Cannabis and the Environment

Policy Considerations for a Sustainable Cannabis Industry

wm policy

WM Policy is the government relations, research, education, and public engagement arm of Weedmaps.

The WM Policy staff—with decades of legislative, regulatory and public policy experience, and an impressive record of achievement in local, state and national political campaigns; far reaching and impactful policy development; effective and creative public awareness efforts; and powerful, change-making coalition building—works with lawmakers, advocates, industry groups and other allies to forge safe, open, and sensible cannabis policy across the country and around the world.

Executive Summary

Young and burgeoning industries face an increasingly small window to implement meaningful sustainability solutions. With modern technological and economic advances, today's business environment is especially conducive to rapid growth—and as growth accelerates, environmental caretaking usually stagnates. Without early attention to sustainability, changes in business practices become less likely, more costly, and more incremental. To develop a truly sustainable business or industry, actions must be taken early, before runaway growth gives way to environmental decline. In this sense, cannabis is not unique. As more consumers demand cannabis, more will be cultivated. More cultivation means more resources like water, electricity, and soil will be required. More products on the market means more packaging, more transportation, and more waste. Without intervention now, the cannabis industry will join the ranks of other big polluters—missing an opportunity to establish the industry as a leader in protecting and even restoring the planet. This paper will explore the range of environmental impacts derived from cannabis and outline how public policy can ensure a sustainable industry well into the future.

Resource Conservation and Efficiency

Cannabis faces the same challenges as traditional agriculture with resource use and degradation. Unsound cultivation practices can lead to soil erosion, which further causes nutrient loss, decreases in available carbon, and detriments to water permeability. For industrial hemp in particular, land intensity is a great concern. Misuse or overuse of pesticides, herbicides, fungicides, and fertilizers contributes to runoff, which poisons waterways, fertile soil, and wildlife. Illegal grow operations are notorious for water diversions—taking away the lifeblood of local farms, vineyards, and habitats. Habitat loss is another concern associated with irresponsible land use. Indoor and outdoor cultivation each have their own drawbacks that must be considered carefully.

Effects of Different Cultivation Methods

Outdoor and indoor cannabis cultivation methods have varying degrees of environmental impact. While no current evidence suggests that one method is concretely more environmentally-friendly than another, the differences between each method should be understood by all cultivators, and each business should build their operation around what best suits their business model, while taking every precaution to protect the environment. Policymakers have a responsibility to incentivize sustainable practices for all cultivators.

Packaging and Waste

Cannabis has a waste problem. Even before reaching the end consumer, countless amounts of plant material go to waste, along with materials used in cultivation and processing. Product packaging accounts for the lion's share of cannabis waste—with disposable vaporizer pens and cartridges and excessive amounts of plastic often resulting from misguided packaging regulations, cannabis is contributing to the world's plastic problem. Creating incentives for reusable, recyclable, and compostable packaging, which can be made from hemp, is imperative.

State and Local Environmental Policy Frameworks

There are many quality examples of states and localities administering responsible environmental regulations and guidelines for the cannabis industry. This section describes just a few examples from around the country.

Policy Recommendations

1. Provide government-backed incentives for cannabis businesses to adopt renewable energy sources (on-site or contracted).

2. Encourage and approve utility programs that incentivize the adoption of renewable energy (on-site or contracted) for cannabis businesses, along with accessible energy efficiency programs.

3. Ensure accessible financing options for cannabis businesses to adopt clean energy solutions.

4. Create regulatory disincentives for illegal water diversions, and educate cultivators on the impacts of detrimental and illegal water use.

5. Create land restoration programs that require cannabis businesses to offset the negative results of their business operations (e.g., deforestation, habitat loss).

6. Establish soil management best practices for cannabis cultivators and provide educational resources and services.

7. Create incentive programs and education campaigns to encourage the adoption of sustainable chemical alternatives, such as alternative pest control methods and organic fertilizers.

8. Conduct public outreach and education campaigns that provide insights to cultivators on the environmental risks and benefits of varying cultivation methods.

9. Incentivize the formation of partnerships between cannabis businesses and biodigesters/composters to sustainably manage waste and utilize waste byproducts.

10. Create incentive programs to encourage recycling in the cannabis industry, including plant materials, packaging materials, and chemical solvents.

11. Establish incentives for cannabis brands to employ sustainable packaging materials, such as hemp.

12. Allow consumers to use their own opaque exit containers at cannabis retailers.

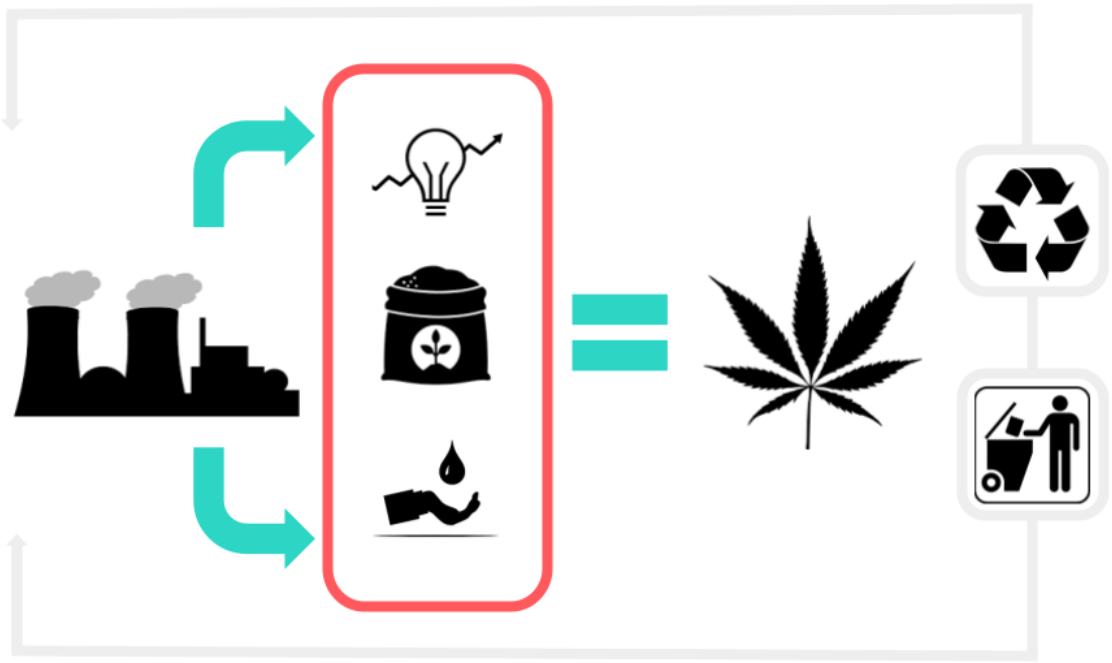
13. Conduct state-funded scientific studies on the environmental impact of the cannabis industry to better inform future policy decisions.

14. Incentivize commercial cannabis cultivation and manufacturing businesses to submit comprehensive sustainability plans.

An Overview of the Environmental Impacts of Cannabis

Humans and cannabis have traveled side-by-side for millennia. Evidence shows that cannabis use began as long as 12,000 years ago, making it one of the oldest purposefully-cultivated crops in the world.[1] After evolving in Central Asia, humans soon introduced the plant to Africa, Europe, and the Americas.[2] For thousands of years, cannabis was grown as a source of medicine, construction material, fuel, fiber, and food. Somewhere along the way, whether intentionally or by accident, our ancestors began selecting cannabis varieties based on psychoactive and other physical effects—opening the door to modern cannabis genetics. Historically, the utilization of the cannabis plant for all of the aforementioned purposes was ultimately a positive for environmental health. Cannabis is a renewable resource, and the fact that it has so many uses makes it promising for the environment, industry, and society.. However, with the advent of indoor cultivation and commercialization in some areas of the world, cannabis's delicate balance with the environment has begun to tip in a negative direction.

Many modern agricultural practices are not rooted in sustainability.[3] Excessive and unnecessary use of pesticides, herbicides, fungicides, and inorganic fertilizers, paired with unsustainable water use, energy consumption, and soil degradation can lead to severe environmental consequences that can impact many generations to come. Cannabis is not exempt from these impacts. As displayed in the illustration below, this paper will explore the key facets of cannabis's impact on the environment. While these effects are formidable, public policy holds many potential solutions. To mitigate the negative environmental impacts of a modern cannabis economy, public policy can play a role in shaping regulations and incentivizing sustainability—but first, the problems must be quantified.



Resource Conservation and Efficiency

Cannabis is a resource intensive plant. To meet the quality standards of modern cannabis consumers, the plant must receive copious amounts of light, nutrients, and water. For sustainable cultivation, these inputs must be used efficiently and in proper balance or otherwise risk environmental degradation. This balance has historically been fairly achievable with outdoor cultivation, but with modern

commercial-scale activity and the rapid growth of indoor cultivation, cannabis's environmental footprint has grown and will continue to do so. Public policy is an employable tool for mitigating the negative environmental impacts of cannabis cultivation while simultaneously incentivizing methods and tools that promote sustainability.

Energy Use Considerations

Energy consumption is a growing concern in the cannabis industry. Historically, cannabis has been grown outdoors (along with nearly every other crop), gathering all of its energy needs from natural sunlight. In the modern era, the cannabis plant has largely migrated indoors—the result of accelerating commercialization, controllable environments, and federal prohibition. By moving cultivation indoors, cannabis producers have avoided raids from federal officials while simultaneously increasing their control over the growing environment. This added layer of environmental control also comes with costs, mostly in the form of greenhouse gas (GHG) emissions and energy usage. Indoor cannabis cultivation accounts for well over 1% of the United States' annual electricity consumption, and 1 kilogram of finished product is associated with GHG emissions equivalent to the average car's annual emissions—about 4,600kg of CO2.[4]

Indoor Cultivation Lighting

The largest culprit behind this intense consumption of energy is what is commonly referred to as the "grow light." This equipment produces artificial light, simulating the Sun, which provides the energy necessary for cannabis plants to progress through their life cycle and produce consumable flowers. These lighting systems range from amateur products designed to supply light for a single plant, to larger industrial-scale products that enable the growth of thousands of cannabis plants in a commercial production environment. On average, these lighting setups can consume upwards of 2,000 watts of electricity for every square meter of cultivation space—exponentially more energy than what might be required for other leafy-green indoor crops.[5] As reported by POLITICO, recent models have suggested that in Massachusetts, the legal cannabis industry accounted for 10% of industrial electricity usage in 2020.

This energy use is no accident—indoor cannabis cultivation allows for plants to be blasted with even more concentrated light than the Sun can provide in outdoor growing conditions. With modern technology, growers can provide their crops with an energy supply that allows them to grow considerably faster and produce higher quantities of consumable buds. These shortened growing cycles and inflated production quantities mean that producers can potentially cultivate more product than outdoor operations more quickly. With this in mind, it is clear that indoor cultivation will likely grow in popularity—and with it, so will emissions and other environmental externalities. To best mitigate these impacts, more sustainable artificial light sources, such as light-emitting diodes (LEDs), should be employed as much as possible. LEDs are more energy efficient than alternatives (like fluorescent lights) and longer-lasting—resulting in less electricity consumption and less-frequent replacement.[6] Using LEDs is considerably more sustainable both environmentally and financially, and public policy can be an avenue to incentivize their use.

Environmental Control Systems

Heating, ventilation, and air conditioning (HVAC) systems also consume significant amounts of electricity. These systems, when paired with proper lighting, allow for strict environmental control of indoor cultivation operations. Modern technology is capable of monitoring and automatically adjusting environmental factors such as humidity levels, air-change rates, temperature, carbon dioxide levels, and

much more. While these systems are essential for a successful large-scale operation, like lighting, they consume large amounts of electricity. Every effort should be made to install energy efficient HVAC systems.

Electricity Supply

Given the intensity of electricity use in indoor cultivation facilities, the source of energy is increasingly important. Business owners depend on reliable and affordable energy supply. As noted previously, indoor cultivation is an emission-heavy process, resulting from the upstream generation of electricity largely by coal and natural gas. As the reality of climate change takes hold and the world continues to undergo a rapid movement toward renewable and non-emitting energy sources, it is imperative that the cannabis industry follow suit.

Indoor cultivation operations possess a unique opportunity to lower their carbon footprint while creating long-term energy savings—on-site solar energy. Large indoor growing facilities come with thousands of square feet of rooftop space, ideal for solar generation that can lessen or eliminate the need for an external energy flow, while simultaneously lowering electricity costs and mitigating harmful GHG emissions. These installations also serve to make energy prices more stable, reducing risk. Further, under federal legalization, cannabis companies will have more optionality in choosing cultivation sites across the country—this opens up access to regions with more widespread and affordable renewable resources, such as abundant hydropower in the Pacific Northwest.

Case Study: Canndescent

In 2019, the California cannabis cultivator *Canndescent* completed the installation of a 282.6 kilowatt on-site solar generation system at its facility in Desert Hot Springs, CA, complete with 734 solar modules placed on 7 different structures[7]: providing enough electricity to power about 50% of the operation.[8] This project allows Canndescent to offset its annual carbon dioxide emissions in a manner consistent with that of a 430-acre forest (about 365 metric tons of carbon dioxide removal). Completion of this project has not only provided Canndescent with favorable energy economics but has complemented their brand, positioning them as a green leader in the industry. However, this venture was not without challenges. The federal illegality of cannabis, paired with banking and financing restrictions, made it difficult to obtain project approvals—highlighting the need for continued reforms.[9]

While the up-front capital expense associated with solar generation is not insignificant, longer-term cost savings balance the equation. On average, residential solar investments in the U.S. have a payback period of approximately 8 years; that is, the time it takes for electricity cost savings to equal the initial capital investment.[10] For commercial and industrial cases, it can be reasonably assumed that the payback period could be even faster, given state and federal tax credits (pending federal legalization), special utility offerings, and economies of scale—although these considerations vary from state to state based on regulatory structures and incentives.

The opportunities for energy innovation do not stop with on-site solar generation. With the advent of increasingly functional battery storage systems, cultivation facilities can utilize the technology in conjunction with solar generation to further increase reliability. Even more exciting, cultivation businesses produce large amounts of plant waste, which (especially with hemp/cannabis) can be used to form partnerships with biofuel operations that utilize organic matter to produce renewable natural gas.

Policymakers can play a role in promoting and incentivizing the adoption of cleaner, more efficient energy sources for cannabis operators.

Energy Efficiency

With the intensive energy use of indoor cultivation operations, every reasonable measure should be taken to ensure the efficiency of equipment and the facility as a whole. As noted by the National Cannabis Industry Association, improved energy efficiency in cannabis facilities not only reduces the carbon footprint of the industry, it also helps states and communities reach mandated energy efficiency goals.[11] Optimal energy efficiency can be achieved through a combination of multiple tools, such as switching to LED lighting, sufficient building/room insulation, and up-to-date modern technology.

Policy Recommendation

Cannabis cultivators should be encouraged and incentivized to procure renewable energy for their facilities, and instill meaningful energy efficiency measures in their operations. This can be achieved through direct state-to-industry incentives, or through utility program offerings. As the market matures, labeling that reflects efficiently-produced products can be added to product labels to provide consumers choice and perhaps allow premium price models.

Water Use Considerations

Similar to energy, cannabis cultivation requires tremendous water consumption. While the most problematic water consumption is primarily associated with indoor grow operations, water use is of equal concern among all cultivation methods: indoor, outdoor, greenhouse, or hydroponic. The cannabis plant is particularly water-intensive, using about 22 liters of water every day—while white grapes (grown in the same conditions as northern California cannabis) use about 12 liters per day.[12] This massive requirement for irrigation can often lead to cultivators making decisions that are not aligned with environmental stewardship principles, especially those operating outside of the regulated marketplace.

One innovative cultivation technique has been increasing in popularity in recent years: vertical farming. This method involves the vertical stacking of pots/planters—maximizing canopy space and introducing efficiencies in water consumption by allowing plants to drop excess water onto the plants below them, among other considerations. This technique has led to incredible technological advancements that can be applied to the cannabis industry, such as the example below.

Case Study: iFarm Plant Dehumidification Systems

As vertical farming grows in popularity, iFarm has developed a plant dehumidification system that allows for the reuse of water that crops naturally evaporate throughout their growth cycle. iFarm claims that vertical farming can use 95% less water than traditional methods, and their technology improves this statistic even further. While it is unclear if iFarm's product has been utilized for cannabis, it certainly has this potential.[13]

Water Diversions

The unsustainable diversion of water from natural sources, such as local streams and lakes, has become a significant concern in cannabis cultivation. This issue is especially prevalent in California and is primarily a concern stemming from illegal cultivation. In a state that has historically struggled with drought, especially in recent years, these water diversions are even more concerning.[14] Many illegal

cannabis grows operate in remote wilderness, using minimal equipment so as to avoid detection by law enforcement. Many times, these operators divert water flows from nearby natural water sources to irrigate their crops—artificially disrupting watersheds in an already water-scarce environment. While highly-accurate estimates are difficult to obtain due to the secretive nature of these cultivation operations, it has been estimated that cannabis-related illegal water diversions in California result in a significant reduction in the water flow through local watersheds, with irrigation needs often exceeding streamflow.[15] This reduction in water flow has significant implications for downstream users of said water, including residential communities and agricultural operations. The impacts on the ecosystem can be devastating—increasing the risk of wildfires and destroying the habitats of flora and fauna. These impacts are even more pronounced given the possibility (and sometimes reality) of seasonal water restrictions in California, placing even more pressure on cultivators and creating lose-lose scenarios.

To mitigate these water diversions, the following steps should be taken: (i) expand the legal market and minimize barriers to entry, especially for cultivators,, (ii) increase regulatory scrutiny of water sources, and (iii) crack down on large-scale illegal cannabis growing operations on public lands. By expanding opportunities for legacy cultivators to enter the regulated market (e.g., uncapped licenses and low application/license fees), these cultivators can operate freely with no need to hide their operation in the depths of the forest. Additionally, revenue from legal cannabis sales flows directly to environmental remediation efforts in states like California. With the legal market and the opportunities it provides, legacy operators can make use of state-of-the-art technologies and cultivation methods that otherwise might not have been accessible to them. To crack down on potential illegal water diversions by existing regulated cultivators, regulatory enforcement actions should be taken, including but not limited to randomized inspections of water sources and fines or other penalties. Regulatory agencies, along with state and local governments as a whole, should also be encouraged to develop educational materials and programs that inform cannabis cultivators about the impacts of water diversions and alternative steps that can be taken.

Case Study: The CROP Project

The Cannabis Removal on Public Lands (CROP) Project advocates for measures to reduce and eliminate the presence of illegal (trespass) grows on public lands in California. CROP's stated goals include: (i) securing and increasing state and federal resources for trespass grow reclamation, (ii) increasing Forest Service law enforcement and overall presence in National Forests, and (iii) increasing criminal penalties for those bringing toxicants onto public lands. CROP recognizes that illegal cultivators, of which 90% are controlled by drug trafficking organizations, cause untold damage to the environment due to pesticide use and water diversions. Weedmaps is a proud and vocal supporter of CROP, alongside other industry partners.[16]

Policy Recommendation

State regulatory agencies, especially in drought-stricken regions, should intensify enforcement of laws pertaining to illegal water diversions and uses. State and local governments also have a role to play in educating cannabis cultivators about varying cultivation methods, including vertical farming, and the impact these methods have on water consumption.

Agricultural and Land-Use Considerations

Aside from intensive energy use, the most impactful externality of cannabis cultivation is the effect on agricultural sustainability and land use. While cannabis may be unique in its wide-ranging applications, its relationship with the earth and the impacts of its cultivation are not. Although typically on a much smaller scale than modern industrial agriculture (e.g., corn, wheat, etc.), cannabis cultivation does pose environmental risks when conducted without regard for sustainability. In sum, the effect of commercial cannabis cultivation on the environment is highly dependent on scale, growing practices, technology, and remediation efforts.

Soil Impacts

Cannabis plants require significant amounts of nutrients to produce the flowers that become sought-after products. Oftentimes (and 100% of the time for indoor operations) cannabis crops cannot receive their entire lifetime nutrient requirement solely from the natural soil. Fertilizers, specialty soil mixes, and other nutrient additives are frequently employed to improve the viability of soil during the growing process and produce desirable cannabis plants. Since indoor cultivation does not utilize established, "in-ground" soil (i.e., these crops are grown in pots/planters, or hydroponically), the remainder of this section will concern outdoor cultivation. This introduction of additional soil or nutrients does not come without environmental consequences, especially in the long term. Cannabis, like most crops, requires varying concentrations of three basic nutrients: nitrogen, phosphorus, and potassium (along with a host of other compounds on a much smaller scale).[17] The long-term application of these nutrients, with both organic or inorganic product varieties, can lead to a range of both negligible and significant detrimental effects on soil health. These effects can include fluctuations in: soil pH, soil salinity (salt content), cation exchange capacity, organic carbon content, and nitrogen, phosphorus, and potassium availability.[18] However, it is important to note that any given change in a particular metric of soil health is dependent on soil type, local conditions, water flow, and many other factors.

In addition to chemical/nutrient considerations, other aspects of soil management like erosion and tillage can have significant environmental consequences. As seen historically with traditional agricultural practices, the constant seasonal tilling of farm soils (used to control weeds and manage nutrients) leads to catastrophic erosion, which can further aggravate the runoff of nutrients and wastewater. This tillage contributed to the famous "Dust Bowl" in the early 20th century. Since then, the Natural Resources Conservation Service has assisted farmers with implementing practices such as no-till farming, while installing structures like sediment basins, grassed waterways, and diversions to help control erosion.[19] The adoption of practices such as no-till farming should be encouraged for outdoor cannabis cultivators—proper management of structural soil considerations, as well as nutrient concerns, ensures that future generations of cannabis cultivators can enjoy quality growing environments while preserving natural resources.

Chemical Persistence and Runoff

As a result of frequent chemical application to natural soils (for outdoor cultivation) as described in the preceding section, remnants of these chemicals often remain in the soil and can travel to other areas via water flows. These chemicals include fertilizers, nutrient additives, pesticides, fungicides, insecticides, and other chemicals. During heavy rainfall, especially with degraded soil, localized chemicals used for plant/soil treatment can be carried across water tables into streams, lakes, and other bodies of water. Historically, there is a clear tie between the introduction of modern fertilizers and elevated nitrogen and phosphorus levels in the world's oceans.[20] The impact of these chemicals reaching waterways is

significant for both environmental and human health, commonly leading to the following effects, among others:

- **Direct exposure:** acute contact with agricultural chemicals (via dermal (skin) uptake, inhalation, or ingestion) by humans or wildlife can produce effects ranging from mild irritation to major injury, depending on concentration and chemical type.
- **Bioaccumulation:** agricultural chemicals can build-up over time, increasing in concentration and distribution. This can lead to long-term effects such as cancer and toxicity in humans and contaminated food supplies for humans and wildlife (such as mercury accumulation in fish).
- **Other environmental impacts:** aside from direct toxic impacts to humans and wildlife, chemical persistence in waterways and soil can lead to increased algal blooms, changes in water quality (pH, oxygen content, etc.), and species of pests, fungi, etc. becoming resistant to chemical deterrents.[21]

These impacts are significant, but many tools and methods exist for mitigating chemical persistence and runoff, while still recognizing the legitimate need for modern fertilizers. Cultivators can install "buffer strips" along the perimeter of their fields, trapping and filtering chemical runoff before it reaches waterways.[22] Soil can also be graded in a manner that inhibits water flow toward waterways, and instead, redirects flows toward environmental features that are more resilient and further filter chemicals before they reach waterways. However, the most sustainable mitigation option lies at the source of the issue: chemical application. Cultivators should take great care in applying fertilizers and pesticides, and opt for organic alternatives when possible. Purely biological alternatives can also be practical, such as the introduction of ladybugs to control mite and aphid presence—with an added benefit of affordability.[23]

Deforestation and Habitat Loss

Cannabis cultivation, especially when done at a large scale outdoors, can lead to significant deforestation of the surrounding area. The destruction of trees and other vegetation that reside in desired planting areas are often clear-cut—taking any wildlife and wildlife habitat with them. In a 2017 Ithaca College study, researchers examined the effects of outdoor cannabis cultivation on forest loss in Humboldt County, California, comparing the results with the effects of timber harvesting. It was found that cannabis cultivation created 1.5 times more forest loss than timber harvesting, and 2.5 times more fragmentation of the landscape, segmenting large forests into smaller disconnected patches, and displacing wildlife habitats.[24] Removal of this habitat, such as nesting areas, hunting grounds, or shelter from predators, forces wildlife into increasingly small and segmented areas of forest where predation becomes more concentrated and competition for food and shelter increases. Over time, and with no remediation, local clusters of flora and fauna and even entire species can become endangered and face potential extinction.

Case Study: California's Outdoor Cultivation Size Limits

The State of California offers multiple tiers of outdoor cultivation licenses determined by total canopy size. Under state law, the maximum allowable outdoor cultivation total canopy space is 1 acre (per a "Medium Outdoor" license designation. This requirement ensures that no single cultivation operation becomes so large that it begins to displace large amounts of habitat and other natural resources.[25]

Pollen Drift

Cross-contamination of unwanted pollen is a potentially damaging scenario that outdoor cannabis cultivators face. The cannabis plant is dioecious, meaning that male and female flowers are located on separate plants. For a female plant to produce seeds, it must be fertilized from the pollen of a male plant. From a consumer's perspective, seeds are undesirable in female cannabis flowers (the commonly smoked/consumed variety), so cultivators take great care in ensuring that their crops are not pollinated. Even further, unpollinated female cannabis plants produce a higher quantity of larger flowers—an important aspect of profitability and adequate supply.[26]

With this knowledge available, it is easy to see the risk posed to outdoor cultivation from nearby male cannabis plants. While "Farmer A" might be growing female plants intended for quality flower production, "Farmer B" down the road may be cultivating male plants for breeding or industrial hemp purposes. In this instance, the occurrence of pollen "drift" is entirely possible. Pollen from the male plants can easily be carried by the wind, potentially fertilizing any downwind female plants; this phenomenon is commonly observed in other crops as well. Pollen drift poses huge risks to farmers, potentially jeopardizing the yield and quality of their entire crop and creating human conflict. Michigan State University's Extension Services cites the simplest solution to pollen drift being adequate geographic separation between cultivation sites, with industry experts recommending a minimum distance of 10 miles between farms. However, the "best" distance is difficult to determine, as factors such as wind speed, wind direction, humidity, topography, and other weather conditions play a large role in determining the potential for pollen drift.[27] While governments should not mandate excessive separation between outdoor cannabis cultivators, policymakers can play a role in educating and notifying businesses of any potential for pollen drift in their area.

Policy Recommendations

Cannabis regulatory agencies have a responsibility to promote the protection of natural resources, along with other state agencies. Best practices should be established for soil management, and regulators should play a role in educating the cannabis industry about these practices. Incentives and educational resources should also be provided for the use of alternative chemical applications, such as organic fertilizers and innovative pest control techniques. With respect to pollen drift, outdoor cultivators should be notified of their proximity to nearby cultivators and provided resources for how to mitigate pollen drift concerns.

Effects of Different Cultivation Methods

As briefly touched-on throughout this paper, different methods of cultivating cannabis can have widely varying effects on the environment. There are 5 distinct types of cannabis cultivation: outdoor cultivation, traditional indoor cultivation, hydroponic indoor cultivation, greenhouse cultivation, and vertical cultivation.

Cannabis Cultivation Methods
Outdoor cultivation: Cannabis grown outdoors, utilizing natural sunlight. Plants can be rooted in the ground, or in pots/planters containing soil. **Indoor cultivation (traditional):** Cannabis grown indoors, utilizing artificial light sources such as light-emitting diodes (LEDs), fluorescent lights, or high-pressure sodium (HPS) lights, for example. With "traditional" indoor cultivation, plants are rooted in pots/planters containing soil. **Indoor cultivation (hydroponic):** Cannabis grown indoors, utilizing artificial light sources such as light-emitting diodes (LEDs), fluorescent lights, or high-pressure sodium (HPS) lights, for example. With hydroponic indoor cultivation, plants are not rooted in soil—instead, roots are submerged in a reservoir that cycles fresh water and nutrients. **Greenhouse cultivation:** Cannabis grown indoors, in a "hybrid" method of sorts—utilizing natural sunlight via a transparent/translucent greenhouse roof, while otherwise using indoor cultivation methods. **Vertical cultivation:** A novel indoor cultivation method where plants are stacked vertically to make more efficient use of growing space.

While expert opinion varies widely on what may be the "best" method of cannabis cultivation, each growing method has a distinct and measurable environmental impact that must be balanced with the benefits of each method to achieve maximum sustainability. The figure below illustrates the varying considerations with each cultivation type:

	Cultivation Types				
	Outdoor	Indoor (Traditional)	Indoor (Hydroponic)	Greenhouse	Vertical
Energy Use					
Fertilizer Use					
Pesticide Use					
Habitat Destruction					

Outdoor Cultivation

The primary environmental concerns associated with outdoor cannabis cultivation involve soil degradation, chemical persistence and runoff, and habitat destruction—each of which has been assessed in preceding sections of this paper. Outdoor cultivation, due to its presence in the natural environment, is much more susceptible to pests and other contaminants—creating a higher demand for pesticides, fungicides, and herbicides. The presence and concentration of these chemicals in cannabis products has been highly scrutinized in terms of the human health impact, but environmental considerations must not be overlooked. Cultivators wishing to lessen the environmental footprint of their operation should consider the use of organic chemical applications while following strict protocols to minimize the amount of foreign material introduced into the environment. However, with these effects in mind, it is important to note that outdoor cultivation requires minimum to no energy use—a fundamental consideration when compared with energy-intensive indoor cultivation. In this sense, some semblance of cost/benefit balance exists when comparing outdoor cultivation with the effects of indoor growing.

Ultimately, outdoor cultivation requires land with adequate soil quality in areas with favorable climatic conditions (e.g., California's "Emerald Triangle"); this geographic constraint may serve to limit the potential for widespread environmental degradation as a result of outdoor cultivation. However, as the legal market for cannabis continues to expand and become more commercialized, it is certainly possible that large-scale "industrial" cultivation operations will become more widespread, and with them, negative environmental impacts that must be carefully considered. Along with this, cannabis genetics are constantly evolving and plants may be modified to be more suitable for less-arable environments.

Indoor Cultivation—Traditional

The traditional indoor cultivation format that has emerged as a result of federal prohibition and modern technology is certainly the most common growing method. According to Cannabis Business Times, 42% of surveyed cultivators operated exclusively indoors as of 2020, with the remaining 58% reporting growing in either greenhouses, outdoors, or some mix of cultivation methods.[28]

When compared with outdoor growing, indoor cultivation enjoys a host of advantages regarding pest control, modifiable environmental conditions, and cultivation time. With many indoor operations utilizing a "clean room" structure for their cultivation spaces, the risks associated with pests are considerably decreased, therefore reducing or even eliminating the need for pesticides and other chemical deterrents.[29] Controllable climatic conditions can offer a level of consistency and security that outdoor growing simply cannot. In addition, the closed environment of an indoor operation typically means that applied chemicals have a much harder time reaching local waterways and harming wildlife, depending on soil management practices (i.e., disposal of used soil).

Ultimately, the benefits of indoor cultivation do come with a cost: energy consumption. Indoor growing operations are notorious for their exorbitant electricity demands due to lighting sources, HVAC, and climate control systems (as explored in previous sections), with much of the energy used being generated from heavy carbon-emitting sources like coal and natural gas.

Indoor Cultivation—Hydroponic

Hydroponic cannabis cultivation is similar to traditional indoor growing in many respects, but involves the constant cycling of water and nutrients through the plants' root systems in lieu of earthy soil. While it is commonly asserted that hydroponic cultivation produces larger plants with higher yields, this does not come without environmental costs. Due to the lack of soil, hydroponically-grown plants are dependent on much higher concentrations of added nutrients and fertilizers. Without proper filtration and disposal methods, wastewater from these operations can introduce chemicals into the natural environment. In addition, indoor hydroponic growing encounters the same issues as traditional indoor cultivation with respect to energy use.[30]

Greenhouse Cultivation

Growing cannabis in greenhouses involves a closed indoor environment with transparent or translucent roofs/walls to allow natural sunlight and heat to enter the growing environment. In many ways, greenhouse cultivation can be viewed as the "best of both worlds"—benefitting from natural sunlight (therefore reducing/eliminating the need for artificial light), while maintaining some aspects of a controllable environment derived from indoor cultivation methods. The environmental impacts of greenhouse operations are very similar to those of indoor grows with respect to soil/water disposal and chemical applications, but without the tremendous electricity usage resulting from artificial light sources.[31]

Vertical Cultivation

Vertical cannabis cultivation has seen a growing prevalence in recent years, following similar trends in traditional agriculture. Vertical farming involves the stacking of crops above each other, making more efficient use of the size of a facility and requiring less property. This allows cultivators to double, or even triple, their canopy space and production capability without the same increase in costs.[32] Since vertical cultivation occurs indoors, the same respective environmental concerns apply. However, the significance of vertical cultivation's efficiency should not be underestimated, especially with regards to its ability to better utilize growing space and reduce the need for larger properties, which inevitably bring more negative environmental impacts. As highlighted earlier in this paper, vertical cultivation can also greatly reduce water consumption.

Policy Recommendation

Regulators should rely on best available science to conduct public outreach and education regarding the varying methods of cannabis cultivation and their impact on the environment. Regulators should encourage the legal cannabis industry and open up markets to allow tax revenue from the sale of legal cannabis to help fund further environmental research and remediation associated with cannabis grows.

Packaging and Waste

Cannabis has a waste problem. This issue is not unique to the cannabis industry—nearly every aspect of the modern economy generates massive amounts of waste, both throughout the supply chain and after final sale to the consumer. In the pre-retail supply chain, boundless opportunities exist for entrepreneurs to find economical solutions for cannabis waste management. Across the industry, and especially for consumer-facing stages of the supply chain, the cannabis plant itself can drive solutions for waste and sustainability concerns.

Waste in the Cannabis Industry

At each stage of the supply chain prior to reaching the end consumer, cannabis generates multiple waste streams, the most significant being discarded plant material, single-use plastic packaging, secondary cultivation byproducts (e.g., spent soil, wastewater), and secondary packaging materials (bulk packaging that does not reach consumers).

Plant and Other Biological Waste

The cultivation, processing, and manufacturing stages of the supply chain for cannabis products result in inordinate amounts of biological waste. Rough estimates describe disposed cannabis plant material reaching into the millions of tons each year, with up to 80-95% of original plant weight becoming waste.[33,34] As more and more states legalize and develop commercial cannabis markets, annual tonnage of cannabis waste will most certainly continue to increase. With the cannabis flower being the sought-after part of the plant, stalks, leaves, and trim material are often discarded—with one exception being the use of cannabis leaves for producing some extracts. As outlined by Cristina Commendatore with Waste360, cannabis plant waste can generally be disposed of via four different methods: permitted landfills, composting, in-vessel digestion, or incineration. The most promising of these methods—in-vessel digestion and composting—are much more environmentally-sound than landfill disposal or incineration and can even produce byproducts that can be fed back into the cannabis industry. In-vessel digestion, otherwise known as anaerobic digestion or "biodigestion," is a "process through which bacteria break down organic matter—such as animal manure, wastewater biosolids, and food wastes—in the absence of oxygen" (United States Environmental Protection Agency). This process results in two major byproducts: biogas and digestate. Biogas, primarily methane, can be used in lieu of traditional natural gas (or mixed with it) to generate electricity, provide heat, and more. Digestate—residual liquid and solid materials remaining after digestion—can be treated to be used as organic fertilizers, composts, or even bioplastics.[35]

As the cannabis industry grows, entrepreneurs and existing waste-handlers are likely to develop cannabis-specific biodigestion operations that use plant waste to not only produce fuel for cannabis operators, but also generate organic, nutrient-dense fertilizers for the next generation of cannabis plants. While typically on a much smaller scale, composting cannabis plant waste is an equally viable waste disposal method. Cannabis plant material can be mixed with other biological material that, when

allowed to break down, forms nutrient-rich compost material that can be used for agricultural purposes or even for community gardening projects.[36] Ultimately, it is entirely achievable for a large proportion of cannabis plant waste to be utilized in beneficial ways for the industry—further promoting sustainability while contributing positively to industry economics.

Case Study: GAIACA Waste Revitalization

As of June 2020, GAIACA claimed to be the United States' first licensed cannabis waste disposal business and has recycled over 5 million pounds of waste at its site in San Jose, CA. With a strong ethic of sustainability and environmental stewardship, GAICA partners with industry brands and offers a wide array of services including: site evaluations, waste management plans, secure waste storage, environmental consulting, proprietary onsite rendering, and recycling/waste manifests. The company manages both plant waste (stems, leaves, etc.) and packaging-related waste. Notably, GAIACA has partnerships with respected brands such as Harborside and Kiva for vape pen recycling.[37]

In addition to actual plant tissue, other biological waste materials, such as spent soil and wastewater, can be better utilized to promote sustainability and mitigate environmental damage. The careless disposal of these materials, as described previously, results in consequences for water quality and subsequent human and animal health. Spent soils can be blended with new soil to ensure that all nutrients are utilized and not leaked into waterways. This soil can also be used for composting, as previously explored. Wastewater that was used to irrigate cannabis plants typically contains varying concentrations of nutrients, especially when added nutrients were applied to the plant. If allowed to escape into the environment, the aforementioned effects on water quality take hold. All wastewater associated with cannabis cultivation can be filtered to remove excess nutrients, making it more suitable for reintroduction to the local environment.[38, 39]

Plastic and Other Inorganic Waste

The cannabis industry is no stranger to plastic. With strict packaging requirements in some jurisdictions and the growth of products like disposable vaporization pens, plastic has infiltrated the cannabis sector just as it has every other aspect of the modern economy. It is estimated that the U.S. cannabis industry generated 1 billion pieces of single-use plastic just in 2020 alone.[40] These plastics pollute oceans, forests, caves, lakes, and even human bloodstreams; the dangers of plastic are widely known and scientifically undisputed.

This problem exists both before and after cannabis reaches the consumer. As cannabis products progress through the supply chain, as with other products, secondary packaging is used to ship bulk items and protect products before reaching retail locations. While secondary packaging is impactful and its sustainability should be addressed, the most significant contributor to cannabis industry waste is single-use plastic packaging. Individually-wrapped edibles, plastic pre-roll containers, plastic pouches for cannabis flower, and the ever-popular disposable vape cartridges–nearly every product category in the cannabis sector contains plastic in its packaging. While yes, plastic can be recycled, recycling is highly dependent on consumer behavior and only approximately 9% of discarded plastic is actually recycled.[41] Another culprit behind plastic waste is the common requirement for products purchased at a retailer to be packed into an opaque container before leaving the premises with the customer—usually referred to as "exit packaging." To reduce this waste stream, consumers should be permitted to bring their own opaque containers (that meet regulatory thresholds), similar to bringing a reusable grocery bag to the store.

In addition to plastic, the use of chemical solvents in the manufacturing of some cannabis products creates a waste issue. While these solvents, including butane, ethanol, or hexane, are sometimes necessary for certain cannabinoid extraction processes, they produce significant amounts of waste, sometimes hazardous.[42] As product categories that require extraction (e.g., edibles, concentrated oils) continue to grow, so will the use of solvents. Thankfully, processes exist to recycle these chemicals, allowing for their re-use while removing waste products.[43]

Sustainable Packaging Options

Although cannabis has an especially problematic relationship with plastic packaging, modern and innovative solutions exist that can transform the industry and set a meaningful example for other sectors of the economy. The largest challenge with sustainable packaging materials is of a financial nature—because modern sustainable options are not widespread and often involve niche manufacturing processes, alternative packaging materials are often cost-prohibitive for cannabis brands. However, recent studies suggest that cannabis consumers are willing to take on this burden, with 74% of surveyed consumers stating that they are willing to pay more for sustainable packaging, and approximately a quarter of those consumers willing to pay in excess of 10% more for sustainably-packaged cannabis.[44]

Hemp-Based Packaging

The cannabis plant itself holds solutions to its own packaging. Hemp, the "industrial" version of cannabis, is a federally-legal cannabis variety (given that it has less than 0.3% THC) that has an expansive range of sustainable uses including fuel, textiles, food, building materials, and yes, packaging.[45] Hemp-based plastics and paper-like products are biodegradable, recyclable, and can contribute to the creation of a circular economy within the cannabis industry—using cannabis industry-produced products to supply the industry's own supply chain.[46]

Case Study: New York's Hemp Packaging Incentive (Proposed; 2022)

A bill has been introduced in New York's state Senate during the 2021-2022 legislative session that would encourage hemp-based packaging for cannabis products by creating a "Sustainable Cannabis Packaging Incubator Program". This program would offer monetary incentives for packaging material consisting of at least 30% hemp. As of June 2022, this bill awaits a vote in the Senate Finance Committee.[47,48]

Other Alternative Packaging Materials

While hemp is certainly the most intriguing and potentially impactful sustainable packaging material, other options exist that can sometimes be more economical and easily accessible with current market conditions. Options include, but are not limited to: recycled plastic, cellulose, cornstarch, other compostable materials, and even mushroom packaging. The bottom line is that cannabis companies should be encouraged through effective public policy and incentives to opt for more sustainable packaging options.

Policy Recommendation

Cannabis cultivators should be incentivized to enter partnerships with biodigester facilities and other biological waste management services. Incentives should also exist for recycling of inorganic materials, like plastic, and be further extended for the adoption of sustainable packaging materials like hemp. Consumers should also be allowed to use their own opaque exit containers at cannabis retailers.

An Overview of Federal Environmental Policy

Federal environmental policy is expansive and complex. Modern environmental regulations from the federal government began picking-up steam in the 1970s. Since then, activities ranging from waste disposal to endangered species protection have been heavily regulated with steep penalties for noncompliance. Since the onset of state-level legalization of medical and adult-use cannabis, a de-facto gray area has existed for environmental regulation of cannabis businesses. Given cannabis' federal illegality, there have been conflicting assessments on the enforcement of federal environmental law on cannabis operators, along with a general lack of focus on the industry. However, it has become clear in recent years and months that the tide is rising, and both federal and state governments are beginning to ramp up enforcement efforts on regulated cannabis businesses, holding them to the same standard as any other sector of the economy.[49] While a comprehensive analysis of federal environmental law as it applies to cannabis businesses would warrant an entirely separate effort, listed below are a handful of the most fundamental federal laws underpinning environmental protection. These descriptions are simply overviews and do not include all aspects of each law.

Federal Environmental Laws

Clean Water Act of 1972 (CWA): What was formerly known as the Federal Water Pollution Control Act, initially passed in 1948, was significantly expanded in 1972 and reborn as the CWA. This Act outlines the basic regulation of pollutant discharges into bodies of water, sets standards for water quality and contaminants, and gives the EPA authority to implement pollution control programs for industry.[50]

Clean Air Act of 1970 (CAA): Originally passed in 1970, with major revisions in 1977 and 1990, the CAA requires the EPA to regulate "criteria pollutants" and other toxic chemicals that affect air quality. This involves the creation of national ambient air quality standards and subsequent enforcement.[51]

Resource Conservation and Recovery Act of 1976 (RCRA): RCRA was originally passed in 1976 and gives the EPA authority to regulate hazardous and solid waste from "cradle-to-grave"—the production, transport, treatment, storage, and disposal of toxic wastes. RCRA is the fundamental federal body of law dealing with waste management.[52]

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA): CERCLA, also commonly known as the "Superfund" Act, was passed in 1980 and created a tax on chemical and petroleum industries for purposes of funding the cleanup of hazardous materials that may endanger environmental health. The Act has varying regulations for short-term and long-term cleanups.[53]

Endangered Species Act of 1973 (ESA): The ESA was enacted in 1973 and tasks the U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration with protecting and conserving threatened and endangered species, and their respective habitats.[54]

Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA): First enacted in 1947 and amended in 1972 and 2003, FIFRA governs the sale, distribution, and use of pesticides. This includes EPA review of all products to determine environmental safety and optimal use practices.[55]

While legal precedent for enforcement of these Acts (and others) on state-regulated cannabis businesses is thin, enforcement is ramping up and cannabis operators must be aware of consequences, which range

from fines to outright business shutdown. With concerns ranging from cultivation encroachment on wildlife habitat (ESA), pesticide use (FIFRA), and waste disposal practices (CERCLA/RCRA), business owners have a vested interest in ensuring environmental compliance—from an ecological protection standpoint and to protect their pocketbooks.

Effective State and Local Policy Frameworks

Being that states and localities are bound to certain minimum federal standards for protecting and enforcing environmental health (via the ESA, CWA, CAA, RCRA, etc.), many regulations regarding waste disposal, air emissions, and water protection, among others, are similar in nature. This section will highlight areas of innovative and effective state and local regulations of environmental concerns as they pertain to cannabis businesses.

Responsible Energy Use—Boulder County, Colorado

In Colorado, Boulder County has implemented a program dubbed the "Boulder County Energy Impact Offset Fund" that incentivizes cannabis cultivators to embrace renewable energy for their operations. Under the program, commercial cannabis cultivators must either offset their facility's electricity use with local renewable sources or pay a tax of 2.16 cents per kilowatt-hour (a standard unit of measure for energy consumption). The revenue generated from this tax is used to "educate and support best in industry practices with regards to energy usage as well as for funding other carbon pollution reducing projects such as low-income renewable energy" (Boulder County). In Boulder County, it was determined that the average electricity consumption of a 5,000 square-foot indoor cannabis cultivation facility was about 41,808 kilowatt-hours per month, translating to approximately $900 monthly in due taxes if the tax avenue was chosen by the facility.[56] Otherwise, businesses can enroll in local utility programs that utilize wind and/or solar energy—an often far-cheaper alternative than paying the tax.

Sustainable Water Use—California

With a strong push from increasingly common drought conditions and impending climate change effects, California's Water Resources Control Board has established rules regarding water rights and cannabis cultivation. Cannabis growers that wish to legally divert water for irrigation purposes must obtain a "water right" from the state. Further, cultivators are prohibited from diverting water during the dry season (April 1—October 31).[57] These rules serve to ensure that all natural water flows can reach the destinations that rely on them, especially during the dry season.

Comprehensive Sustainability Planning—Grand Rapids, Michigan

The City of Grand Rapids maintains a cannabis ordinance that requires cannabis businesses to enroll in the city's "2030 District" program prior to beginning operations. This requires cultivators and microbusinesses to submit plans to the city within 6 months of operation that outline energy load, emissions forecasts, water efficiency plans, wastewater and toxic substances loads, and waste management plans. The ordinance also mandates the use of energy-efficient lighting and compels a whole-building energy audit. Any license renewals must also include energy sustainability plans and proof of compliance.[58]

Policy Recommendations

Provide government-backed incentives for cannabis businesses to adopt renewable energy sources (on-site or contracted).
Cannabis cultivators' largest environmental footprint is energy consumption, and state governments should provide incentives for cannabis businesses to build on-site renewable energy sources or procure them from outside sources.

Encourage and approve utility programs that incentivize the adoption of renewable energy (on-site or contracted) for cannabis businesses, along with accessible energy efficiency programs.
Utility programs that create a more favorable investment framework for sustainable energy solutions should be accessible to cannabis businesses, and these programs should be adopted where they don't currently exist. This can include favorable electricity rate structures, purchase rebates, bill savings, and other incentives for energy efficiency.

Ensure accessible financing options for cannabis businesses to adopt clean energy solutions.
State regulators should ensure that along with any incentives to adopt clean energy, accessible financing should also be available to cannabis businesses. Because most banks may not work with cannabis businesses, state and local governments should explore options for providing loans and other financing for state-incentivized clean energy investments.

Create regulatory disincentives for illegal water diversions, and educate cultivators on the impacts of detrimental and illegal water use.
Appropriate regulatory agencies should step-up enforcement and monitoring of illegal water diversions, including but not limited to increased fines, license suspension or termination, and/or mandated remediation. State and local governments should also provide educational resources on the effects of water diversions and sustainable alternatives.

Create land restoration programs that require cannabis businesses to offset the negative results of their business operations (e.g., deforestation, habitat loss).
Any cannabis businesses that meet predetermined criteria regarding their environmentally-destructive activities should be required to take actions to offset their impacts in accordance with state and federal environmental statutes.

Establish soil management best practices for cannabis cultivators and provide educational resources and services.
State and local governments should provide educational materials and services to cannabis cultivators that outline best practices for soil management. For this, public-private partnerships with universities and farm associations should be explored.

Create incentive programs and education campaigns to encourage the adoption of sustainable chemical alternatives, such as alternative pest control methods and organic fertilizers.
Along with state- and local-provided educational campaigns and resources, governments should establish incentives for the adoption of sustainable alternatives to traditional pesticides and fertilizers. This can be achieved through public-private partnerships with universities and farm associations.

Conduct public outreach and education campaigns that provide insights to cultivators on the environmental risks and benefits of varying cultivation methods.
Without making direct recommendations, policymakers should provide educational resources to cultivators explaining the environmental impacts to consider for differing cultivation methods.

Incentivize the formation of partnerships between cannabis businesses and biodigesters/composters to sustainably manage waste and utilize waste byproducts.
Cannabis cultivators should be incentivized to enter agreements with biodigesting/composting facilities to manage biological waste. These agreements should result in both parties receiving benefits derived from state incentives.

Create incentive programs to encourage recycling in the cannabis industry, including plant materials, packaging materials, and chemical solvents.
Cannabis businesses should be incentivized to recycle a range of materials across their operations, as many large-scale commercial recycling services can be costly.

Establish incentives for cannabis brands to employ sustainable packaging materials, such as hemp.
State and local governments should provide incentives for cannabis brands to utilize recyclable, compostable, and/or hemp-based packaging for their products.

Allow consumers to use their own opaque exit containers at cannabis retailers.
Customers of cannabis retail businesses should be permitted to bring their own opaque, sealable exit containers for use at the point of purchase. State and local governments should establish reasonable criteria for consumer-provided exit containers.

Conduct state-funded scientific studies on the environmental impact of the cannabis industry to better inform future policy decisions.
State governments should explore partnerships with universities and other research institutions to study the environmental impacts of the cannabis industry to better inform incentive programs and industry regulations.

Incentivize commercial cannabis cultivation and manufacturing businesses to submit comprehensive sustainability plans.
Cannabis businesses should be encouraged to develop and submit comprehensive sustainability plans for their operations to regulatory agencies and the general public. Regulators should incentivize these plans—potentially by reducing license application and renewal fees after submission of a sustainability plan that meets predetermined standards.

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