. 179027, which prohibited the establishment of new medical marijuana collectives until such time as a permanent ordinance could be adopted. Significantly, the City broadly defined the prohibited activity. The City defined a "Medical Marijuana Dispensary" as follows: "**any** use, facility, or **location**, including but not limited to a retail store, office building, or structure **that distributes, transmits, gives, dispenses, facilitates or otherwise provides marijuana in any manner**, in accordance with State law, in particular, California Health and Safety Code Sections 11362.5 through 11362.83, inclusive." (emphasis added). A total of 219 medical marijuana collectives registered with the City under the ICO.

In 2010, the City adopted permanent Medical Marijuana Ordinance ("MMO") No. 181069. Section 45.19.6.1(B) of the MMO defined a "Medical Marijuana Collective" as follows: "An incorporated or unincorporated association, composed solely of four of more qualified patients, persons with identification cards, and designated primary caregivers of qualified patients and persons with identification cards . . . who associate at a particular location to collectively or cooperatively cultivate marijuana for medical purposes, in strict accordance with California Health and Safety Code Sections 11362.5. *et seq.*" No permits or "registrations" were issued by the City under the MMO and the City subsequently adopted Temporary Urgency Ordinance No. 181530, which amended the MMO to comply with court order.

The City's proposed Ordinance bans "medical marijuana businesses," which are defined in the draft ordinance as either of the following: "(1) Any location where marijuana is cultivated, processed, distributed, delivered or given away to a qualified patient, a person with an identification card, or a primary caregiver. (2) Any vehicle or other mode of transportation, stationary or mobile, which is used to transport, distribute, deliver, or give away marijuana to a qualified patient, a person with an identification card, or a primary caregiver." *See* Section 45.19.6.1(1)-(2). However, the proposed ordinance specifically excludes from the definition "Any **dwelling unit** where a maximum of three (3) or fewer qualified patients, persons with an identification card, and/or primary caregivers process or associate to **collectively or cooperatively cultivate marijuana on-site** for their own personal medical use or, with respect to the primary caregivers, for the personal medical use of the qualified patients or persons with an identification card who have designated the individual as a primary caregiver, in accordance with California Health and Safety Code Sections 11362.5 and 113621 et seq.;" *See* Section 45.19.6.1(3)(a) (emphasis added). Notably, the proposed ordinance requires all cultivation of medical marijuana to be conducted on-site within the City of Los Angeles and only allows medical marijuana collectives of less than four persons in "dwelling units."

Environmental Baseline

The CEQA Narrative ("Narrative") prepared by the Planning Department (ENV 2012-1273-CE) erroneously concludes that "the environmental baseline currently consists of no legally entitled medical marijuana business that the proposed ordinance will now restrict." Narrative at 5. The Narrative further states that "because currently no medical marijuana businesses are operating in conformance with the Zoning Code and should not be existing under the law, for purposes of CEQA the City exercise[s] its discretion to exclude them from the environmental baseline." *Id.* However, the legality of the existing medical marijuana collectives in the City does not relieve the City of the obligation to include them in the environmental baseline. In *Riverwatch v. County of San Diego* (1999) 76 Cal. App.4th 1428, 1451, the court held that the proper baseline is the existing condition of the site, even if that condition may be the result of prior illegal activity. The court explained in *Riverwatch* that CEQA is not "the appropriate forum for determining the nature and consequence of a prior conduct of a project applicant." 76 Cal. App.4th at 1452. The decision in *Riverwatch* has been followed by other courts. *See Eureka Citizens for Responsible Government v. City of Eureka* (2007) 147 Cal. App. 4th 357, 370 (citing *Riverwatch* and stating that the "environmental impacts should be examined in light of the environment as it exists when a project is approved.").

Moreover, it is a fundamentally accepted principle that environmental impacts should be examined in light of the environment as it exists when a project is approved. (Guidelines, § 15125, subd. (a); *Bloom v. McGurk* (1994) 26 Cal. App. 4th 1307, 1315, fn. 2; *City of Carmel-by-the-Sea v. Board of Supervisors* (1986) 183 Cal. App. 3d 229, 246; *Christward Ministry v. Superior Court* (1986) 184 Cal. App. 3d 180, 190; *Environmental Planning & Information Council v. County of El Dorado* (1982) 131 Cal. App. 3d 350, 358; Remy et al., Guide to the Cal. Environmental Quality Act (10th ed. 1999) p. 165.). In this case, there are at least 372 medical marijuana collectives in the City that have obtained tax registration certificates as of November 1, 2011, many of which the City has regulated and taxed for over 6 years. To exclude the consideration of these collectives on the basis that they are operating in violation of zoning code is an abuse of discretion and not supported by substantial evidence.

The City Has Failed to Consider Significant Environmental Impacts of New Cultivation Requirement

The Ordinance establishes several new legal requirements that did not previously exist under either the MMO or TUO. Notably, the Ordinance requires all cultivation of medical marijuana to be conducted on-site within the City of Los Angeles and only allows medical marijuana collectives of less than four persons in "dwelling units." Section 45.19.6.1(3)(a). Neither the MMO nor TUO required cultivation to take place in the City of Los Angeles or in a "dwelling unit," something that is not required under state law. Further, *City of Lake Forest v. Evergreen Holistic Collective* (4th Dist. 2012) 203 Cal.App.4th 1413, which held that cultivation was required to take place "on-site," has been accepted for review by the California Supreme Court and not citable pursuant to California Rules of Court. *Lake Forest, City of v. Evergreen Holistic Collective,* 2012 Cal. LEXIS 4728 (Cal. May 16, 2012). Currently, the medical marijuana used by existing qualified patients in the City of Los Angeles is not exclusively cultivated in the City of Los Angeles. The City has completely failed to address the significant environmental effects associated with this new requirement. The environmental impacts associated with indoor cultivation are significant and profound. A recent study entitled *The Carbon Footprint of Indoor Cannabis Production*, published in *The International Journal of the Political, Economic, Planning, Environmental and Social Aspects Energy*, detailed the environmental impacts of indoor cannabis cultivation (Exhibit 1). The following are highlights from the study:

- Indoor cannabis production utilizes highly energy intensive processes to control environmental conditions during cultivation.

- Indoor cannabis production results in energy expenditures of $6 billion each year--6-times that of the entire U.S. pharmaceutical industry--with electricity use equivalent to that of 2 million average U.S. homes. This corresponds to 1% of national electricity consumption or 2% of that in households.

- One average kilogram of cannabis is associated with 4600 kg of carbon dioxide emissions (greenhouse-gas pollution) to the atmosphere, or that of 3 million average U.S. cars when aggregated across all national production.

- In California, the top-producing state, indoor cultivation is responsible for about 3% of all electricity use or 9% of household use.

- The unchecked growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies.

- Shifting cultivation outdoors can nearly eliminate energy use for the cultivation process.

This study was the product of previous research conducted by the same author (Exhibit 2). The Narrative completely fails to analyze any of the reasonably foreseeable impacts of the Ordinance's cultivation requirement in "dwelling units." The Ordinance is not exempt from CEQA and there are significant environmental impacts, as outlined in the aforementioned studies, that the City has failed to mitigate.

Environmental Impacts of Forced Closure of Existing Medical Marijuana Collectives in the City

The City has failed to consider the impacts associated with the closure of the hundreds of existing medical marijuana collectives in the City and the significant environmental impacts associated with the creation of thousands of smaller, "micro-collectives" comprised of three or fewer persons in "dwelling units." Initially, it is important to understand that a project, or in this case the adoption of a new ordinance, need not directly effect a physical change in the environment: reasonably foreseeable indirect or secondary effects must also be analyzed. The relative inquiry is whether or not the project will ultimately culminate in physical changes to the environment. As described below, the Ordinance will unquestionably culminate in a physical change to the environment if existing medical marijuana collectives are compelled by the City to close and be replaced by thousands of small, "micro-collectives" cultivating within the City limits in "dwelling units." The City has completely failed to analyze the impacts of both the forced closure of existing collectives and the establishment of new "micro-collectives."

The environmental impacts of the Ordinance could be profound. The environmental factors that the City is compelled to consider include the following: (1) Aesthetics, (2) Agriculture and Forestry, (3) Air Quality, (4) Biological Resources, (5) Cultural Resources, (6) Geology / Soils, (7) Greenhouse Gas Emissions, (8) Hazards & Hazardous Materials, (9) Hydrology / Water Quality, (10) Land Use / Planning, (11) Mineral Resources, (12) Noise, (13) Population / Housing, (14) Public Services, (15) Recreation, (16) Transportation/Traffic, and (17) Utilities / Service Systems. While the Ordinance may not have a significant effect on the environment with respect to one particular environmental factor (e.g. Mineral Resources), it may nonetheless have a significant environmental effect on another factor (e.g. Transportation / Traffic). Without conducting an Initial Study and providing an opportunity for stakeholders to formally comment, the City has no way of knowing the effects on the environment. The Narrative prepared by the Planning Department is an inadequate substitute to the completion of an Initial Study.

Forcing all medical marijuana collectives in the City of Los Angeles to close will create thousands of small, "micro-collectives." Patients that currently are members of established medical marijuana collectives will be required to establish new, albeit much smaller, "micro-collectives" comprised of three or fewer persons, and will be required to cultivate marijuana in "dwelling units." There are reasonably foreseeable environmental consequences that implicate agriculture, air quality, water quality, traffic, land use planning, etc. Consider the following facts:

- Assuming medical marijuana patients comprise 2% of the Los Angeles population then there are 76,987 patients in Los Angeles.
- Since only collectives of three or fewer persons will be authorized under the Ordinance, at least 25,662 "micro-collectives" will need to be established to meet patient needs in the City of Los Angeles.
- Assuming patients use 1 ounce of marijuana per month, then 57,740 pounds of cannabis per year would need to be cultivated to meet patient needs in the City of Los Angeles.

The establishment of thousands of new "micro-collectives" and the cultivation of medical marijuana in "dwelling units," including single family residential zones, implicate significant environmental concerns and require meaningful review under CEQA. Obviously, cultivation sites will proliferate as a result of the Ordinance and additional waste water will be created as a result of these cultivation activities. Moreover, additional waste plant material (a.k.a bio-waste) will be created that must be disposed of properly. However, because these activities must take place in "dwelling units," the proper means of disposal is unclear and the City has failed to mitigate the foreseeable environmental impacts. Further, and as noted above, there will also be an increase in the electrical consumption that will be required. These facts are compelling and demonstrate potential significant environmental effects in terms of (1) Greenhouse Gas Emissions, (2) Hazards & Hazardous Materials, (3) Hydrology / Water Quality, and (4) Utilities / Service Systems.

Moreover, there are transportation/traffic and air quality issues that are implicated as well. It is undisputed that the Ordinance will require hundreds of existing medical marijuana collectives to close and create thousands of "micro-collectives" throughout the City. The Ordinance will also have another intended consequence – it will cluster these smaller "micro-collectives" within the areas of the City where "dwelling units" exist, including single family residential zones. There are significant environmental concerns associated with the cultivation of almost all medical marijuana in "dwelling units," as required by the Ordinance. Further, as previously noted, the City did not require all cultivation to take place in the City under the MMO and TUO. Moreover, the City did not require cultivation to take place exclusively in "dwelling units." Indeed, the City established "buffer zones" to ensure that such activities were kept a certain distance away from "sensitive uses." The Ordinance, however, completely eliminates such a requirement and the City has erroneously determined that the proposed action "will not result in a direct, or reasonably foreseeable indirect physical change in the environment." The establishment of new "micro-collectives" in residential zones creates significant environment impacts that the City has failed to mitigate, including, for example, the significant increases in electrical and water consumption required by cultivation in "dwelling units," the potentially hazardous waste associated with fertilizing and harvesting marijuana plants, and the odor associated with cultivation. Allowing larger groups of people to collectively cultivate medical marijuana provides for economies of efficiency that can reduce the inevitable environmental impacts of an inherently agricultural activity. Further, allowing such activities to take place outside "dwelling units" can reduce environmental impacts. City has failed to mitigate the impacts associated with the Ordinance to ensure that they are "less than significant."

Further, the City has failed to consider the traffic impacts associated with the closure of existing collectives and the establishment of thousands of smaller "micro-collectives." Because collectives are necessarily comprised of patients and caregivers that live in the community (and presumably in residential areas), these individuals (who have a medical need) may have to travel much further to visit the "micro-collective" of which they are a member. Patients will likely travel by car or public transit. Also, those patients that were previously within walking distance of their collective must now drive or use public transit to visit their new "micro-collective." In essence, the closure of existing collectives and the establishment of thousands of new "micro-collectives" turn certain patients into commuters. Further, significant land use/planning impacts may result from the Ordinance. The creation of thousands of new "micro-collectives" in areas of the City where "dwelling units" exist (such as single family residential zones) creates land use compatibility problems that the City is compelled to analyze under CEQA. There are also environmental concerns in the form of "Public Services." Collectives are inherently formed for the collective cultivation of medical marijuana and are comprised of patients with medical needs. Patient member services (which span the gamut and are often designed for healing) will be impacted when existing collectives are forced and be destroyed then. This could have an effect on "public services."

Finally, there are cultural resources that the City must consider under CEQA. Existing medical marijuana collectives are communities made up of patients and caregivers. A collective is NOT about the mere distribution and cultivation of medical marijuana. For example, ADHC offers a range of patient member services, including (1) Live Music, (2) Organic Food, (3) Community Gardening, (4) Art, and (5) Counseling. Both patients and healing practitioners visit ADHC to assist patients who are experiencing medical problems. ADHC also has a gallery and curator. Artists often come from the local community, including patients. Counseling is also provided such as acupuncture, tax advice, and emotional counseling. Much like a church is much more than just a place to worship, a collective is more than a place for the collective cultivation of marijuana. On the contrary, a wide range of patient member services are offered at many collectives and communities have developed around these collectives. An Ordinance requiring the closure of all existing medical marijuana collectives threatens to destroy this community. Local artists would not have ADHC has a venue to display work and, most importantly, an established piece of the local community for over 6 years would simply disappear. Any ordinance that threatens to shut down a patient organization is disrupting the culture that has developed within these collectives. This would certainly impact cultural resources and requires review under CEQA.

Conclusion

While the above discussion is not intended to be an exhaustive list of the reasonably foreseeable indirect or secondary effects of the Ordinance, it is illustrative of the types of impacts that the City must analyze. A fair argument has been outlined regarding the significant environmental effects of the Ordinance. As such, the City is compelled to prepare an Initial Study pursuant to §15063 of the California Public Resources Code as there are no applicable exemptions established in Division 13, Articles 18 or 19 of the California Public Resources Code. The Narrative prepared by the Planning Department is an inadequate substitute to an Initial Study and is seriously flawed. Moreover, even if the Narrative were an adequate substitute to an Initial Study, as demonstrated in the instant letter and previous Analysis filed with the City Clerk, the Ordinance will have a significant effect on the environment and the City has failed to mitigate these impacts as required under CEQA. As such, the City is required to prepare an Environmental Impact Report. CEQA Guidelines, § 15002, subd. (k); *No Oil, Inc. v. City of Los Angeles* (1974) 13 Cal. 3d 68, 74 (If the initial study shows that the project may have a significant effect, the lead agency takes the third step and prepares an Environmental Impact Report.)

Sincerely,

Jamie T. Hall
Attorney for Union of Medical Marijuana Patients and Arts District Healing Center

Exhibit 1

Energy Policy 46 (2012) 58–67

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The carbon footprint of indoor *Cannabis* production

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ARTICLE INFO

Article history:
Received 7 September 2011
Accepted 10 March 2012
Available online 17 April 2012

Keywords:
Energy
Buildings
Horticulture

ABSTRACT

The emergent industry of indoor *Cannabis* production – legal in some jurisdictions and illicit in others – utilizes highly energy intensive processes to control environmental conditions during cultivation. This article estimates the energy consumption for this practice in the United States at 1% of national electricity use, or $6 billion each year. One average kilogram of final product is associated with 4600 kg of carbon dioxide emissions to the atmosphere, or that of 3 million average U.S. cars when aggregated across all national production. The practice of indoor cultivation is driven by criminalization, pursuit of security, pest and disease management, and the desire for greater process control and yields. Energy analysts and policymakers have not previously addressed this use of energy. The unchecked growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. While criminalization has contributed to the substantial energy intensity, legalization would not change the situation materially without ancillary efforts to manage energy use, provide consumer information via labeling, and other measures. Were product prices to fall as a result of legalization, indoor production using current practices could rapidly become non-viable.

1. Introduction

On occasion, previously unrecognized spheres of energy use come to light. Important historical examples include the pervasive air leakage from ductwork in homes, the bourgeoning energy intensity of computer datacenters, and the electricity "leaking" from billions of small power supplies and other equipment. Intensive periods of investigation, technology R&D, and policy development gradually ensue in the wake of these discoveries. The emergent industry of indoor *Cannabis* production appears to have joined this list.[1]

This article presents a model of the modern-day production process – based on public-domain sources – and provides first-order national scoping estimates of the energy use, costs, and greenhouse-gas emissions associated with this activity in the United States. The practice is common in other countries but a global assessment is beyond the scope of this report.

2. Scale of activity

The large-scale industrialized and highly energy-intensive indoor cultivation of *Cannabis* is a relatively new phenomenon, driven by criminalization, pursuit of security, pest and disease management, and the desire for greater process control and yields (U.S. Department of Justice, 2011a; World Drug Report, 2009). The practice occurs across the United States (Hudson, 2003; Gettman, 2006). The 415,000 indoor plants eradicated by authorities in 2009 (and 10.3 million including outdoor plantations) (U.S. Department of Justice, 2011a, b) presumably represent only a small fraction of total production.

Cannabis cultivation is today legal in 15 states plus the District of Columbia, although it is not federally sanctioned (Peplow, 2005). It is estimated that 24.8 million Americans are eligible to receive a doctor's recommendation to purchase or cultivate *Cannabis* under existing state laws, and approximately 730,000 currently do so (See Change Strategy, 2011). In California alone, 400,000 individuals are currently authorized to cultivate *Cannabis* for personal medical use, or sale for the same purpose to 2100 dispensaries (Harvey, 2009). Approximately 28.5 million people in the United States are repeat consumers, representing 11% of the population over the age of 12 (U.S. Office of National Drug Control Policy, 2011).

Cultivation is also substantial in Canada. An estimated 17,500 "grow" operations in British Columbia (typically located in residential buildings) are equivalent to 1% of all dwelling units Province-wide, with an annual market value of $7 billion (Easton, 2004).

Official estimates of total U.S. *Cannabis* production varied from 10,000 to 24,000 metric ton per year as of 2001, making it the nation's largest crop by value at that time (Hudson, 2003; Gettman, 2006). A recent study estimated national production at far higher levels (69,000 metric ton) (HIDTA, 2010). Even at the

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[1] This article substantively updates and extends the analysis described in Mills (2011).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.03.023

lower end of this range (chosen as the basis of this analysis), the level of activity is formidable and increasing with the demand for *Cannabis*.

No systematic efforts have previously been made to estimate the aggregate energy use of these activities.

3. Methods and uncertainties

This analysis is based on a model of typical *Cannabis* production, and the associated energy use for cultivation and transportation based on market data and first-principals buildings energy end-use modeling techniques. Data sources include equipment manufacturer data, trade media, the open literature, and interviews with horticultural equipment vendors. All assumptions used in the analysis are presented in Appendix A. The resulting normalized (per-kilogram) energy intensity is driven by the effects of indoor-environmental conditions, production processes, and equipment efficiencies.

Considerable energy use is also associated with transportation, both for workers and for large numbers of small-quantities transported and then redistributed over long distances before final sale.

This analysis reflects typical practices, and is thus intended as a "central estimate". While processes that use less energy on a per-unit-yield basis are possible, much more energy-intensive scenarios also occur. Certain strategies for lowering energy inputs (e.g., reduced illumination levels) can result in lower yields, and thus not necessarily reduce the ultimate energy-intensity per unit weight. Only those strategies that improve equipment and process energy efficiency, while not correspondingly attenuating yields would reduce energy intensity.

Due to the proprietary and often illicit nature of Cannabis cultivation, data are intrinsically uncertain. Key uncertainties are total production and the indoor fraction thereof, and the corresponding scaling up of relatively well-understood intensities of energy use per unit of production to state or national levels could result in 50% higher or lower aggregate results. Greenhouse-gas emissions estimates are in turn sensitive to the assumed mix of on- and off-grid power production technologies and fuels, as off-grid production (almost universally done with diesel generators) can – depending on the prevailing fuel mix in the grid – have substantially higher emissions per kilowatt-hour than grid power. Final energy costs are a direct function of the aforementioned factors, combined with electricity tariffs, which vary widely geographically and among customer classes. The assumptions about vehicle energy use are likely conservative, given the longer-range transportation associated with interstate distribution.

Some localities (very cold and very hot climates) will see much larger shares of production indoors, and have higher space-conditioning energy demands than the typical conditions assumed here. More in-depth analyses could explore the variations introduced by geography and climate, alternate technology configurations, and production techniques.

4. Energy implications

Accelerated electricity demand growth has been observed in areas reputed to have extensive indoor *Cannabis* cultivation. For example, following the legalization of cultivation for medical purposes (Phillips, 1998; Roth, 2005; Clapper et al., 2010) in California in 1996, Humboldt County experienced a 50% rise in per-capita residential electricity use compared to other parts of the state (Lehman and Johnstone, 2010).

Aside from sporadic news reports (Anderson, 2010; Quinones, 2010), policymakers and consumers possess little information on the energy implications of this practice. A few prior studies tangentially mentioning energy use associated with *Cannabis* production used cursory methods and under-estimate energy use significantly (Plecas et al., 2010 and Caulkins, 2010).

Driving the large energy requirements of indoor production facilities are lighting levels matching those found in hospital operating rooms (500-times greater than recommended for reading) and 30 hourly air changes (6-times the rate in high-tech laboratories, and 60-times the rate in a modern home). Resulting power densities are on the order of 2000 W/m^2, which is on a par with that of modern datacenters. Indoor carbon dioxide (CO_2) levels are often raised to 4-times natural levels in order to boost plant growth. However, by shortening the growth cycle, this practice may reduce final energy intensity.

Specific energy uses include high-intensity lighting, dehumidification to remove water vapor and avoid mold formation, space heating or cooling during non-illuminated periods and drying, pre-heating of irrigation water, generation of carbon dioxide by burning fossil fuel, and ventilation and air-conditioning to remove waste heat. Substantial energy inefficiencies arise from air cleaning, noise and odor suppression, and inefficient electric generators used to avoid conspicuous utility bills. So-called "grow houses" – residential buildings converted for *Cannabis* production – can contain 50,000 to 100,000 W of installed lighting power (Brady, 2004). Much larger facilities are also used.

Based on the model developed in this article, approximately 13,000 kW/h/year of electricity is required to operate a standard production module (a $1.2 \times 1.2 \times 2.4$ m ($4 \times 4 \times 8$ ft) chamber). Each module yields approximately 0.5 kg (1 pound) of final product per cycle, with four or five production cycles conducted per year. A single grow house can contain 10 to 100 such modules.

To estimate national electricity use, these normalized values are applied to the lower end of the range of the aforementioned estimated production (10,000 t per year), with one-third of the activity takes place under indoor conditions. This indicates electricity use of about 20 TW/h/year nationally (including off-grid production). This is equivalent to that of 2 million average U.S. homes, corresponding to approximately 1% of national electricity consumption — or the output of 7 large electric power plants (Koomey et al., 2010). This energy, plus associated fuel uses (discussed below), is valued at $6 billion annually, with associated emissions of 15 million metric ton of CO_2 — equivalent to that of 3 million average American cars (Fig. 1 and Tables 1–3.)

Fuel is used for several purposes, in addition to electricity. The carbon dioxide injected into grow rooms to increase yields is produced industrially (Overcash et al., 2007) or by burning propane or natural gas within the grow room contributes about 1–2% to the carbon footprint and represents a yearly U.S. expenditure of $0.1 billion. Vehicle use associated with production and distribution contributes about 15% of total emissions, and represents a yearly expenditure of $1 billion. Off-grid diesel- and gasoline-fueled electric generators have per-kilowatt-hour emissions burdens that are 3- and 4-times those of average grid electricity in California. It requires 70 gallon of diesel fuel to produce one indoor *Cannabis* plant (or the equivalent yield per unit area), or 140 gallon with smaller, less-efficient gasoline generators.

In California, the top-producing state, indoor cultivation is responsible for about 3% of all electricity use, or 9% of household use.[2] This corresponds to the electricity use of 1 million average California homes, greenhouse-gas emissions equal to those from 1 million average cars, and energy expenditures of $3 billion per

[2] This is somewhat higher than estimates previously made for British Columbia, specifically, 2% of total Provincial electricity use or 6% of residential use (Garis, 2008; Bellett, 2010).

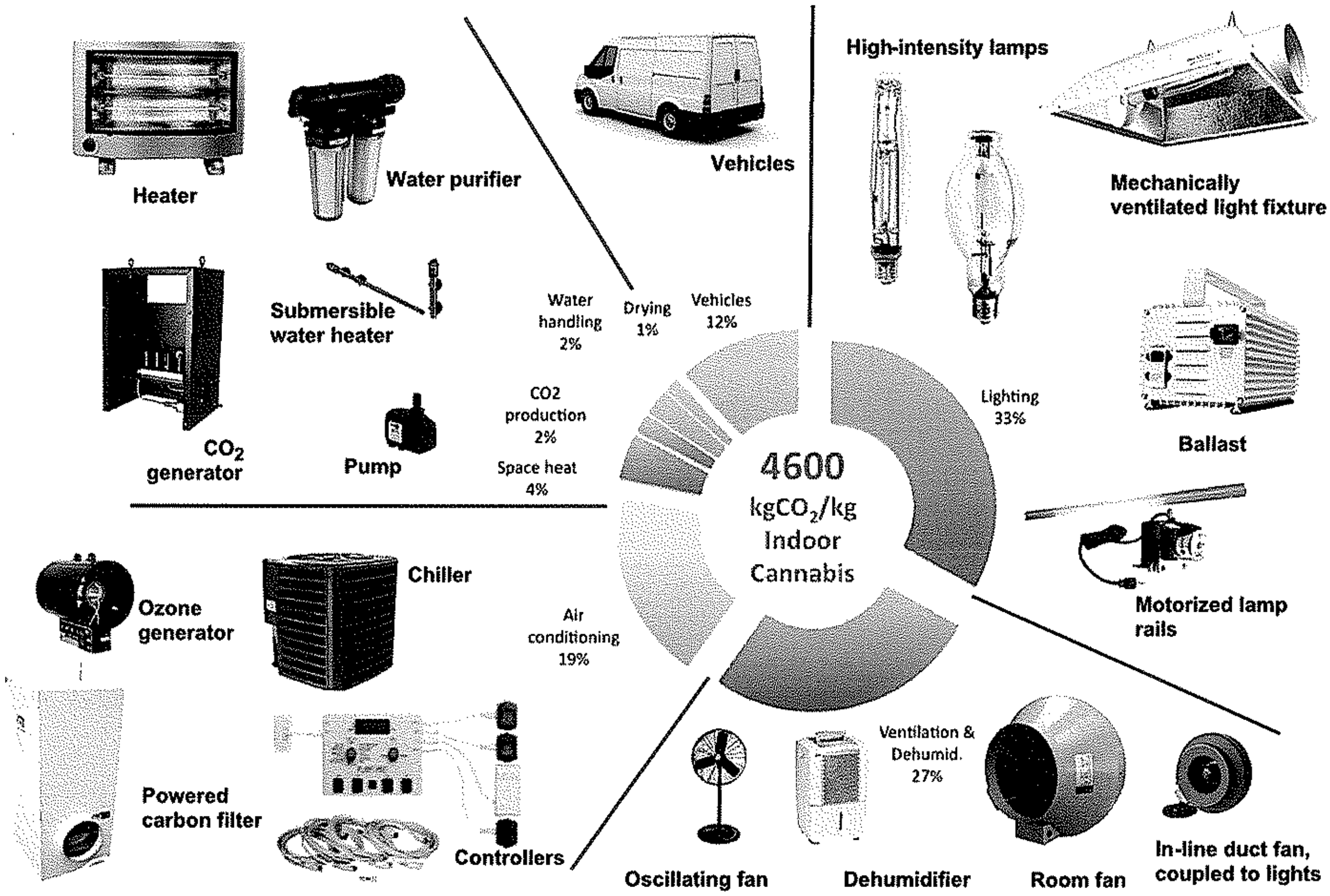

Fig. 1. Carbon footprint of indoor Cannabis production.

Table 1
Carbon footprint of indoor *Cannabis* production, by end use (average U.S conditions).

	Energy intensity (kW/h/kg yield)	Emissions factor ($kgCO_2$ emissions/kg yield)	
Lighting	2283	1520	33%
Ventilation & dehumid.	1848	1231	27%
Air conditioning	1284	855	19%
Space heat	304	202	4%
CO_2 injected to increase foliage	93	82	2%
Water handling	173	115	2%
Drying	90	60	1%
Vehicles		546	12%
Total	6074	4612	100%

Note: The calculations are based on U.S.-average carbon burdens of 0.666 kg/kW/h. "CO_2 injected to increase foliage" represents combustion fuel to make on-site CO_2. Assumes 15% of electricity is produced in off-grid generators.

year. Due to higher electricity prices and cleaner fuels used to make electricity, California incurs 50% of national energy costs but contributes only 25% of national CO_2 emissions from indoor *Cannabis* cultivation.

From the perspective of individual consumers, a single *Cannabis* cigarette represents 1.5 kg (3 pounds) of CO_2 emissions, an amount equal to driving a 44 mpg hybrid car 22 mile or running a 100-watt light bulb for 25 h, assuming average U.S. electricity emissions. The electricity requirement for one single production module equals that of an average U.S. home and twice that of an average California home. The added electricity use is equivalent to running about 30 refrigerators.

From the perspective of a producer, the national-average annual energy costs are approximately $5500 per module or $2500 per kilogram of finished product. This can represent half the wholesale value of the finished product (and a substantially lower portion at retail), depending on local conditions. For average U.S. conditions, producing one kilogram of processed *Cannabis* results in 4600 kg of CO_2 emissions to the atmosphere (and 50% more when off-grid diesel power generation is used), a very significant carbon footprint. The emissions associated with one kilogram of processed *Cannabis* are equivalent to those of driving across country 11 times in a 44-mpg car.

These results reflect typical production methods. Much more energy-intensive methods occur, e.g., rooms using 100% recirculated air with simultaneous heating and cooling, hydroponics, or energy end uses not counted here such as well-water pumps and water purification systems. Minimal information and consideration of energy use, coupled with adaptations for security and privacy (off-grid generation, no daylighting, odor and noise control) lead to particularly inefficient configurations and correspondingly elevated energy use and greenhouse-gas emissions.

The embodied energy of inputs such as soil, fertilizer, water, equipment, building materials, refinement, and retailing is not estimated here and should be considered in future assessments. The energy use for producing outdoor-grown *Cannabis* (approximately two-thirds of all production) is also not estimated here.

Table 2
Equivalencies.

Indoor Cannabis production consumes...	**3%**	of California's total electricity, and	**9%**	of California's household electricity	**1%**	of total U.S. electricity, and	2% of U.S. household electricity
U.S. Cannabis production & distribution energy costs...	**$ 6**	Billion, and results in the emissions of	**15**	Million tonnes per year of greenhouse gas emissions (CO_2)	Equal to the emissions of	**3**	million average cars
U.S. electricity use for Cannabis production is equivalent to that of...	**1.7**	Million average U.S. homes	**or**	**7**	Average U.S. power plants		
California Cannabis production and distribution energy costs...	**$ 3**	Billion, and results in the emissions of	**4**	Million tonnes per year of greenhouse gas emissions (CO_2)	Equal to the emissions of	**1**	Million average cars
California electricity use for Cannabis production is equivalent to that of...	**1**	Million average California homes					
A typical 4 × 4 × 8-ft production module, accomodating four plants at a time, consumes as much electricity as...	**1**	Average U.S. homes, or	**2**	Average California homes	or	**29**	Average new refrigerators
Every 1 kilogram of Cannabis produced using national-average grid power results in the emissions of...	**4.3**	Tonnes of CO_2	Equivalent to	**7**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Every 1 kg of Cannabis produced using a prorated mix of grid and off-grid generators results in the emissions of...	**4.6**	Tonnes of CO_2	Equivalent to	**8**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Every 1 kg of Cannabis produced using off-grid generators results in the emissions of...	**6.6**	Tonnes of CO_2	Equivalent to	**11**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Transportation (wholesale+retail) consumes...	**226**	Liters of gasoline per kg	or	**$ 1**	Billion dollars annually, and	**546**	Kilograms of CO_2 per kilogram of final product
One Cannabis cigarette is like driving...	**37**	km in a 5.3 l/100 km (44 mpg) car	Emitting about	**2**	kg of CO_2, which is equivalent to operating a 100-watt light bulb for	**25**	Hours
Of the total wholesale price...	**49%**	Is for energy (at average U.S. prices)					

If improved practices applicable to commercial agricultural greenhouses are any indication, such large amounts of energy are not required for indoor *Cannabis* production.[3] The application of cost-effective, commercially-available efficiency improvements to the prototypical facility modeled in this article could reduce energy intensities by at least 75% compared to the typical-efficiency baseline. Such savings would be valued at approximately $40,000/year for a generic 10-module operation (at California energy prices and $10,000/year at U.S. average prices) (Fig. 2(a)–(b). These estimated energy use reductions reflect practices that are commonplace in other contexts such as more efficient components and controls (lights, fans, space-conditioning), use of daylight, optimized air-handling systems, and relocation of heat-producing equipment out of the cultivation room. Moreover, strain choice alone results in a factor-of-two difference in yields per unit of energy input (Arnold, 2011).

5. Energy intensities in context

Policymakers and other interested parties will rightfully seek to put these energy indicators in context with other activities in the economy.

One can readily identify other energy end-use activities with far greater impacts than that of *Cannabis* production. For example, automobiles are responsible for about 33% of U.S. greenhouse-gas emissions (USDOE, 2009), which is100-times as much as those produced by indoor *Cannabis* production (0.3%). The approximately 20 TW/h/year estimated for indoor *Cannabis* production is about one/third that of U.S. data centers (US EPA, 2007a, 2007b), or one-seventh that of U.S. household refrigerators (USDOE, 2008). These shares would be much higher in states where *Cannabis* cultivation is concentrated (e.g., one half that of refrigerators in California (Brown and Koomey, 2002)).

On the other hand, this level of energy use is high in comparision to that used for other indoor cultivation practices, primarily owing to the lack of daylighting. For comparison, the energy intensity of Belgian greenhouses is estimated at approximately 1000 MJ/m^2 (De Cock and Van Lierde, No date), or about 1% that estimated here for indoor *Cannabis* production.

[3] See, e.g., this University of Michigan resource: http://www.hrt.msu.edu/energy/Default.htm

Table 3
Energy indicators (average U.S. conditions).

	per cycle, per production module	per year, per production module	
Energy use			
Connected load		3,225	(watts/module)
Power density		2,169	(watts/m^2)
Elect	2756	12,898	(kW/h/module)
Fuel to make CO_2	0.3	1.6	(GJ)
Transportation fuel	27	127	(Gallons
On-grid results			
Energy cost	846	3,961	$/module
Energy cost		1,866	$/kg
Fraction of wholesale price		47%	
CO_2 emissions	1936	9,058	kg
CO_2 emissions		4,267	kg/kg
Off-grid results (diesel)			
Energy cost	1183	5,536	$/module
Energy cost		2,608	$/kg
Fraction of wholesale price		65%	
CO_2 emissions	2982	13,953	kg
CO_2 emissions		6,574	kgCO_2/kg
Blended on/off grid results			
Energy cost	897	4,197	$/module
Energy cost		1,977	$/kg
Fraction of wholesale price		49%	
CO_2 emissions	2093	9,792	kg
CO_2 emissions		4,613	kgCO_2/kg
Of which, indoor CO_2 production	9	42	kgCO_2
Of which, vehicle use			
Fuel use			
During production		79	Liters/kg
Distribution		147	Liters/kg
Cost			
During production		77	$/kg
Distribution		143	$/kg
Emissions			
During production		191	kgCO_2/kg
Distribution		355	kgCO_2/kg

Energy intensities can also be compared to those of other sectors and activities.

- Pharmaceuticals — Energy represents 1% of the value of U.S. pharmaceutical shipments (Galitsky et al., 2008) versus 50% of the value of Cannabis wholesale prices. The U.S. "Pharma" sector uses $1 billion/year of energy; Indoor Cannabis uses $6 billion.
- Other industries — Defining "efficiency" as how much energy is required to generate economic value, Cannabis comes out the highest of all 21 industries (measured at the three-digit SIC level). At ~20 MJ per thousand dollars of shipment value (wholesale price), Cannabis is followed next by paper (~14), nonmetallic mineral products (~10), primary metals (~8), petroleum and coal products (~6), and then chemicals (~5) (Fig. 3). However, energy intensities are on a par with *Cannabis* in various subsectors (e.g., grain milling, wood products, rubber) and exceed those of *Cannabis* in others (e.g., pulp mills).
- Alcohol — The energy used to produce one marijuana cigarette would also produce 18 pints of beer (Galitsky et al., 2003).
- Other building types — Cannabis production requires 8-times as much energy per square foot as a typical U.S. commercial building (4x that of a hospital and 20x that of a building for religious worship), and 18-times that of an average U.S. home (Fig. 4).

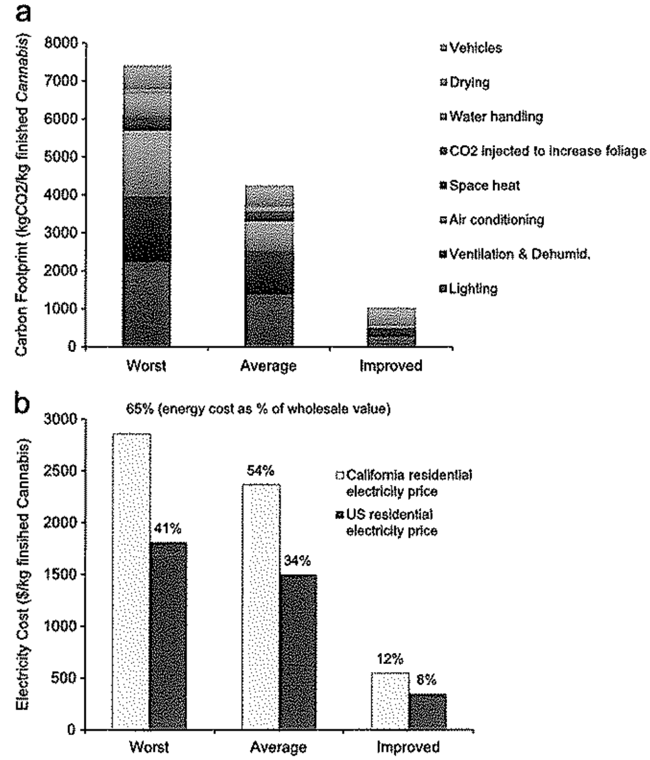

Fig. 2. Carbon footprint and energy cost for three levels of efficiency. (a) Indoor cannabis: carbon footprint. (b) Indoor cannabis: electricity cost. Assumes a wholesale price of $4400/kg. Wholesale prices are highly variable and poorly documented.

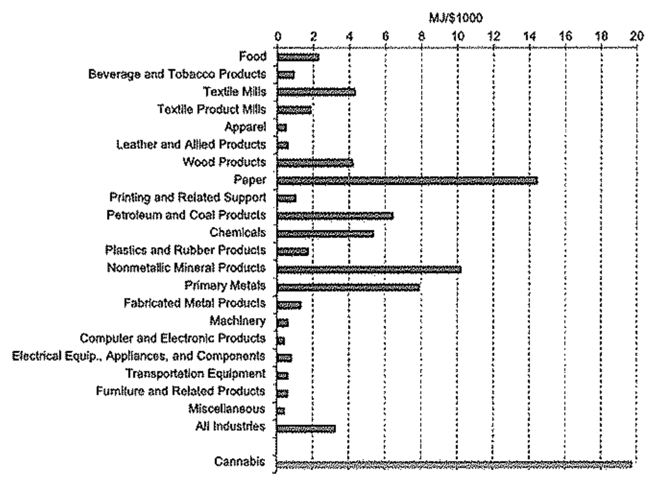

Fig. 3. Comparative energy intensities, by sector (2006).

6. Outdoor cultivation

Shifting cultivation outdoors can nearly eliminate energy use for the cultivation process. Many such operations, however, require water pumping as well as energy-assisted drying techniques. Moreover, vehicle transport during production and distribution remains part of the process, more so than for indoor operations.

A common perception is that the potency of *Cannabis* produced indoors exceeds that of that produced outdoors, leading

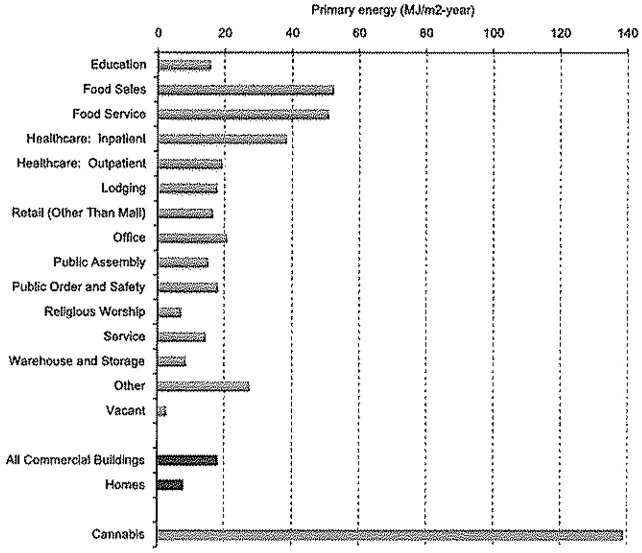

Fig. 4. Comparative energy intensities, by U.S. building type (2003).

consumers to demand *Cannabis* produced indoors. Federal sources (National Drug Intelligence Center, 2005) as well as independent testing laboratories (Kovner, 2011) actually find similar potencies when best practices are used.

Illegal clearing of land is common for multi-acre plantations, and, depending on the vegetation type, can accordingly mobilize greenhouse-gas emissions. Standing forests (a worst-case scenario) hold from 125 to 1500 t of CO_2 per hectare, depending on tree species, age, and location (National Council for Air and Soil Improvement, 2010). For biomass carbon inventories of 750 t/ha and typical yields (5000 kg/ha) (UNODC, 2009), associated biomass-related CO_2 emissions would be on the order of 150 kg CO_2/kg *Cannabis* (for only one harvest per location), or 3% of that associated with indoor production. These sites typically host on the order of 10,000 plants, although the number can go much higher (Mallery, 2011). When mismanaged, the practice of outdoor cultivation imposes multiple environmental impacts aside from energy use. These include deforestation; destruction of wetlands, runoff of soil, pesticides, insecticides, rodenticides, and human waste; abandoned solid waste; and unpermitted impounding and withdrawals of surface water (Mallery, 2011; Revelle, 2009). These practices can compromise water quality, fisheries, and other ecosystem services.

7. Policy considerations

Current indoor *Cannabis* production and distribution practices result in prodigious energy use, costs, and unchecked greenhouse-gas pollution. While various uncertainties exist in the analysis, the overarching qualitative conclusions are robust. More in-depth analysis and greater transparency of the energy impacts of this practice could improve decision-making by policymakers and consumers alike.

There is little, if any, indication that public policymakers have incorporated energy and environmental considerations into their deliberations on *Cannabis* production and use. There are additional adverse impacts of the practice that merit attention, including elevated moisture levels associated with indoor cultivation that can cause extensive damage to buildings,[4] as well as electrical fires caused by wiring out of compliance with safety codes (Garis, 2008). Power theft is common, transferring those energy costs to the general public (Plecas et al., 2010). As noted above, simply shifting production outdoors can invoke new environmental impacts if not done properly.

Energy analysts have also not previously addressed the issue. Aside from the attention that any energy use of this magnitude normally receives, the hidden growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. For example, Auffhammer and Aroonruengsawat (2010) identified a

[4] For observations from the building inspectors community, see http://www.nachi.org/marijuana-grow-operations.htm

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%	

Table A2
Assumptions and conversion factors.

Service levels		
Illuminance*	25–100	1000 lux
Airchange rates*	30	Changes per hour
Operations		
Cycle duration**	78	Days
Cycles/year**	4.7	Continuous production
Airflow**	96	Cubic feet per minute, per module
Lighting		
Leafing phase		
Lighting on-time*	18	hrs/day
Duration*	18	days/cycle
Flowering phase		
Lighting on-time*	12	hrs/day
Duration*	60	days/cycle
Drying		
Hours/day*	24	hrs
Duration*	7	days/cycle
Equipment		
Average air-conditioning age	5	Years
Air conditioner efficiency [Standards increased to SEER 13 on 1/23/2006]	10	SEER
Fraction of lighting system heat production removed by luminaire ventilation	0.3	
Diesel generator efficiency*	27%	55 kW
Propane generator efficiency*	25%	27 kW
Gasoline generator efficiency*	15%	5.5 kW
Fraction of total prod'n with generators*	15%	
Transportation: Production phase (10 modules)	25	Miles roundtrip
Daily service (1 vehicle)	78	Trips/cycle. Assume 20% live on site
Biweekly service (2 vehicles)	11.1	Trips/cycle
Harvest (2 vehicles)	10	Trips/cycle
Total vehicle miles**	2089	Vehicle miles/cycle
Transportation: Distribution		
Amount transported wholesale	5	kg per trip
Mileage (roundtrip)	1208	km/cycle
Retail (0.25oz × 5 miles roundtrip)	5668	Vehicle-km/cycle
Total**	6876	Vehicle-km/cycle
Fuel economy, typical car [a]	10.7	l/100 km
Annual emissions, typical car [a]	5195	$kgCO_2$
	0	$kgCO_2$/mile
Annual emissions, 44-mpg car**	2,598	$kgCO_2$
	0.208	$kgCO_2$/mile
Cross-country U.S. mileage	4493	km
Fuels		
Propane [b]	25	MJ/liter
Diesel [b]	38	MJ/liter
Gasoline [b]	34	MJ/liter
Electric generation mix*		
Grid	85%	share
Diesel generators	8%	share
Propane generators	5%	share
Gasoline generators	2%	share
Emissions factors		
Grid electricity — U.S. [c]	0.609	$kgCO_2$/kW/h
Grid electricity — CA [c]	0.384	$kgCO_2$/kW/h
Grid electricity — non-CA U.S. [c]	0.648	$kgCO_2$/kW/h
Diesel generator**	0.922	$kgCO_2$/kW/h
Propane generator**	0.877	$kgCO_2$/kW/h
Gasoline generator**	1.533	$kgCO_2$/kW/h
Blended generator mix**	0.989	$kgCO_2$/kW/h
Blended on/off-grid generation — CA**	0.475	$kgCO_2$/kW/h
Blended on/off-grid generation — U.S.**	0.666	$kgCO_2$/kW/h
Propane combustion	63.1	$kgCO_2$/MBTU
Prices		
Electricity price — grid (California — PG&E) [d]	0.390	per kW/h (Tier 5)
Electricity price — grid (U.S.) [e]	0.247	per kW/h
Electricity price — off-grid**	0.390	per kW/h
Electricity price — blended on/off — CA**	0.390	per kW/h
Electricity price — blended on/off — U.S.**	0.268	per kW/h
Propane price [f]	0.58	$/liter
Gasoline price — U.S. average [f]	0.97	$/liter
Diesel price — U.S. average [f]	1.05	$/liter
Wholesale price of Cannabis [g]	4,000	$/kg
Production		
Plants per production module*	4	
Net production per production module [h]	0.5	kg/cycle
U.S. production (2011) [i]	10,000	metric tonnes/y
California production (2011) [i]	3,902	metric tonnes/y
Fraction produced indoors [i]	33%	
U.S. indoor production modules**	1,570,399	
Calif indoor production modules**	612,741	
Cigarettes per kg**	3,000	
Other		
Average new U.S. refrigerator	450	kW/h/year
	173	$kgCO_2$/year (U.S. average)
Electricity use of a typical U.S. home — 2009 [j]	11,646	kW/h/year
Electricity use of a typical California home — 2009 [k]	6,961	kW/h/year

Notes:
* Trade and product literature; interviews with equipment vendors.
** Calculated from other values.
Notes for Table A2.
[a]. U.S. Environmental Protection Agency., 2011.
[b]. *Energy conversion factors*, U.S. Department of Energy, http://www.eia.doe.gov/energyexplained/index.cfm?page=about_energy_units, [Accessed February 5, 2011].
[c]. United States: (USDOE 2011); California (Marnay et al., 2002).
[d]. Average prices paid in California and other states with inverted-block tariffs are very high because virtually all consumption is in the most expensive tiers. Here the PG&E residential tariff as of 1/1/11, Tier 5 is used as a proxy for California http://www.pge.com/tariffs/ResElecCurrent.xls, (Accessed February 5, 2011). In practice a wide mix of tariffs apply, and in some states no tier structure is in place, or the proportionality of price to volume is nominal.
[e]. State-level residential prices, weighted by *Cannabis* production (from Gettman, 2006) with actual tariffs and U.S. Energy Information Administration, "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State", http://www.eia.doe.gov/electricity/epm/table5_6_a.html, (Accessed February 7, 2011)
[f]. U.S. Energy Information Administration, Gasoline and Diesel Fuel Update (as of 2/14/2011) – see http://www.eia.gov/oog/info/gdu/gasdiesel.asp Propane prices – http://www.eia.gov/dnav/pet/pet_pri_prop_a_EPLLPA_PTA_dpgal_m.htm, (Accessed April 3, 2011).
[g]. Montgomery, 2010.
[h]. Toonen et al., 2006); Plecas et al., 2010.
[i]. *Total Production*: The lower value of 10,000 t per year is conservatively retained. Were this base adjusted to 2011 values using 10.9%/year net increase in number of consumers between 2007 and 2009 per U.S. Department of Health and Human Services (2010), the result would be approximately 17 million tonnes of total production annually (indoor and outdoor). *Indoor Share of Total Production*: The three-fold changes in potency over the past two decades, reported by federal sources, are attributed at least in part to the shift towards indoor cultivation See http://www.justice.gov/ndic/pubs37/37035/national.htm and (Hudson, 2003). A weighted-average potency of 10% THC (U.S. Office of Drug Control Policy, 2010) reconciled with assumed 7.5% potency for outdoor production and 15% for indoor production implies 33.3%::67.7% indoor::outdoor production shares. For reference, as of 2008, 6% of eradicated plants were from indoor operations, which are more difficult to detect than outdoor operations. A 33% indoor share, combined with per-plant yields from Table 2, would correspond to a 4% eradication success rate for the levels reported (415,000 indoor plants eradicated in 2009) by the U.S. Drug Enforcement Agency (http://www.justice.gov/dea/programs/marijuana.htm). Assuming 400,000 members of medical Cannabis dispensaries in California (each of which is permitted to cultivate), and 50% of these producing in the generic 10-module room assumed in this analysis, output would slightly exceed this study's estimate of total statewide production. In practice, the vast majority of indoor production is no doubt conducted outside of the medical marijuana system.
[j]. Total U.S. electricity sales: U.S. energy information administration, "retail sales of electricity to ultimate customers: Total by end-use sector" http://www.eia.gov/cneaf/electricity/epm/table5_1.html, (Accessed March 5, 2011)
[k]. California Energy Commission, 2009; 2011.

statistically significant, but unexplained, increase in the growth rate for residential electricity in California during the years when indoor *Cannabis* production grew as an industry (since the mid-1990s).

Table A3
Energy model.

ELECTRICITY	Energy type	Penetration	Rating (Watts or %)	Number of 4 × 4 × 8-ft production modules served	Input energy per module	Units	Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	kW/h/cycle	kW/h/year per production module
Light												
Lamps (HPS)	elect	100%	1,000	1	1,000	W		12		60	720	3,369
Ballasts (losses)	elect	100%	13%	1	130	W		12		60	94	438
Lamps (MH)	elect	100%	600	1	600	W	18		18		194	910
Ballast (losses)	elect	100%	0	1	78	W	18		18		25	118
Motorized rail motion	elect	5%	6	1	0.3	W	18	12	18	60	0	1
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Ventilation and moisture control												
Luminare fans (sealed from conditioned space)	elect	100%	454	10	45	W	18	12	18	60	47	222
Main room fans — supply	elect	100%	242	8	30	W	18	12	18	60	31	145
Main room fans — exhaust	elect	100%	242	8	30	W	18	12	18	60	31	145
Circulating fans (18")	elect	100%	130	1	130	W	24	24	18	60	242	1,134
Dehumidification	elect	100%	1,035	4	259	W	24	24	18	60	484	2,267
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Spaceheat or cooling												
Resistance heat or AC [when lights off]		90%	1,850	10	167	W	6	12	18	60	138	645
Carbon dioxide Injected to Increase foliage												
Parasitic electricity	elect	50%	100	10	5	W	18	12	18	60	5	24
AC (see below)	elect	100%										
In-line heater	elect	5%	115	10	0.6	W	18	12	18	60	1	3
Dehumidification (10% adder)	elect	100%	104	0	26	W	18	12	18	60	27	126
Monitor/control	elect	100%	50	10	5	W	24	24	18	60	9	44
Other												
Irrigation water temperature control	elect	50%	300	10	15	W	18	12	18	60	19	89
Recirculating carbon filter [sealed room]	elect	20%	1,438	10	29	W	24	24	18	60	54	252
UV sterilization	Elect	90%	23	10	2.1	W	24	24	18	60	4	18
Irrigation pumping	elect	100%	100	10	10	W	2	2	18	60	2	7
Fumigation	elect	25%	20	10	1	W	24	24	18	60	1	4
Drying												
Dehumidification	elect	75%	1,035	10	78	W		24		7	13	61
Circulating fans	elect	100%	130	5	26	W		24		7	4	20
Heating	elect	75%	1,850	10	139	W		24		7	23	109
Electricity subtotal	elect										2,174	10,171
Air-conditioning				10	420	W					583	2,726
Lighting loads				10		W					259	1,212
Loads that can be remoted	elect	100%	1,277	10		W					239	1,119
Loads that can't be remoted	elect	100%	452	10		W					85	396
CO2-production heat removal	elect	45%	1,118	17		W	18	12	18	60	—	—
Electricity Total	elect				3,225	W					2,756	12,898
FUEL	Units	Technology Mix	Rating (BTU/h)	Number of 4 × 4 × 8-ft production modules served	Input energy per module		Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	GJ or $kgCO_2$/cycle	GJ or $kgCO_2$/year
On-site CO_2 production												
Energy use	propane	45%	11,176	17	707	kJ/h	18	12	18	60	0.3	1.5
CO2 production -> emissions	kg/CO_2										20	93
Externally produced Industrial CO_2		5%		1	0.003	liters CO_2/hr	18	12	18	60	0.6	2.7
Weighted-average on-site/purchased	$kgCO_2$										2	10

For *Cannabis* producers, energy-related production costs have historically been acceptable given low energy prices and high product value. As energy prices have risen and wholesale commodity prices fallen, high energy costs (now 50% on average of wholesale value) are becoming untenable. Were product prices to fall as a result of legalization, indoor production could rapidly become unviable.

For legally sanctioned operations, the application of energy performance standards, efficiency incentives and education, coupled with the enforcement of appropriate construction codes could lay a foundation for public-private partnerships to reduce undesirable impacts of indoor *Cannabis* cultivation.[5] There are early indications of efforts to address this.[6] Were such operations to receive some form of independent certification and product labeling, environmental impacts could be made visible to otherwise unaware consumers.

Acknowledgment

Two anonymous reviewers provided useful comments that improved the paper. Scott Zeramby offered particularly valuable insights into technology characteristics, equipment configurations, and market factors that influence energy utilization in this context and reviewed earlier drafts of the report.

Appendix A

See Tables A1–A3.

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UNODC, 2009. World Drug Report: 2009. United Nations Office on Drugs and Crime, p. 97. 〈http://www.unodc.org/unodc/en/data-and-analysis/WDR-2009.html〉 For U.S. conditions, indoor yields per unit area are estimated as up to 15-times greater than outdoor yields.

Exhibit 2

ENERGY UP IN SMOKE

THE CARBON FOOTPRINT OF INDOOR CANNABIS PRODUCTION

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April 5, 2011

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* The research described in this report was conducted and published independently by the author, a long-time energy analyst and Staff Scientist at the Lawrence Berkeley National Laboratory, University of California. Scott Zeramby provided valuable insights into technology characteristics, equipment configurations, and market factors that influence energy utilization.

The report can be downloaded from: http://evan-mills.com/energy-associates/Indoor.html

On occasion, previously unrecognized spheres of energy use come to light. Important examples include the pervasive air leakage from ductwork in homes, the bourgeoning energy intensity of computer datacenters, and the electricity "leaking" from millions of small power supplies and other equipment. Intensive periods of investigation, technology R&D, and policy development gradually ensue in the wake of these discoveries.

The emergent industry of indoor Cannabis production appears to have joined the list. This report presents a model of the modern-day production process—based on public sources and equipment vendor data—and provides national scoping estimates of the energy use, costs, and greenhouse-gas emissions associated with this activity in the United States.[1]

Large-scale industrialized and highly energy-intensive indoor cultivation of Cannabis is a relatively new phenomenon, driven by criminalization, pursuit of security, and the desire for greater process control and yields.[2,3] The practice occurs in every state,[4] and the 415,000 indoor plants eradicated in 2009[5] represent only the tip of the iceberg.

Aside from sporadic news reports,[6,7] policymakers and consumers possess little information on the energy implications of this practice.[8] Substantially higher electricity demand growth is observed in areas reputed to have extensive indoor Cannabis cultivation. For example, following the legalization of cultivation for medical purposes in California in 1996, Humboldt County experienced a 50% rise in per-capita residential electricity use compared to other areas.[9] Cultivation is today legal in 17 states, albeit not federally sanctioned. In California, 400,000 individuals are authorized to grow Cannabis for personal medical use, or sale to 2,100 dispensaries.[10] Official estimates of total U.S. production varied from 10,000 to 24,000 metric tons per year in 2001,[4] making it the nation's largest crop by value.[11] As of 2006, one third of national indoor production was estimated to occur in California.[12] Based on a rising number of consumers (6.6% of U.S. population above the age of 12),[13] national production in 2011 is estimated for the purposes of this study at 17,000 metric tons, one-third occurring indoors.[14]

Driving the large energy requirements of indoor production facilities are lighting levels matching those found in hospital operating rooms (500-times greater than recommended for reading) and 30 hourly air changes (6-times the rate in high-tech laboratories, and 60-times the rate in a modern home). Resulting electricity intensities are 200 watts per square foot, which is on a par with modern datacenters. Indoor carbon dioxide (CO_2) levels are often raised to four-times natural levels in order to boost plant growth.

Specific energy uses include high-intensity lighting, dehumidification to remove water vapor, space heating during non-illuminated periods and drying, irrigation water pre-heating, generation of CO_2 by burning fossil fuel, and ventilation and air-conditioning to remove waste heat. Substantial energy inefficiencies arise from air cleaning, noise and odor suppression, and inefficient electric generators used to avoid conspicuous utility bills.

Based on these operational factors, the energy requirements to operate a standard production module—a 4x4x8 foot chamber—are approximately 13,000 kWh/year of electricity and 1.5×10^6 BTU/year of fossil fuel. A single grow house can contain 10 or more such modules. Power use scales to about 20 TWh/year nationally (including off-grid production and power theft), equivalent to that of 2 million average U.S. homes. This corresponds to 1% of national electricity consumption or 2% of that in households—or the output of 7 large electric power plants.[15] This energy, plus transportation fuel, is valued at $5 billion annually, with associated emissions of 17 million metric tons of CO_2—equivalent to that of 3 million average American cars. (See Figure 1 and Tables 1-5.)

Fuel is used for several purposes, in addition to electricity. Carbon dioxide, generated industrially[16] or by burning propane or natural gas, contributes about 2% to the carbon footprint. Vehicle use for production and distribution contributes about 15% of total emissions, and represents a yearly expenditure of $1 billion. Off-grid diesel- and gasoline-fueled electric generators have emissions burdens that are three- and four-times those of average grid electricity in California. It requires 70 gallons of diesel fuel to produce one indoor Cannabis plant, or 140 gallons with smaller, less-efficient gasoline generators.

In California, the top-producing state, indoor cultivation is responsible for about 3% of all electricity use or 8% of household use, somewhat higher than estimates previously made for British Columbia.[17] This corresponds to the electricity use of 1 million average California homes, greenhouse-gas emissions equal to those from 1 million average cars, and energy expenditures of $3 billion per year. Due to higher electricity prices and cleaner fuels used to make electricity, California incurs 70% of national energy costs but contributes only 20% of national CO_2 emissions from indoor Cannabis cultivation.

From the perspective of individual consumers, a single Cannabis cigarette represents 2 pounds of CO_2 emissions, an amount equal to running a 100-watt light bulb for 17 hours assuming average U.S. electricity emissions (or 30 hours on California's cleaner grid). The emissions associated with one kilogram of processed Cannabis are equivalent to those of driving across country 5 times in a 44-mpg car. One single production module doubles the electricity use of an average U.S. home and triples that of an average California home. The added electricity use is equivalent to running about 30 refrigerators. Producing one kilogram of processed Cannabis results in 3,000 kilograms of CO_2 emissions.

The energy embodied in the production of inputs such as fertilizer, water, equipment, and building materials is not estimated here and should be considered in future assessments.

Minimal information and consideration of energy use, coupled with adaptations for security and privacy, lead to particularly inefficient configurations and correspondingly elevated energy use and greenhouse-gas emissions. If improved practices applicable to commercial agricultural greenhouses are any indication, such large amounts of energy are not required for indoor Cannabis production.[18] Cost-effective efficiency improvements of 75% are conceivable, which would yield energy savings of about $25,000/year for a generic 10-module operation. Shifting cultivation outdoors virtually eliminates energy use (aside from transport), although, when mismanaged, the practice imposes other environmental impacts.[19] Elevated moisture levels associated with indoor cultivation can cause extensive damage to buildings.[20] Electrical fires are an issue as well.[21] For legally sanctioned operations, the application of energy performance standards, efficiency incentives and education, coupled with the enforcement of appropriate construction codes could lay a foundation for public-private partnerships to reduce undesirable impacts.[22] Were compliant operations to receive some form of independent certification and product labeling, environmental impacts could be made visible to otherwise unaware consumers.

* * *

Current indoor Cannabis production and distribution practices result in prodigious energy use, costs, and greenhouse-gas pollution. The hidden growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. More in-depth analysis and greater transparency in the energy impacts of this practice could improve decision-making by policymakers and consumers alike.

Figure 1. Carbon Footprint of Indoor Cannabis Production

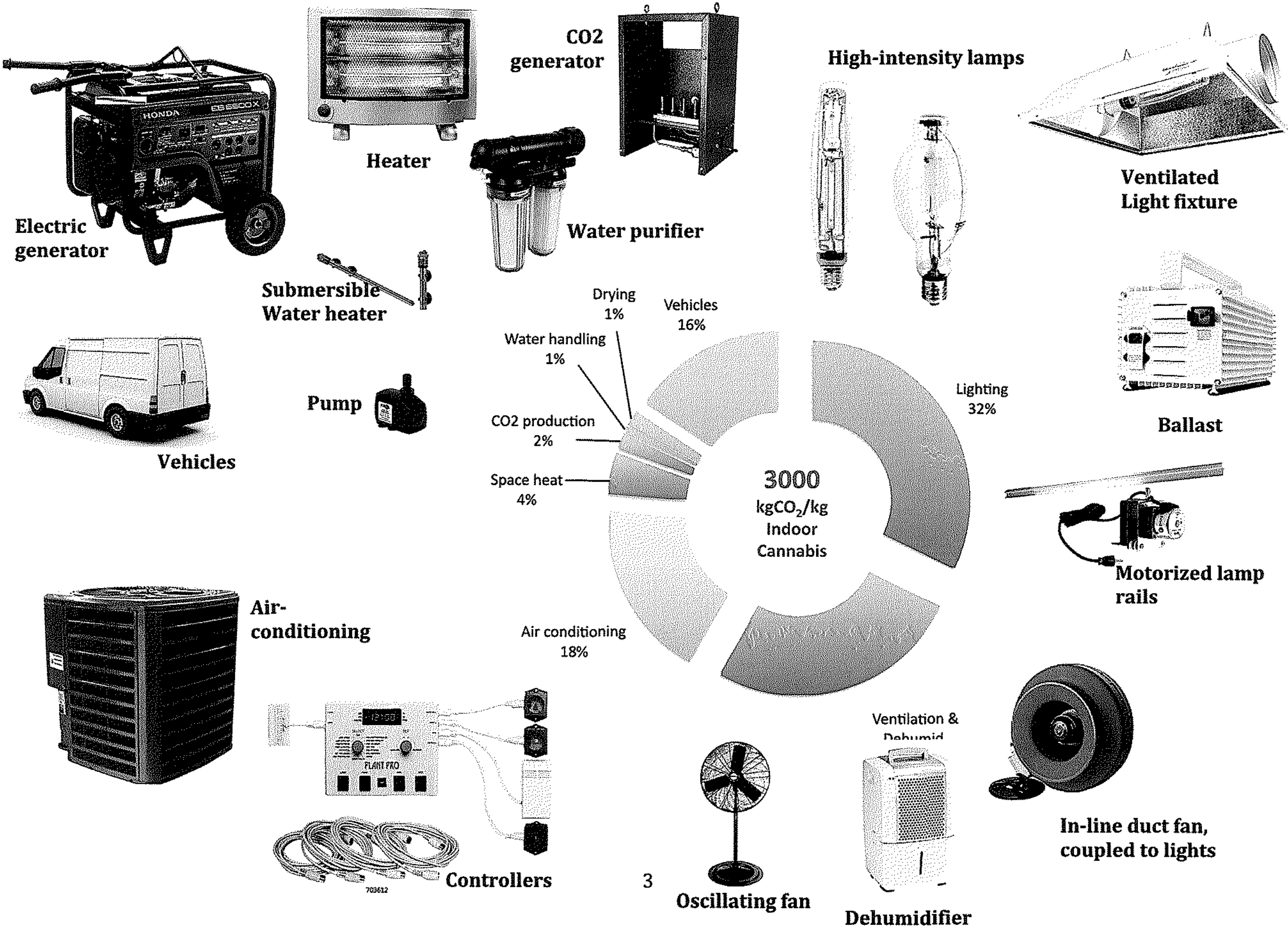

Table 1. Configuration, Environmental Conditions, and Setpoints		
Production parameters		
Growing module	16	square feet (excl. walking area)
Number of modules in a room	10	
Area of room	240	square feet
Cycle duration	78	days
Production continuous throughout the year	4.7	cycles
Illumination	*Leaf phase*	*Flowering phase*
Lamp type	Metal halide	High-pressure sodium
Watts/lamp	600	1000
Ballast losses (mix of magnetic & digital)	13%	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/1000W 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	40	gallons/room-day
Heating	Electric submersible heaters	
	75	F
Space conditioning		
Indoor setpoint - day	82	F
Indoor setpoint - night	68-70	F
AC efficiency	10.0	SEER
Dehumidification	7x24	hours
CO2 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	Outside 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%	
Vehicle use		
workers during production	2089	vehicle miles/cycle
wholesale distribution	750	vm/cycle
retail distribution (1 bounce)	3520	vm/cycle

Table 2. Assumptions & conversion factors		
Service Levels		
Illuminance*	25-100,000	lux
Airchange rates*	30	changes per hour
Operations		
Cycle duration**	78	days
Cycles/year**	4.7	continuous production
Production module area*	16	square feet (excl. walking area)
Production module volume**	192	cubic feet
Airflow**	96	cubic feet per minute
Modules per room*	10	
Lighting		
Leafing phase		
Lighting on-time*	18	hrs/day
Duration*	18	days/cycle
Flowering phase		
Lighting on-time*	12	hrs/day
Duration*	60	days/cycle
Drying		
Hours/day*	24	hrs
Duration*	7	days/cycle
Equipment		
Average air-conditioning age	5	years
Air conditioner efficiency (SEER)	10	Minimum standard as of 1/2006
Fraction of lighting system heat production removed by luminaire ventilation	30%	
Diesel generator efficiency*	27%	55kW
Propane generator efficiency*	25%	27kW
Gasoline generator efficiency*	15%	5.5kW
Fraction of total prod'n with generators*	15%	
Water use [indoor]*	1	gallons/day-plant
Transportation: Production phase (10 modules)	25	miles roundtrip
Daily service (1 vehicle)	78	trips/cycle. Assume 20% live on site
Biweekly service (2 vehicles)	11	trips/cycle
Harvest (2 vehicles)	10	trips/cycle
Total vehicle miles**	2089	vehicle miles/cycle
Transportation: Distribution		
Amount transported wholesale	5	kg per trip
Mileage (roundtrip)	750	vm/cycle
Retail (0.25oz x 5 miles roundtrip)	3520	vm/cycle
Total**	4270	vm/cycle
Fuel economy, typical car [a]	22	mpg
Annual emissions, typical car [a]	5195	kg CO2
	0.416	kg CO2/mile
Annual emissions, 44-mpg car**	2598	kg CO2
	0.208	kg CO2/mile
Cross-country US mileage	2790	miles

Fuels		
Propane [b]	91,033	BTU/gallon
Diesel [b]	138,690	BTU/gallon
Gasoline [b]	124,238	BTU/gallon
Electric Generation Mix*		
Grid	85%	share
Diesel generators	8%	share
Propane generators	5%	share
Gasoline generators	2%	share
Emissions Factors		
Grid electricity - US [c]	0.609	kgCO2/kWh
Grid electricity - CA [c]	0.384	kgCO2/kWh
Grid electricity - non-CA US [c]	0.648	kgCO2/kWh
Diesel generator**	0.922	kgCO2/kWh
Propane generator**	0.877	kgCO2/kWh
Gasoline generator**	1.533	kgCO2/kWh
Blended generator mix**	0.989	kgCO2/kWh
Blended on/off-grid generation - CA**	0.475	kgCO2/kWh
Blended on/off-grid generation - US**	0.666	kgCO2/kWh
Propane combustion	63.1	kgCO2/MBTU
Prices		
Electricity price - grid (California - PG&E) [d]	$0.390	per kWh (Tier 5)
Electricity price - grid (US, excl. CA) [e]	$0.127	per kWh
Electricity price - off-grid**	$0.390	per kWh
Electricity price - blended on/off - CA**	$0.390	per kWh
Electricity price - blended on/off - US**	$0.166	per kWh
Propane Price [f]	$2.20	per gallon
Gasoline Price - US average [f]	$3.68	per gallon
Diesel Price - US average [f]	$3.98	per gallon
Wholesale price of Cannabis [g]	$4,000	$/kg
Production		
Plants per production module*	4	
Net production per production module [h]	0.7	kg/cycle
US production (2011) [i]	16,974	metric tonnes/y
California production (2011) [i]	5,922	metric tonnes/y
Fraction produced indoors [i]	33%	
US indoor production modules**	1,727,283	
Calif indoor production modules**	602,597	
Cigarettes per kg**	3,000	
Other		
Average new refrigerator	450	kWh/year
	173	kgCO2/year (US average)
Electricity use of a typical US home - 2009 [j]	11,646	kWh/year
Electricity use of a typical California home - 2009 [k]	6,961	kWh/year

* trade and product literature; interviews with equipment vendors
** calculated from other values

Table 3. Carbon footprint of indoor Cannabis Production
(Average US conditions)

	kWh/kg	kgCO2 emissions/kg	
Lighting	1,479	985	32.2%
Ventilation & Dehumid.	1,197	797	26.1%
Air conditioning	827	551	18.0%
Space heat	197	131	4.3%
CO_2 production	54	49	1.6%
Water handling	28	19	0.6%
Drying	73	48	1.6%
Vehicles		479	15.7%
Total	3,855	**3,059**	100.0%

Note: "CO2 production" represents combustion fuel to make on-site CO2. Assumes 15% of electricity is produced in off-grid generators. As the fuels used for CO2 contain moisture, additional dehumidification is required (and allocated here to the CO2 energy row). Air-conditioning associated with CO2 production (as well as for lighting, ventilation, and other incidentals) is counted in the air-conditioning category.

Table 4. Equivalencies

Indoor Cannabis production consumes...	3%	of California's total electricity, and	8%	of California's household electricity	1%	of total US electricity, and	2%	of US household electricity
U.S. Cannabis production & distribution energy cost...	$5	Billion, and results in the emissions of	17	million tonnes per year of greenhouse gas emissions (CO_2)	equal to the emissions of	3	million average cars	
U.S. electricity use for Cannabis production is equivalent to that of...	2	million average US homes						
California Cannabis production and distribution energy cost	$3	Billion, and results in the emissions of	4	million tonnes per year of greenhouse gas emissions (CO_2)	equal to the emissions of	1	million average cars	
California electricity use for Cannabis production is equivalent to that of...	1	million average California homes						
A typical 4x4x8-foot production module, accomodating four plants at a time, consumes as much electricity as...	1	average U.S. homes, or	2	average California homes	or	28	average new refrigerators	
Every 1 kilogram of Cannabis produced using national-average grid power results in the emissions of...	2.8	tonnes of CO_2	equivalent to	4.9	cross-country trips in a 44mpg car			
Every 1 kilogram of Cannabis produced using a prorated mix of grid and off-grid generators results in the emissions of...	3.1	tonnes of CO_2	equivalent to	5.3	cross-country trips in a 44mpg car			
Every 1 kilogram of Cannabis produced using off-grid generators results in the emissions of...	4.3	tonnes of CO_2	equivalent to	7.4	cross-country trips in a 44mpg car			
Transportation (wholesale+retail) consumes...	52	gallons of gasoline per kg	or	$1	billion dollars annually, and	479	kilograms of CO_2 per kilogram of final product	
One Cannabis cigarette is like driving...	15	miles in a 44mpg car	emitting about	2	pounds of CO_2, which is equivalent to operating a 100-watt light bulb for	17	hours	
Of the total wholesale price...	24%	is for energy (at average U.S. prices)						

Table 5. Indicators (Average US conditions)	per cycle, per production module	per year, per production module	
Energy Use			
Connected Load		3,039	watts/module
Power Density		190	watts/ft2
Elect	2,698	12,626	kWh/module
Fuel to make CO2	0.3	1.5	MBTU
Transportation fuel	37	172	gallons
On-grid results			
Energy cost	592	2,770	$/module
Energy cost		846	$/kg
Fraction of wholesale price		21%	
CO2 emissions	1,988	9,302	kg
CO2 emissions		2,840	kg/kg
Off-grid results (diesel)			
Energy cost	1,196	5,595	$/module
Energy cost		1,708	$/kg
Fraction of wholesale price		43%	
CO2 emissions	3,012	14,094	kg
CO2 emissions		4,303	kgCO2/kg
Blended on/off grid results			
Energy cost	682	3,194	$/module
Energy cost		975	$/kg
Fraction of wholesale price		24%	
CO2 emissions	2,141	10,021	kg
CO2 emissions		3,059	kgCO2/kg
Of which, indoor CO2 production	9	42	kgCO2
Of which, vehicle use			
Fuel use			
During Production		14	gallons/kg
Distribution		39	gallons/kg
Cost			
During Production		$50	$/kg
Distribution		$143	$/kg
Emissions			
During Production		124	kgCO2/kg
Distribution		355	kgCO2/kg

Table 6. Model	Energy type	Penetration	Rating	Number of 4x4x8-foot production modules served	Input energy per module	Units	Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	kWh / cycle	kWh/year per production module
Light												
Lamps (HPS)	elect	100%	1000	1	1000	W		12		60	720	3,369
Ballasts (losses)	elect	100%	13%	1	130	W		12		60	94	438
Lamps (MH)	elect	100%	600	1	600	W	18		18		194	910
Ballast (losses)	elect	100%	13%	1	78	W	18		18		25	118
Motorized rail motion	elect	5%	5.5	1	0.3	W	18	12	18	60	0	1
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Ventilation and moisture control												
Luminare fans (sealed from conditioned space)	elect	100%	454	10	45	W	18	12	18	60	47	222
Main room fans - supply	elect	100%	242	8.1	30	W	18	12	18	60	31	145
Main room fans - exhaust	elect	100%	242	8.1	30	W	18	12	18	60	31	145
Circulating fans (18")	elect	100%	130	1	130	W	24	24	18	60	242	1,134
Dehumidification	elect	100%	1,035	4	259	W	24	24	18	60	484	2,267
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Spaceheat												
Resistance heat [when lights off]		90%	1,850	10	167	W	6	12	18	60	138	645
Carbon Dioxide												
Parasitic electricity	elect	50%	100	10	5	W	18	12	18	60	5	24
AC (see below)	elect	100%										
In-line heater	elect	5%	115	10	0.6	W	18	12	18	60	1	3
Dehumidification (10% adder)	elect	50%	104	0.4	26	W	18	12	18	60	27	126
Monitor/control	elect	50%	50	10	3	W	24	24	18	60	5	22
Water												
Heating	elect	100%	300	10	30	W	18	12	18	60	19	89
Pumping - irrigation	elect	100%	55	10	5.5	W	1	1	18	60	0	2
Drying												
Dehumidification	elect	75%	1,850	10	139	W		24		7	23	109
Circulating fans	elect	100%	130	5	26	W		24		7	4	20
Heating	elect	75%	1,850	10	139	W		24		7	23	109
Electricity subtotal	elect										2,119	9,918
Air-conditioning											579	2,709
Lighting loads											239	1,117
Loads that can be remoted	elect	100%	1,180	10	118	W					221	1,034
Loads that can't be remoted	elect	100%	450	10	45	W					84	394
CO2-production heat removal	elect	50%	1,118	16.7	34	W	18	12	18	60	35	164
Electricity Total	**elect**				**3,039**	**W**					**2,698**	**12,626**
ON-SITE FUEL	**Units**	**Technology Mix**	**Rating (BTU/ hour)**	**Number of 4x4x8-foot production modules served**	**Input energy per module**		**Hours/day (leaf phase)**	**Hours/day (flower phase)**	**Days/cycle (leaf phase)**	**Days/cycle (flower phase)**	**MBTU or kgCO2/cycle**	**MBTU or kgCO2/year**
On-site CO2 production												
Energy use	propane	45%	11,176	16.7	671	BTU/ho	18	12	18	60	0.3	1.5
CO2 production --> emissions	kg/CO2										20	93
Externally produced Industrial CO2		5%		1	0.011	gallonsCO2/hr	18	12	18	60	1	3
Weighted-average on-site / purchased	kgCO2										2	10
Weighted average on-site / purchased	kg CO2										9	42

Notes for Tables

[a]. U.S. Environmental Protection Agency. "Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks." http://www.epa.gov/oms/consumer/f00013.htm [accessed February 5, 2011]

[b]. *Energy Conversion Factors,* U.S. Department of Energy, http://www.eia.doe.gov/energyexplained/index.cfm?page=about_energy_units [Accessed February 5, 2011]

[c]. U.S. Department of Energy, "Voluntary Reporting of Greenhouse Gases Program" http://www.eia.doe.gov/oiaf/1605/ee-factors.html [Accessed February 7, 2011]. CA: Marnay, C., D. Fisher, S. Murtishaw, A. Phadke, L. Price, and J. Sathaye. 2002. "Estimating Carbon Dioxide Emissions Factors for the California Electric Power Sector." Lawrence Berkeley National Laboratory Report No. 49945. http://industrial-energy.lbl.gov/node/148

[d]. PG&E residential tariff as of 1/1/11, Tier 5 http://www.pge.com/tariffs/ResElecCurrent.xls [Accessed February 5, 2011]. In practice a wide mix of tariffs apply, but the relative shares are not known.

[e]. State-level residential prices, weighted by Cannabis production from [Reference 4], with actual tariffs and U.S. Energy Information Administration, "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State," http://www.eia.doe.gov/electricity/epm/table5_6_a.html [Accessed February 7, 2011]

[f]. U.S. Energy Information Administration, Gasoline and Diesel Fuel Update (as of 2/14/2011) - see http://www.eia.gov/oog/info/gdu/gasdiesel.asp Propane prices - http://www.eia.gov/dnav/pet/pet_pri_prop_a_EPLLPA_PTA_dpgal_m.htm [Accessed April 3, 2011]

[g]. Montgomery, M. 2010. "Plummeting Marijuana Prices Create A Panic in Calif." http://www.npr.org/templates/story/story.php?storyId=126806429

[h]. Toonen, M., S. Ribot, and J. Thissen. 2006. "Yield of Illicit Indoor Cannabis Cultivation in the Netherlands." *Journal of Forensic Science*, 15(5):1050-4. http://www.ncbi.nlm.nih.gov/pubmed/17018080

[i]. See Reference 14 for derivation.

[j]. Total U.S. Electricity Sales: U.S. Energy Information Administration, "Retail Sales of Electricity to Ultimate Customers: Total by End-Use Sector" http://www.eia.gov/cneaf/electricity/epm/table5_1.html [Accessed March 5, 2011]

[k]. California Energy Commission. "Energy Almanac." http://energyalmanac.ca.gov/electricity/us_per_capita_electricity.html [Accessed February 19, 2011]. See also Total California Electricity Sales: California Energy Commission. 2009. *California Energy Demand: 2010-2020 -- Adopted Forecast.* Report CEC-200-2009-012-CMF), December 2009 (includes self-generation).

References

1. This report presents a model of typical production methodologies and associated transportation energy use. Data sources include equipment manufacturer data, trade media, the open literature, and interviews with horticultural supply vendors. All assumptions used in the analysis are presented in Table 2. The resultant normalized (per-kilogram) energy intensity is driven by the target environmental conditions, production process, and equipment efficiencies. While less energy-intensive processes are possible (either with lower per-unit-area yields or more efficient equipment and controls), much more energy-intensive scenarios are also possible (e.g., rooms using 100% recirculated air with reheat, hydroponics, and loads not counted here such as well-water pumps and water purification systems). The assumptions about vehicle energy use are likely conservative, given the longer-range transportation associated with interstate distribution. Some localities (very cold and very hot climates) will see much larger shares of production indoors, and have higher space-conditioning energy demands than the typical conditions assumed here. Some authors [See Plecas, D. J. Diplock, L. Garis, B. Carlisle, P. Neal, and S. Landry. *Journal of Criminal Justice Research,* Vol. 1 No 2., p. 1-12.] suggest that the assumption of 0.75kg yield per production module per cycle is an over-estimate. Were that the case, the energy and emissions values in this report would be even higher, which is hard to conceive. Additional key uncertainties are total production and the indoor fraction of total production (see note 14), and the corresponding scaling up of relatively well-understood intensities of energy use per unit of production to state or national levels by weight of final product. Greenhouse-gas emissions estimates are in turn sensitive to the assumed mix of on- and off-grid power production technologies and fuels, as off-grid production tends to have substantially higher emissions per kilowatt-hour than grid power. Costs are a direct function of the aforementioned factors, combined with electricity tariffs, which vary widely across the country and among customer classes. More in-depth analyses could explore the variations introduced by geography and climate, alternate technology configurations, and production techniques.
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3. World Drug Report: 2009. United Nations Office on Drugs and Crime, p. 97. http://www.unodc.org/unodc/en/data-and-analysis/WDR-2009.html For U.S. conditions, indoor yields per unit area are estimated as up to 15-times greater than outdoor yields.
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it under-estimates the electrical demand and applies energy prices that fall far short of the inclining marginal-cost tariff structures applicable in many states, particularly California.

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11. See Gettman, *op cit.,* at ref 4.
12. See Gettman, *op cit.,* at ref 4.
13. U.S. Department of Health and Human Services, SAMHSA, 2009 National Survey on Drug Use and Health (September 2010). https://nsduhweb.rti.org/
14. Total Production: The only official domestic estimate of U.S. Cannabis production was 10,000 to 24,000 tonnes for the year 2001. Gettman (*op cit.,* at ref. 4) conservatively retained the lower value for the year 2006. This 2006 base is adjusted to 2011 values using 10.9%/year net increase in number of consumers between 2007 and 2009, per U.S. Department of Health and Human Services (*op cit.,* at ref. 12). The result is approximately 17 million tonnes of total production annually (indoor and outdoor). Indoor Share of Total Production: The three-fold changes in potency over the past two decades, reported by federal sources, are attributed at least in part to the shift towards indoor cultivation [See http://www.justice.gov/ndic/pubs37/37035/national.htm and Hudson *op cit.,* at ref 4]. A weighted-average potency of 10% THC (U.S. Office of Drug Control Policy. 2010. "Marijuana: Know the Facts"), reconciled with assumed 7.5% potency for outdoor production and 15% for indoor production implies 33.3%::67.7% indoor::outdoor production shares. For reference, as of 2008, 6% of eradicated plants were from indoor operations, which are more difficult to detect than outdoor operations. A 33% indoor share, combined with per-plant yields from Table 2, would correspond to a 4% eradication success rate for the levels reported (415,000 indoor plants eradicated in 2009) by the DEA (*op cit.,* at ref 5). Assuming 400,000 members of medical Cannabis dispensaries in California (each of which is permitted to cultivate), and 50% of these producing in the generic 10-module room assumed in this analysis, output would slightly exceed this study's estimate of total statewide production. In practice, significant indoor production is no doubt conducted outside of the medical marijuana system.
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21. See Garis, L., *op cit.,* at ref 17.
22. The City of Fort Bragg, CA, has implemented elements of this in *TITLE 9 – Public Peace, Safety, & Morals,* Chapter 9.34. http://city.fortbragg.com/pages/searchResults.lasso?-token.editChoice=9.0.0&SearchType=MCsuperSearch&CurrentAction=viewResult#9.32.0