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ENVIRONMENTAL SUSTAINABILITY IN THE CANNABIS INDUSTRY

IMPACTS, BEST MANAGEMENT PRACTICES, AND POLICY CONSIDERATIONS

The NCIA environmental committee was formed to write a technical report on "Environmental Impacts, Best Management Practices and Policies for the Cannabis Industry" necessary to position the cannabis industry as a leader in environmental sustainability at the local, state, and national levels and to help inform environmental policy.

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EXECUTIVE SUMMARY

The cannabis industry continues to mature as cannabis legalization spreads across the country. Today thirty-three states have passed laws allowing for the production and sale of medical marijuana. And eleven U.S. states have passed laws allowing for the production and sale of adult-use marijuana. In December 2018, Congress passed the Agriculture Improvement Act of 2018 (the "Farm Bill"), significantly expanding the legal protections for a subset of cannabis plants defined as "industrial hemp." Most recently, numerous states deemed cannabis "essential" as other businesses were required to temporarily close due to the coronavirus pandemic (Spring 2020). This fast-growing and highly regulated industry (at the state level) is poised to lead on evolving business challenges, including the adoption of environmentally sound business practices that demonstrate to the broader agriculture sector that comprehensive environmental sustainability is achievable.[1]

Some of the challenges facing the cannabis industry present opportunities to implement environmentally sustainable practices.[2] Companies that focus on sustainable practices reduce their resource dependence and associated costs, positioning them to outperform competitors in the long-term.

Keeping pace with global sustainability goals may soon be necessary from an investment standpoint. In the coming years, municipal, state, and federal regulators may be required to demonstrate efforts to support *Sustainable Development Goals*, and financing may be available to engage businesses that specifically target them.[3] Sustainable investing strategies over the past decade demonstrate that businesses should form collaborative coalitions to access municipal and federal green bonds to finance the development of sustainable technology, infrastructure, and waste reduction solutions[4]. As consumers consistently demonstrate their willingness to pay more for sustainable brands, with 1/3 willing to pay 25% more for sustainable products in 2019[5], *Environmental, Social, & Governance* (ESG) strategies may even potentiate greater retail taxes.

> ***NCIA suggests that forward-thinking standard-setting bodies, self-regulatory organizations, and government regulators take note and create workable standards with supporting resources to set the cannabis industry apart as a leader in environmental sustainability.***

Below, we provide a review of the impacts cannabis has on soils and land use, water, energy generation and consumption, air quality, and the challenges associated with waste. Each respective section explores current and emerging best management practices and their corresponding policy considerations. In many cases, existing policies can be broadened or modified to include the cannabis industry. However, the cannabis industry is as unique as the plant itself, and particular growing, processing, and packaging practices may benefit from cannabis-specific policies outlined herein. Legalization of cannabis is an unprecedented opportunity for environmentally sustainable practices to be adopted as the national industry standard from the outset, positioning the cannabis industry to emerge as a leader in environmental sustainability.

NCIA suggests that forward-thinking standard-setting bodies, self-regulatory organizations, and government regulators take note and create workable standards with supporting resources to set the cannabis industry apart as a leader in environmental sustainability. Any such standards should take cost into account, as we don't want to further encourage illicit market actors by creating unfunded mandates for state-legal operators.

1. While the National Cannabis Industry Association does not develop national standards and likewise does not operate as a "self regulatory organization," we recognize that standards setting bodies can and should evaluate national standards on environmental sustainability for the cannabis industry.
2. Jackson, Margaret. *Avoiding The Greenwashing Trap*, Marijuana Business Magazine (Vol. 6, Issue 10, Nov.-Dec. 2019), https://mjbizmagazine.com/digital-issues/2019-10-NovDec/140/ Last Accessed 2020-06-16
3. Press Release, *30 Business Titans Join UN Push to Scale Up Private Sector Investment for Sustainable Development,* United Nations. (October 16, 2019), https://www.un.org/sustainabledevelopment/blog/2019/10/gisd-alliance/ Last Accessed 2020-06-16
4. *Sustainable Signals: Growth and Opportunity in Asset Management.* Morgan Stanley Institute for Sustainable Investing & Bloomberg L.P. (February 19, 2019), https://www.morganstanley.com/assets/pdfs/2415532_Sustainable_Signals_Asset_Mgmt_L.pdf Last Accessed 2020-06-16
5. *CGS Survey Reveals Sustainability Is Driving Demand and Customer Loyalty* GlobeNewswire (January 10, 2019) https://www.globenewswire.com/news-release/2019/01/10/1686144/0/en/CGS-Survey-Reveals-Sustainability-Is-Driving-Demand-and-Customer-Loyalty.html Last Accessed 2020-06-17

SUMMARY OF ENVIRONMENTAL IMPACTS

Importance of Displacing the Illegal Market

One of the primary goals in supporting the shift to environmental excellence should be to displace the unregulated, untested, and unsafe illicit market. For decades the illicit cannabis market failed to implement environmentally sustainable methods of production. Whether this was the result of a lack of education, efforts for concealment, or a lack of access to mainstream agricultural and waste management resources, the environmental damage caused by the illicit market is significant. The good news is that the regulated cannabis market carries myriad environmental protections. Discouraging purchases from the illicit market will inevitably drive consumers to the regulated marketplace where more environmentally sustainable practices (and myriad safety precautions) are increasingly being adopted as the cannabis industry matures.

Soil Degradation Impacts

Similar to traditional agricultural practices, the cultivation of cannabis can cause soil degradation which threatens a vital part of the ecosystem. Soil erosion, nutrient loss, reduction in organic carbon stored within the soil, and increased acidity are all inextricably linked to traditional destructive agriculture practices. If the cannabis industry adopts environmentally sustainable practices, it can become a leader in how to reduce the environmental degradation and climate change impacts associated with other traditional agricultural operations. Some outdoor industrial farming practices - such as intensive use of pesticides and synthetic fertilizers and replacing native vegetation with single-row annually planted crops - lead to unintended and avoidable impacts to land use and soil health. An industry that is proactive on environmental issues can offer affirmative environmental benefits. For example, cannabis can remediate radioactive and heavy metal contamination by literally absorbing harmful contaminants from the soil.[6,7] For the same reason, however, cannabis soils should be rigorously and regularly tested for quality assurance, and cannabis used for remediation purposes must never be consumed.

Water Impacts

Cannabis, like many other crops, often relies upon water supplied through artificial irrigation. Agricultural runoff from traditional and cannabis farming has impacts on the environment from pesticides, heavy metals, excess and elevated nutrients, as well as other pollutants from wastewater. Indoor cultivation has the potential to put pressure on municipal water systems from the discharge of excess nutrients and industrial cleaners, which increases the stresses on existing wastewater treatment facilities. Increased load on water systems also leads to indirect air quality impacts through increased carbon emissions. The illegal cultivation of cannabis outdoors, which has commonly taken place in remote areas, can negatively impact water resources absent adequate regulation and compliance.

Energy Impacts

The cannabis industry leverages a range of energy infrastructure in a variety of different cultivation and production environments, including indoor and outdoor facilities. Depending on production methods, cannabis can be an energy-intensive crop. Industry innovation in more energy-efficient practices will result in reduced greenhouse gas emissions associated with power generation. Data collection is the first step in identifying and implementing methods for reducing fossil fuel consumption (from energy production) and optimizing an individual facility's energy efficiency. Access to energy infrastructure (power grids) for remote regulated cultivators is a challenge that can cause a reliance on inefficient and greenhouse gas-emitting generators that run on fossil fuels and result in negative air quality impacts. Facilities that rely on existing energy infrastructure contribute to the demand and may increase the maintenance and upgrades required for these systems to operate.

Air Quality Impacts

Emissions of air pollutants may occur at multiple points during the cultivation and processing of crops, and the cannabis industry is no exception. Cultivation and processing of cannabis, along with the electricity generated to power indoor growing facilities, and transportation of cannabis products all contribute to air emissions. Volatile organic compounds (VOCs) are emitted from all plants as they grow, with cannabis plants emitting VOCs as terpenes throughout their growth cycle and processing. These same terpenes contribute to nuisance odors, similar to the odor impacts from other industrial-scale agricultural or processing operations. VOCs are also emitted from cannabis production (extraction) through the use of solvents in the process. VOC emissions from the cannabis industry contribute to the formation of harmful ground-level ozone in urban areas, which threatens public health and the environment. Studies are underway to better understand the quantity and characteristics of cannabis industry emissions, specifically on VOCs from cultivation. Emissions of VOCs, nitrogen oxides (NO_X), and greenhouse gasses contribute to climate change, as do other air contaminants resulting from fossil-fuel-based electricity generation and transportation of products.

Waste Impacts

A significant portion of the waste generated from industrial-scale cultivation and processing of cannabis is the organic plant waste and single-use consumer packaging. The environmental impacts from these waste streams are similar to various other consumer goods and are the result of inefficient and antiquated waste management models for all of society (i.e., excessive landfilling, flawed recycling infrastructure with recently failed end

6. Citterio, S., Santagostino, A., Fumagalli, P. et al. *Heavy metal tolerance and accumulation of Cd, Cr and Ni by Cannabis sativa L.,* Plant and Soil 256, 243–252 (October 2003), https://doi.org/10.1023/A:1026113905129.

7 Petrová, Š., Benešová, D., Soudek P. et al. *Enhancement of metal(loid)s phytoextraction by Cannabis sativa L.* Journal of Food, Agriculture and Environment Vol 10 (1) 631-641 (January 10, 2012), https://www.votehemp.com/wp-content/uploads/2018/09/e0.pdf

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markets, and weak end-markets for compost). Environmental impacts include contributing to landfills, ocean pollution, and greenhouse gas emissions. Additional consumer waste from vape pen cartridges, single-use (disposable) plastic containers, and redundant packaging. Waste associated with the cultivation and processing of cannabis and its byproducts contributes to the significant amount of waste that ends up in landfills or as waste shipped offshore and processed in unregulated systems.

SUMMARY OF BEST MANAGEMENT PRACTICES

As a relatively nascent legal industry, the cannabis industry can lead by example from the outset and raise the bar for more sustainable best management practices. Cannabis businesses that incorporate environmentally sustainable practices will reduce impacts on the environment, while simultaneously increasing profit margins and saving their consumers money. These savings will be optimized if government partners collaborate with the industry to provide supporting resources, regulations, and policies.

Proper Land Use

Proper land-use planning is the foundation upon which sustainable practices are built. It starts with a comprehensive plan for cultivation, informed by soil characterization, which enables cultivators to consider the short, medium, and long-term impacts of the decisions they are making. Soil testing before and throughout the business's lifecycle allows an operator to gain the knowledge needed to optimize soil health. The cannabis sector can lead the way in integrating these practices, along with the fundamental elements of regenerative agriculture, to ensure the viability of the land and soil it depends on.

Water Conservation

Geographical considerations, along with the use of other natural resources, should be taken into account when sourcing and managing water during the cultivation and processing of cannabis. Industry best practices need to focus on minimizing water usage as well as eliminating adverse impacts to water quality from any discharges back into the environment. An excellent first step is to plan to use only the minimally required water volume for cultivation and other uses. Implementing methods for automated irrigation and capturing excess water for reuse within the cultivation operation will aid in reducing waste. Treating water, along with continual quality testing, also minimizes waste and reduces the likelihood of contaminated water being reused or being discharged into the environment. Properly permitted cannabis farms commonly make use of proper water storage, alternative water sources, and discharge pre-treatment methods that substantially decrease the environmental impacts associated with crop irrigation.

Efficient Energy Use

Cost-efficient and appropriately designed technologies are necessary to reduce the energy needed for the industrial-scale cannabis industry and to reduce the depletion of natural resources. The cannabis industry can advance the research necessary to become less dependent on fossil fuels by actively pursuing more sustainable energy solutions. Through proactive planning and the leveraging of business networks, the cannabis industry should collaboratively pursue more energy-efficient practices. Many indoor grow facilities, for example, have implemented LED lighting and more efficient HVAC systems. Optimizing space utilization and scheduling the use of high-energy equipment around peak demand can also reduce the energy impacts of the cannabis industry.

Air Quality Controls

Existing emission control technologies have the potential to be broadly applied across the cannabis industry to mitigate adverse air quality impacts. Carbon filtration is currently viewed as the ideal form of emissions and odor control in the indoor cannabis industry. Processing operations may also significantly reduce solvent losses and associated air emissions with cold traps and condensers in closed-loop extraction systems. These technological advances are critical to reducing harmful air emissions but need to be evaluated against the power used to operate them to avoid shifting environmental impact down the line. The utilization of energy-efficient lighting and equipment, as well as low-emission vehicles for transport, will also improve air quality impacts associated with the industry.

Waste Reduction

Due to flaws in our current waste management and diversion systems, consumer waste has exacerbated "end of life" environmental impacts. As the industry actively moves toward federal legalization, standardized packaging requirements are a likely result. Manufacturers and retail cannabis facilities should collaborate on best practices that promote and integrate reusable and refillable containers for their products, instead of disposable single-use packaging designs. This includes plastics as well as organic-based materials such as "compostable" and "biodegradable," as the vast majority of single-use compostable packaging is disposed of in landfills, which contributes to greenhouse gas emissions. Cannabis product designs are evolving as the market shifts to demanding long-lasting materials that can be circulated between production and consumption without losing the integrity required to meet child-resistant and other mandated packaging requirements. Implementing packaging 'take-back' programs at retail locations is another way to help reduce single-use waste.

Plant waste is the other major waste stream from the cannabis industry. It typically ends up in the landfill due to regulations requiring that it be mixed 50% with non-marijuana waste before disposal. This makes composting incredibly challenging. An emerging best practice for managing plant waste involves on-site anaerobic digestion that uses the plant waste to generate and capture methane (to be used as energy), carbon dioxide (to be used in extraction or cultivation), and nutrient-rich fertilizer (to be integrated back into soils or cultivation) - providing 100% diversion from landfills and the reuse of plant waste. Cannabis production facilities that adopt energy-efficient technology and green chemistry will also help to reduce harmful linear waste streams.

SUMMARY OF POLICY CONSIDERATIONS FOR A SUSTAINABLE FUTURE

Federal Legalization

The establishment of cooperative policies and standards across local, state, regional, and national levels for both marijuana and hemp markets will be critical to the sustainable advancement of the cannabis industry. Federal legalization of marijuana will open access to federal programs such as U.S. Department of Agriculture (USDA) financial and technical assistance, Small Business Administration (SBA) loan assistance, Environmental Protection Agency (EPA) grants and technical assistance, education, research, and traditional funding through nationally recognized financial institutions. Federal legalization also has the opportunity to advance the industry while protecting consumers and the natural environment with a national regulatory structure that considers environmental sustainability. Regulators should consider how existing policies and regulations for other industries apply to cannabis while also shaping new policies and regulations that are appropriate to meet the unique needs of the cannabis industry. Existing infrastructure networks, combined with new technologies, will need to work together to ensure environmental efficiency while increasing the rapidly growing cannabis industry's capacity to benefit the communities in which they operate.

Land and Soil Sustainability

Absent federal legalization, the marijuana industry is unable to qualify for federal programs. Absent eligibility for existing federal organic certification programs, the marijuana industry should engage with voluntary industry-specific certification programs that identify and uphold sustainable and organic best practices. Beyond certifications, a national cannabis geographical indication (appellations) program for specific regions would provide value if developed to help protect the integrity of the agricultural industry, as well as the livelihoods of its stakeholders. These appellations would raise awareness of opportunities for local "craft" cannabis businesses by allowing outdoor cultivators to draw a boundary around their geographic area and defining a set of sustainable and locally-tailored standards and practices unique to their region. Standardized final product testing requirements would reduce the number of unregulated fertilizers, toxic pesticides, and other harmful chemicals used in the production and manufacturing of cannabis-based products while protecting human health and the environment.

Improving Water Quality

Impacts on water quality can be addressed by having sound regulations and policies that set usage limits and stipulate disposal requirements appropriate for the geographical area and types of discharge. Understanding that water rights are regulated at the state level is critical to inform and guide decision-making at the federal level. It is crucial to consider the implications of policies that create barriers to cannabis cultivators' access to legal markets. The increasing water demand of the cannabis industry and its reliance on groundwater resources could be mitigated by developing and increasing access to more complex water networks. This is particularly critical because many outdoor cannabis cultivation settings are isolated from existing major water networks, resulting in many farmers being forced to consider using marginal irrigation methods. This only comes with descheduling and federal regulation by EPA and other federal agencies.

Energy Policy

For decades, marijuana cultivators were forced indoors due to the nature of unregulated markets. This reality, as well as public safety concerns, contributed to the legal market adopting the practice of using controlled production environments made possible by indoor cultivation, which is energy-intensive. Indoor cultivation is further encouraged by the market demand for high-quality cannabis products year-round in the absence of environmental considerations like adverse weather and fluctuating daylight. This has resulted in an estimated 63% of commercial cultivation settings being conducted indoors with another 20% in partial-indoor operations like greenhouses. The energy used for lighting, environmental controls, and hydration at indoor cultivation operations can require up to 5,000 kilowatt-hours of electricity per kilogram of output. Given the realities of this ever-growing industry, it is critical that policymakers set specific energy and climate goals that are communicated to all market participants to ensure they have the information, resources, and tools necessary to achieve the goals. The incorporation of energy and operational Best Management Practices in policy and regulation will help establish sustainable growth for the industry. This can be achieved by incorporating structural and financial support to incentivize the adoption of Best Management Practices, ongoing education of market participants, and providing transparent access to energy and market data. Of course, de-scheduling cannabis and the inevitable interstate commerce that would allow cannabis to be grown outdoors and sold in states where outdoor grows are unworkable.

> *"Cannabis businesses that incorporate environmentally sustainable practices will reduce impacts on the environment, while simultaneously increasing profit margins and saving their consumers money. These savings will be optimized if government partners collaborate with the industry to provide supporting resources, regulations, and policies."*

Air Quality Improvements

By requiring cannabis business applicants to plan for emissions controls up-front, major environmental impacts, and the costs associated with violating environmental regulations can be avoided. Existing air quality permit programs should work in tandem with state cannabis licensing authorities. Depending on the type and size of the cannabis operation and the resulting air emissions, an air permit may be required and should be in place prior to the construction or installation of equipment. Cannabis facilities should also plan how odors will be managed to minimize adverse odor impacts on nearby communities. In some cases, the same controls for reducing emissions may also help mitigate odors. National or state-level incentive programs should also be considered. This could consist of providing credits for businesses working to reduce greenhouse gas emissions in the cannabis space. Negative impacts on ambient air quality may also be minimized by establishing and enforcing data-informed parameters around odor ordinances and proper zoning methods.

Regulating Waste

The policy shift with the most potential to have an immediate and lasting impact on plant waste generated from cultivation would be the abolishment of the common 50/50 mixing rule for marijuana plant waste which often requires landfilling of double the operation's waste stream. If marijuana plant waste were not required to be mixed with 50% non-marijuana waste before disposal, it would reduce greenhouse gas emissions and cut down on landfill space while supporting more environmentally effective diversion practices such as composting and on-site anaerobic digestion.

The cannabis industry generates a significant amount of single-use disposable packaging (including plastic and biodegradable packaging). Packaging manufacturers and retailers should be supported with regulatory policies that incentivize take-back programs that integrate reusable packaging designs. Waste mitigation through standardized reusable packaging designs is an important consideration, but in many states, it is illegal to recycle cannabis packaging. Statutory and regulatory changes are therefore required in some jurisdictions. These programs would encourage both the producers and consumers to work together in a regenerative model that moves packaging back and forth multiple times through reuse and repurposing. Compliance can be enforced through concept programs like Extended Producer Responsibility (EPR), which holds companies accountable for single manufacturing use disposable products that generate large volumes of waste with no mitigation plan in place.

KEY TAKEAWAYS

1. Optimizing all resource usage in the cannabis industry will simultaneously reduce environmental impacts and increase profit margins while maintaining product quality.
2. Data tracking and environmental metrics analysis is the key to advancing environmental sustainability in the cannabis industry.
3. Contact environmental permitting agencies early in the planning process. Air quality, stormwater, and hazardous waste permits may be required for industrial-scale growers and processors, and permits need to be acquired prior to beginning construction and operation.
4. Building and retaining Soil Organic Matter by employing thoughtful land management and consistent soil health testing, will ensure resource and quality maximization while maintaining and enhancing the natural environment.
5. Water quality and availability must be considered in the planning phase of cultivation. Growers should attempt to reduce their water usage as much as possible while also eliminating any potentially harmful or hazardous discharge through inherently protective operations and technology.
6. Reduce energy used for cultivation and processing by replacing and upgrading outdated and inefficient equipment (energy efficiency), and reduce CO_2 emissions of cultivation by using renewable energy resources and battery back-ups where practicable.
7. Carbon filtration systems should be installed at indoor cultivation and processing facilities to control odor and reduce emissions of air contaminants.
8. While still maintaining compliance with marijuana waste regulations (e.g. 50/50 plant waste mixing rule), companies should strive to divert marijuana plant waste from landfills by pursuing composting, fiber recovery, or anaerobic digestion.
9. Reusable packaging with incentivized consumer take-back and Extended Producer Responsibility programs should be implemented to reduce the cannabis industry's single use packaging waste.
10. Regulations, policies, and resources need to support and help drive environmental sustainability within the cannabis industry.

PREFACE, LIMITATIONS, AND ACKNOWLEDGEMENTS

This paper has been prepared by a group of environmental policy and cannabis experts with a wide range of expertise. The emerging cannabis industry has experienced fundamental changes across local, state, and federal jurisdictions over the past few decades. This has led to a scarcity of available information on fundamental metrics related to the industry, geographically skewed the available data, and limited its reliability. With that context in mind, this paper has been prepared with the best available information at the time of its publication (Summer 2020). Informational gaps are the result of the limited availability of industry data at this time. A periodic review of the industry, available data, best practices, and policies are suggested to keep the cannabis industry at the forefront of environmental sustainability.

The National Cannabis Industry Association and NCIA's Policy Council are grateful for the pro-bono work by the contributing authors listed below. NCIA is a non-profit association and relies upon pro-bono contributors to help us to deliver cutting edge and impactful research papers and other important work.

We are particularly grateful for this team's work.

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LEADING THE WAY

The emerging hemp and marijuana sectors provide a unique opportunity to establish industry standards and operating procedures that align with an informed understanding of the impacts on our environment. While NCIA is not a standards-setting body, we do support the work by standards-setting bodies for the industry, including ASTM's D-37 Committee. This white paper provides a review of the impacts cannabis (and most other agricultural products) has on soils and land use, water, energy generation and consumption, air quality, and the challenges associated with waste. Each respective section explores current and emerging best management practices and their corresponding policy considerations. While there have been a growing number of new technologies emerging over the past few decades in some regions, the normalization of the marijuana and hemp industries is an unprecedented opportunity for environmentally sustainable practices to be adopted as the national industry standard from the outset, positioning the cannabis industry to emerge as a leader for environmental sustainability. NCIA suggests that standard-setting bodies, self-regulatory organizations, and government regulators take note of the suggestions herein, and create national standards to set the cannabis industry apart as a leader in environmental sustainability.

ILLEGAL MARKET THREATENS THE SUSTAINABILITY OF THE LEGAL INDUSTRY

DRIVEN BY ECONOMICS

The burgeoning legal marijuana industry is unique because it competes with a well-established, unregulated, untested, and comparatively inexpensive illicit market. For example, despite legalizing cannabis for adult-use in 2016, California still has a thriving legacy market. According to research firm New Frontier Data, as much as 80% of the cannabis sold in California comes from the unregulated market. In fact, New Frontier estimates that the state's illicit marijuana market is worth $3.7 billion, which is more than four times the size of the legal market in California.[8]

While states that have implemented cannabis legalization have seen a substantial shift into the regulated market, it has become clear that cannabis legalization alone has not resulted in the elimination of illicit market cultivation. A combination of factors, including barriers to entry into the regulated market, permitting and tax costs, local city and county bans, and continued federal prohibition have led to a persistent illicit market even in cannabis-legal states. Illicit farming can be categorized as either operation on private land or trespass grows, generally occurring on public lands such as a national forest. The extent of public land grows is difficult to document because measures are taken to conceal them; however, evidence from aerial imagery shows that illicit private land grows are continuing to expand and thrive.[9]

The combination of a rapidly expanding regulated industry and a well-established legacy market is a recipe for unpredictable market fluctuations and presents the possibility that some unsuccessful companies will abandon properties that contain residual environmental hazards. Common sense would dictate that federal legalization would generate a decrease in illegal market activities, and increase legal market tax revenues.

IMPACTS OF AN UNREGULATED MARKET ARE DIRE

There is a historical connection between the unregulated marijuana industry and environmental degradation. The environmental impacts of cannabis are contained within a regulated market as regulations serve to reduce the environmental impact of cannabis cultivation and processing.

8. Kevin Murphy, *Cannabis' Black Market Problem*, Forbes (April 4, 2019), https://www.forbes.com/sites/kevinmurphy/2019/04/04/cannabis-black-market-problem/#65955b2e134f Last Accessed 2020-06-17

9. Butsic V, Carah JK, Baumann M, et al. *The emergence of cannabis agriculture frontiers as environmental threats.* Environmental Research Letters. (12):124017. (December 4, 2018)

The environmental impacts are exacerbated in an unregulated market and can result in negative impacts to land use and soil, water, energy, air, and waste generation.

While the regulated cannabis market strictly controls pesticide use, and in most states requires cannabis products to be tested for pesticides to a significantly higher degree than other agricultural products, this is not the case for illicit growers who often use prohibited pesticides and banned rodenticides. Rodenticides have been traced up the food chain to larger animals, including some that humans hunt for food, meaning that rodenticides may be directly human populations as well as animals.[10] In California's illegal market, prior to the implementation of state cannabis testing regulations in 2018, a subset of irresponsible cultivators utilized toxic pesticides and rodenticides that poisoned rivers, fish, and wildlife, in addition to consumers.[11] Since the establishment of cannabis testing standards, the situation has improved drastically. One study found that the rate of cannabis contamination fell from 24% to 3% within months of the implementation of state-mandated cannabis testing.[12]

Illegal cultivations often power their operations with off-grid fuel-powered generators. The generators create excess emissions and increase the severity of diesel fuel leaks. These harmful emissions degrade regional air quality and contribute to global climate change. As legal production has scaled, growing techniques have evolved, and data shows that commercial cultivation methods can achieve much better energy performance than illicit cultivation approaches.

Cannabis originally gained a reputation as a water-intensive crop, largely due to studies based on outdoor illicit cultivation in Northern California.[13] Illicit operations are notorious for water waste and inefficiency due to unmaintained and unmonitored infrastructure prone to leaks and spillage.[14] Illicit farms also tend to draw opportunistically from streams during summer drought months, threatening endangered fish and other aquatic species.[15] Although permitted farms are likely to use water much more efficiently and are subject to protections for streamflow based on existing policies, the current scale of the illicit market still means that unregulated cannabis farming continues to pose a significant threat to freshwater resources.[16]

The Resource Conservation and Recovery Act is a federal law that regulates solid and hazardous waste with respect to generation, transportation, treatment, storage, and disposal. Common hazardous waste generated by the cannabis industry includes waste ethanol and isopropyl alcohol (ignitable wastes), acetone, and other chemicals and reagents used in quality control testing. The illegal market does not have access to proper hazardous waste disposal. Furthermore, little effort from illegal operations is applied to sourcing recyclable and reusable packaging material as minimal accountability is present from consumers and regulators. As the legal cannabis market matures and seeks to reduce, reuse, and recycle materials, many of the illicit market's contributions to waste accumulation will be minimized as it dissolves. Cannabis should be descheduled, tested, and regulated at the federal level to eliminate the current unchecked environmental impacts of the illegal market.

MINIMIZING THE ILLICIT MARKET

Following the legalization of recreational marijuana in Oregon, growers operating in the illegal market were extended an invitation to obtain a recreational license. The rapid expansion of legal marijuana cultivation in Oregon led to an oversupply, which depressed the price of marijuana, jeopardized industry sustainability and reduced revenues for regulatory oversight.[17] Oklahoma had a similar boom and bust cycle. The open-ended medical marijuana law approved in 2018, combined with the state's alleged aversion to government regulation, appears to have created ideal conditions that attracted marijuana

10. Chelsea Harvey, *Scientists say illegal pot farming operations are poisoning threatened weasels*. The Washington Post (November 4, 2015), https://www.washingtonpost.com/news/energy-environment/wp/2015/11/04/scientists-charge-that-illegal-marijuana-farms-are-poisoning-threatened-weasels/ Last Accessed 2020-06-17

11. Trina Wood, *Pot, Rat Poison and Wildlife Don't Mix.* UC Davis (January 23, 2018), https://www.ucdavis.edu/one-health/pot-rat-poison-wildlife-dont-mix/ Last Accessed 2020-06-17

12. Ben Adlin, *Can Washington Fix Its Broken Cannabis Lab Testing System?* Leafly (June 17, 2019), https://www.leafly.com/news/industry/can-washington-fix-its-broken-cannabis-lab-testing-system Last Accessed 2020-06-17

13. Bauer S, Olson J, Cockrill A, Van Hattem M, Miller L, Tauzer M, Leppig G. Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds. PloS One. 2015;10(3).

14. Dillis C, Grantham T, McIntee C, et al. *Watering the Emerald Triangle: Irrigation sources used by cannabis cultivators in Northern California*. California Agriculture. 12;73(3):146-53 (September 12, 2019)

15. Carah JK, Howard JK, Thompson SE, Short Gianotti AG, Bauer SD, Carlson SM, Dralle DN, Gabriel MW, Hulette LL, Johnson BJ, Knight CA. High time for conservation: adding the environment to the debate on marijuana liberalization. BioScience. 2015 Aug 1;65(8):822-9.

16. Butsic V, Carah JK, Baumann M, et al. *The emergence of cannabis agriculture frontiers as environmental threats*. Environmental Research Letters. (12):124017. (December 4, 2018)

17. Abby Tang, Jennifer Lee and Nisha Stickles, *Oregon has 1 million pounds of unsold cannabis, and it reveals the state's marijuana-surplus problem*. Business Insider (April 10, 2019) https://www.businessinsider.com/why-oregon-has-1-million-pounds-of-unsold-cannabis-2019-4 Last Accessed 2020-06-17

entrepreneurs from other states.[18] This boom has resulted in marijuana entrepreneurs acquiring virtually every vacant shop and building in parts of Oklahoma City. The state of California is at the opposite end of the spectrum with local opposition, high taxes and onerous regulations making it difficult for the legal marijuana industry to compete with legacy markets because state and local taxes can add 45% to a retail purchase.[19] These examples highlight the need for robust marijuana regulatory programs that provide adequate regulatory funding, and balance production with consumer demand.

As the cannabis market continues to open up across the country, industry leaders are moving to promote, change, and advance more sustainable business through the evaluation of the environmental impacts to land use, water, energy, air, and waste. The emerging legal marijuana and hemp market sectors provide a unique opportunity to establish best practices and operating procedures aligned with science's understanding of the human impact on the environment. The primary goals of minimizing the illegal marijuana industry should be to protect public health, minimize organized crime, balance government revenues with market demand, and to bolster a financially sustainable legal marijuana industry. Public education is essential if we are to root out the illegal industry. Any such campaign should emphasize the public benefits of a well-regulated market, such as: increased product safety, reduced organized crime and environmental sustainability. Consumers are more likely to pay a higher price when they understand the benefits of purchasing marijuana through a legal source.

In addition to public education, some legal enforcement will be necessary. The objective should be to prevent illegal marijuana from entering the consumer market. The goal should be to minimize the illegal market by concentrating on the larger grow operations by targeting outdoor grows and then leveraging surveillance techniques to expose industrial-scale indoor growing operations. Historically, law enforcement interventions from state and federal authorities have not succeeded in eliminating or even significantly reducing the unregulated market.[20] However, early case studies in Northern California have suggested that environmental compliance can be incentivized through a combination of lowered barriers to entry, incentives to enter the legal market, and civil enforcement on non-compliant cultivation sites.[21]

A comprehensive national marijuana strategy must include methods for minimizing illegal market sales through enforcement and public education. Therefore, policymakers should develop regulations that are simultaneously protective of the environment and not overly burdensome as to undermine motivation to join the regulated industry.

ILLEGAL GROW AND HASH LAB EXPLOSION

18. Murphy, Sean. "Pot entrepreneurs flocking to the Bible Belt for low taxes." *Local 4 News Detroit*. 3/7/2020. 6/18/2020. https://www.clickondetroit.com/business/2020/03/07/pot-entrepreneurs-flocking-to-the-bible-belt-for-low-taxes/

19. McGreevy, Patrick. "Two years in, California's legal marijuana industry is stuck. Should voters step in?" *Los Angeles Times*. 12/24/2019. 6/18/2020. https://www.latimes.com/california/story/2019-12-24/two-years-california-legal-marijuana-industry-is-stuck

20. Corva D. "Requiem for a CAMP: The life and death of a domestic US drug war institution." *International Journal of Drug Policy*. 2014 Jan 1;25(1):71-80.

21. Smith, Carl. "How a County is Managing a Marijuana Green Rush from Space." *Governing*. 3/20/2020. 6/18/2020. https://www.governing.com/now/How-a-County-Is-Managing-a-Marijuana-Green-Rush-from-Space.html

LAND USE AND SOIL HEALTH

> *We think we're here because of our big brain. We're not. Humans owe our existence to six inches of soil and the fact that it rains.* - **JEFF WALLIN**

LINKING LAND USE AND SOIL HEALTH

Cannabis has deep roots in the story of early America, due in large part to the traditionally fertile soil of the mid-Atlantic and the versatility of the cannabis plant from feed to fiber to fuel. Today, as a newly-legitimized industry seeking to transition from underground production into the world of land use regulation, the emerging cannabis industry provides an opportunity to re-evaluate the role of agriculture in a mechanized and globalized world.

Land-use change has traditionally been driven by expanding global populations that cause increased pressures on land, resources, and the sustainability of the planet. With the boom in global population over the last century, conventional agricultural practices have largely sought to meet demand by prioritizing short-term maximization of yield over the long-term health of the land and soil. With global sustainability increasingly under threat, many of these conventional practices are being re-evaluated, with the understanding that all agriculture, including cannabis, must consider long-term land-use impacts as much as short-term yield. Traditional, short-sighted agricultural cultivation practices that utilize modern technology (e.g., mechanical equipment, manufactured fertilizers, irrigation) and have resulted in:

- Soil loss through wind and water erosion
- Decreases in soil organic matter content
- Observable reduction in soil water-holding capacity, and
- Alterations in microbial composition

Conventional agricultural approaches affect soil chemical processes and conditions that can lead to further soil degradation. Changes in one or more of these properties often have direct or indirect effects on the fertility of soils, which can lead to decreased soil health and ultimately reduce productivity. Major alterations to the composition and chemical properties of the soil from external drivers such as climate and land-use change also influence the soil's ability to function within a larger ecosystem. Soil degradation is often linked to non-sustainable actions or loss of resilience - the ability to recover quickly and wholly from disturbance.[22] As sustainable and regenerative agriculture becomes an increasing priority globally, the newly-emerging legal cannabis industry provides an opportunity to adopt best management practices at the outset that can serve as a model for farming practices that regenerate, rather than degrade, the land that all life depends on.

ENVIRONMENTAL IMPACTS: LAND USE AND SOIL HEALTH

Traditional Agriculture vs Cannabis Cultivation

Existing outdoor cannabis agricultural practices are similar to conventional agriculture. However, one critical distinction is that the land use impact of marijuana production is extremely low when compared to traditional American agriculture. Cannabis is a highly efficient crop in terms of land use. In 2010, the RAND Corporation estimated that 4,400 acres of outdoor marijuana production is necessary to meet demand for the entire U.S. market.[23] These early projections have been reflected in licensing data in the legal market, with licensed production in California hovering around 1,000 acres in early 2019, distributed among thousands of licensed small farmers.[24] For comparison, 448 acres is the average size of a non-cannabis farm nationally.[25]

The land use impact of industrial hemp cultivation is higher than for marijuana and more closely resembles the scale of conventional agriculture. In 2019, there were 60,000 acres of

22 Daniels, J. M. (2016). *The Impacts of Long-Term Cultivation on Soil Degradation in the San Luis Valley, Colorado*. Available from Dissertations & Theses @ Colorado State University. (1870038151).

23. Jonathan P. Caulkins, *Estimated Cost of Production for Legalized Cannabis.* Rand. (July 2010) https://www.rand.org/content/dam/rand/pubs/working_papers/2010/RAND_WR764.pdf Last Accessed: 6-18-2020

24. Andrew Scheeler. *California is growing so much marijuana it could crash the market.* The Sacramento Bee. (March 19, 2019) https://www.sacbee.com/news/politics-government/capitol-alert/article228120439.html Last Accessed 2020-06-18

25. Dave Kranz, *Agricultural census provides snapshot of California farms.* Daily Democrat (April 18, 2019) https://www.dailydemocrat.com/2019/04/18/agricultural-census-provides-snapshot-of-california-farms/ Last Accessed 2020-06-18

hemp production licensed in Oregon[26] and half a million acres nationwide.[27]

Many hemp farmers come from traditional agricultural backgrounds, cultivate on the scale of hundreds of acres, and are accustomed to conventional industrial agricultural techniques. By contrast, many marijuana farmers cultivate on very small scales, do not come from conventional agricultural backgrounds, and utilize intensive manual labor rather than mechanized approaches.[28]

Cannabis cultivation is also split between indoor and outdoor cultivation methods, some of which is driven by state regulation.[29] For example, in Colorado marijuana is grown mostly indoors due to the increased regulatory burden of outdoor cultivation; whereas federally-legal hemp is regulated as an agricultural commodity and can easily be grown outdoors in agriculturally-zoned areas. These distinctions reflect market dynamics and regulatory requirements, as well as cultural factors. Where marijuana is often a "craft" product, with the value of unprocessed marijuana flower closely tied to its potency, smell, appearance, and other factors, cannabis as fiber or seed hemp is more likely to be cultivated as a "commodity" product intended for further processing and subject to less differentiation based on quality.[30] Despite these differences, both marijuana and hemp are fundamentally agricultural goods. As a result, they share a number of potential land-use impacts that are modulated by the specific agricultural practices utilized on a given farm.

Soil Health

Conventional cultivation practices, particularly in water-limited ecosystems, alter the physical, chemical, and biogeochemical properties that are necessary for soil quality and function. When long-standing vegetation is replaced by annually planted row crops, the results are soil erosion, loss of soil nutrients, loss of water permeability, and reduction in stored soil organic carbon, leading to a decline in soil health and reducing long-term productivity.[31]

Erosion

Soil erosion involves the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity. Dust emissions into the atmosphere and delivery of sediment, nutrients, and chemicals to water resources are primary environmental concerns addressed by public policymakers. Understanding and managing these processes has important long-term implications for cropland sustainability, natural resource condition and health, and environmental quality.[32]

The effects of soil erosion go beyond the removal of valuable topsoil. Crop emergence, growth, and yield are directly or indirectly affected by the loss of natural nutrients and applied fertilizers. Important, sometimes costly, and irreplaceable, organic matter from the soil, residues, applied amendments (e.g. compost, manure), and cannabis seeds and plants can be disturbed or completely removed by erosion.

- **Water erosion** occurs when there is excess water on a slope that cannot be absorbed into the soil or is trapped on the surface. Runoff from agricultural land is highest during spring when the soils are typically saturated from snowmelt and have minimal vegetative cover allowing rain impacts to be greater. In effect, the greater the raindrop energy or runoff amounts, the more easily sand, silt, clay, and gravel particles are moved.
- **Wind erosion** damages cannabis through sandblasting of young seedlings or transplants, burial of plants or seed, and exposure of seed. Plants damaged by sandblasting are vulnerable to the entry of disease with a resulting decrease in yield, loss of quality, and market value.
- **Tillage erosion** is the redistribution of soil through the action of preparing the land for growing crops combined with gravity. Tillage erosion impacts crop development and yield. Crop growth on shoulder slopes and hills is slow and stunted due to poor soil structure and loss of organic matter, thus it is more susceptible to stress under adverse conditions.

Fertility and Resilience

The fertility of soil refers to its ability to function in the growing of crop plants. Soil fertility is also referred to as soil health or soil quality. This more comprehensive view considers the physical, biological, and chemical properties of soils that are important to plant growth. The topsoil is the most fertile, containing higher amounts of organic matter and nutrients, more biological

26. April Simpson and Sophie Quinton, *Flood of hemp harvest hitting the market could sink price, profits for farmers*. Philadelphia Inquirer (September 16, 2019) https://www.inquirer.com/business/weed/hemp-farming-glut-no-guarantees-supply-us-20190916.html Last Accessed 2020-06-18
27. *328% Increase in U.S. Hemp Cultivation Acreage - New Frontier Data Releases 2019 U.S. Hemp Study.* Business Wire (September 19, 2019) https://www.businesswire.com/news/home/20190925005565/en/328-Increase-U.S.-Hemp-Cultivation-Acreage Last Accessed 2020-06-18
28. Amy DePierro, *Industrial weed is here. How pot farmers are using machine technology as the business grows*. Palm Springs Desert Sun (January 10, 2019) https://www.desertsun.com/story/money/2019/01/10/weed-farmers-use-machine-technology-automation-marijuana-business-grows/2477883002/ Last accessed 2020-06-18
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31. Lal, R. *Soil Health.* (2006). Encyclopedia of Soil Science, Second Edition. New York: Taylor and Francis Group
32. United States Department of Agriculture, Natural Resources Conservation Service (NRCS). *Erosion.* (2020). Website, url: http//www.nrcs.usda.gov. Last Accessed 2020-03-01

activity, water holding capacity, infiltration, and permeability. Fertility is impacted by poor cultivation practices that include over-application of fertilizer, excessive tillage, over-watering, and compaction.[33]

Soil resilience is defined as the capacity of a soil to recover its functional and structural integrity after a disturbance. Functional and structural integrity is defined as the ability to perform vital soil ecosystem functions, such as:

- sustain biological activity, diversity, and productivity
- regulating and partitioning water and solute flow
- filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including by-products and atmospheric deposition
- storing and cycling nutrients and other elements within the Earth's biosphere.

When soil suffers a disturbance, the fertility and resilience of the soil are negatively impacted.

Natural disturbances include fires, earthquakes, floods, landslides, and storms. Nearly all human activities associated with land management and use can be classified as "disturbances." Agriculture itself is one of the greatest sources of stress and disturbance to the environment (e.g. removal or exclusion of competing plant species).

Pesticides and Runoff

Generally, nonpoint source pollution is caused when rainfall or snowmelt picks up and carries natural and human-made pollutants as it moves over and through the ground, finally depositing them into lakes, wetlands, coastal waters, and groundwater. Nonpoint pollutant sources include excess fertilizers, herbicides, and insecticides from production land; sediment from improperly managed crop and forest lands; salt from irrigation practices; and bacteria and nutrients from livestock waste. Pesticide runoff has historically been an impact of the illicit cannabis industry, but one that has been substantially addressed by legalization and regulation.

Phytoremediation

While many of the impacts addressed above focus on the potential negative environmental impacts of cannabis cultivation, there are positive aspects to the plant that must be taken into consideration like how cannabis naturally cleans out toxins from polluted soils. Cannabis absorbs man-made and naturally occurring pollutants, like pesticides and some radioactive contamination, and heavy metals such as nickel, cadmium, selenium, arsenic, and lead. Marijuana and hemp also store toxins throughout the plant, which can bioaccumulate the toxins in manufactured products. Therefore cannabis grown for remediation should never be used for human consumption. Phytoremediation is widely accepted as a cost-effective environmental restoration technology and is an alternative to engineering procedures that are usually more destructive to the soil.[34]

BEST MANAGEMENT PRACTICES: LAND USE AND SOIL HEALTH

Building and maintaining soil organic matter (SOM) is the underlying component in all fertile and productive soils and therefore is paramount to sustainable cannabis cultivation. The most important indicators of SOM are concentrations of nitrogen, phosphorus, and potassium, which are essential macronutrients that all plants need to grow and reproduce. The best way to evaluate SOM is through soil sampling and analysis by a professional soil scientist. Land use management and planning is key for sustainable cultivation from site selection to plant mapping, soil testing to integrating regenerative agriculture practices.

Land Use Management

Thoughtful land use is built on thorough consideration for the use of the soil to ensure soil fertility, while allowing for the production of high-quality goods on a long-term basis. The natural environment should be treated and managed in such a way as to preserve or restore the cycles and energy fluxes among soil, bodies of water, and atmosphere.[35]

Traditionally land use plans are developed at the city or county level. However, at a cultivation or farm level, a land-use plan is developed by the individual landowner. Having a property-scale plan that consists of a systematic assessment of an individual's land and water potential, alternatives for land use, and socioeconomic conditions provide a guide in selecting and adopting the most viable options for that scale of operations. The purpose of the plan is to select and implement those land uses practices that will best meet short-, medium-, and long-term needs while safeguarding resources for the future. Planning is an iterative and continuous process, so cultivators should plan on coming back to refine goals and processes. The following are a few of the key items that should be included in a sustainable land management plan:

- Soil tests to determine the nutrient needs of the crop to be grown
- Determine cultivation rotations at the field level by maximizing the economic benefits and minimizing the environmental impacts
- Procedure for when and how to apply nutrients to maximize the economic benefit and minimize the environmental impact of the nutrients
- Best management practices that minimize nutrient loss

33. Darity, Jr, William A. *nternational Encyclopedia of the Social Sciences* (Vol. 3. 2nd ed.), Publisher: Gale
34. Sigurdur Greipsson (Department of Biology & Physics, Kennesaw State University) © 2011 *Nature Education Citation*: Greipsson, S. (2011) Phytoremediation. *Nature Education Knowledge* 3(10):7
35. L. Garda Torres et al. (eds). *Conservation Agriculture*, 471-484, Kluwer Academic Publishers, 2003

- Nutrient balances and compositions for each field and amendment
- Nutrient application rates based on crop needs, soil residual NPK

Additional Items of Consideration

- Environmental Conditions - proximity to water bodies, flood plains, drink water/wellhead protection area
- Soil Limitations - leaching, erodibility, and runoff potential
- Vegetation Cover - presence of a growing crop, crop residue, or cover crop
- Regulatory and Permitting - zoning, approvals, etc.
- Other - distance from source to fields, neighbors, etc.

Preventing Pollen Drift

A major concern with marijuana and hemp being grown in the same region is that hemp farms could pollinate nearby marijuana crops, lowering the cannabinoid content and potentially causing it to go to seed.[36] Previous research has shown that cannabis pollen can drift hundreds of miles and still be viable.[37] A new lawsuit from Oregon has added another wrinkle to the pollen drift issue, where one hemp farm is suing another because the second farm's hemp included males which pollinated their plants and lowered the cannabinoid potency.[38] The easiest way to combat pollen drift is to cull all male plants and only grow males indoors in controlled environments where the pollen cannot escape. Cannabis regulations should consider the implementation of a required setback between the different hemp and marijuana farms of approximately 4 miles. Experience in Pueblo, Colorado - where 12-18% of crops have been affected by cross-pollination - has suggested that even a four-mile buffer may not be adequate to prevent unwanted pollination.[39]

Leveraging Soil Testing

Prior to buying or leasing a piece of ground, a baseline soil analysis should be conducted that includes a thorough land-use history. This history should include previous use of herbicides, insecticides, fungicides, pesticides and other chemical products. In addition, marginal lands that have no known land-use history may have higher levels of background heavy metals or hydrocarbons. This is important due to the bioremediation properties of the cannabis species that gives contaminants the potential to bioaccumulate in the plant tissue. This accumulation is often undetectable until final product testing.

Soil testing should be performed across the cultivation site. For all outdoor cultivators, the recommended testing intervals are prior to the growing season, periodic check throughout the growing season, and after harvest. A soil test is important as it:

- Optimizes crop production and aids in the diagnosis of plant culture problems
- Protects the environment from contamination by runoff, leaching, airborne deposition of excess fertilizers and chemicals,
- Improves the nutritional balance of the growing media, and
- Saves money and energy by applying only the amount of soil amendments needed

Additional testing is recommended for all soil amendments prior to use. Testing amendments for chemical properties such as pH, EC (electric conductivity), nutrient content, and heavy metals can reduce the risk of contamination and damage to the row crop. This is critical when cultivating hemp and marijuana, due to their phytoremediation capabilities.

Most, if not all, soils exhibit a change between 6 and 8 inches where the boundary of the soil changes within the root zone of cultivated crops, including cannabis, and should be accounted for during the analysis. It's important to create a catalog of each soil type that exists within the boundary of the cultivation site, along with the sample collection time of day or season. Soil testing parameters are provided in the Appendix.

Sustainable Soil

The reserves of essential plant nutrients, water balance, and plant-available water capacity (AWC), and effective rooting depth are important components that influence soil health. It is the imbalance caused by differences between outputs and inputs of one or more of these components that creates a deficiency in the soil ecosystem.

Soil fertility is restored by long periods of fallow rather than by fertilizers and amendments. Nutrients are recycled between natural vegetation and crops, ecological balance is maintained by adopting diverse and complex cropping systems rather than monoculture, and incorporating restoration (also referred to as regenerative management), is encouraged.

Key elements in sustainable soil management include:

- Maintaining soil structure to reduce physical impact from crusting, compaction, and low infiltration
- Control excess soil erosion
- Manage pests through enhancing biodiversity, by maintaining a healthy balance between predator and prey
- Reduce surface disturbance from mechanical implements
- Strengthen nutrient-recycling mechanisms so that

36. Schaneman, Bart. Cross-pollination drives growing disputes between marijuana, hemp farmers. *Hemp Industry Daily*. 11/14/2019. 6/18/2020. https://hempindustrydaily.com/cross-pollination-drives-growing-disputes-between-marijuana-hemp-farmers/
37. Sinclair, Miles. Pollen Drift: The Cannabis Industry's Ticking Time Bomb. *DOPE Magazine*. 8/25/2017. 6/18/2020. https://dopemagazine.com/pollen-drift-cannabis-industrys-ticking-time-bomb/
38. Member Blog: Cross-Pollination Poised to Prompt Litigation in Light of New USDA Hemp Rules. *National Cannabis Industry Association*. 1/21/2020. 6/18/2020. https://thecannabisindustry.org/member-blog-cross-pollination-poised-to-prompt-litigation-in-light-of-new-usda-hemp-rules/
39. Sinclair, Miles. Pollen Drift: The Cannabis Industry's Ticking Time Bomb. *DOPE Magazine*. 8/25/2017. 6/18/2020. https://dopemagazine.com/pollen-drift-cannabis-industrys-ticking-time-bomb/

nutrients are not lost out of the ecosystems (e.g. biological nitrogen fixation, crop rotation, incorporating cover crops or companion crops, trees and livestock), and

- Judicious use of chemical fertilizers and organic amendments

The benefits of these collective practices increase water and nutrient use efficiency, which directly translates into increased crop yield and reduced adverse impacts to the soil systems and surrounding ecosystems.[40]

Increasing Organic Matter

Organic matter is composed of living or dead animal and plant material. In agriculture, the main sources of organic matter are plant litter (plant roots, stubble, leaves, mulch). Earthworms and microorganisms decompose these materials into a product called humus which reduces soil erosion and the need for fertilizers.[41] This process releases nutrients which can then be taken up by plant roots, a key component in all nutrient cycles.

Ways to Increase Soil Organic Matter in Cannabis

- **Incorporate cannabis waste** – As discussed in the waste chapter, stems need to be mulched for best results, and leaves improve soil chemical and biological properties and can be used as an acceleration agent for soil organic matter biodegradation.
- **Incorporate green manure crops** – Green manure crops provide protective cover until they are ploughed into the soil.
- **Spread manure** – Bulky organic manures will increase organic matter, but frequent and heavy applications are needed to produce significant changes. Test the manure for nutrient levels prior to application.
- **Use organic fertilizers** – Organic fertilizers applied in large amounts can boost organic matter levels but are generally less cost-effective than inorganic fertilizers.
- **Keep tillage to a minimum** – Tilling breaks down the stable aggregates, exposing humus in the aggregates to air and faster decomposition. Direct drill techniques allow you to sow seed while leaving stubble residues on top of the soil and leaving aggregates intact.
- **Concentrate organic matter** – Retain all organic additions, whether roots, stubble or manure, close to the surface. The stability of soil structure is related to the concentration of organic matter at the surface, not the total quantity present overall.

Regenerative Agriculture

Regenerative agriculture is defined as "using the natural dynamics of the ecosystem to construct agricultural systems that yield results for human consumption."[42] In particular, rather than understanding the soil as an inert medium to which external synthetic inputs are added, regenerative agriculture addresses soil as a living system which can be improved by recycling organic material back into soil over time. For example, the Rodale Institute has been doing a pilot study on using cannabis in crop rotations since 2017. Their preliminary research shows that "weed densities in cannabis research plots, in general, were observed to be much lower compared to other soybean fields on the farm." Rodale's research indicates that "the presence of hemp as a summer cover/cash crop and its earlier harvest/termination date not only suppressed weeds season-long but provided a wider window for establishing the winter cover crop."[43]

Several factors render cannabis agriculture an especially promising area for widespread adoption of regenerative agriculture. In areas of traditional outdoor cannabis cultivation, including much of California and Oregon, cannabis farms are typically operated as family farms on very small scales.[44] Nearly all California cannabis farms are smaller than one acre,[45] and the average size of the over 1,000 cannabis farms in Northern California's Emerald Triangle is just one-third of an acre.[46] Regenerative techniques, such as the use of organic fertilizers and avoidance of chemical pesticides, are already widespread on many of these farms,[47] and cannabis laws prohibit the use of toxic pesticides on cannabis products. These prohibitions are subject to robust enforcement as a result of mandatory

40. Lal, R., (2005). Land use. *Encyclopedia of Soil in the Environment* (Vol.3.). Elsevier, Inc.
41. "Soil organic matter" Department of Primary Industries https://www.dpi.nsw.gov.au/agriculture/soils/structure/organic-matter Last Accessed 2020-06-18
42. Chad Hellwinckel and Daniel De La Torre Ugarte, *Peak Oil and the Necessity of Transitioning to Regenerative Agriculture.* Farm Foundation (October 7, 2009) https://www.farmfoundation.org/wp-content/uploads/attachments/1718-Hellwinckel%20and%20De%20La%20Torre%20Ugarte.pdf Last Accessed 2020-06-18
43. Caton, Tara. Industrial Hemp Trials: Preliminary Results. *Rodale Institute.* 1/7/2019. 6/18/2020. https://rodaleinstitute.org/science/articles/industrial-hemp-trials-preliminary-results/
44. *An Emerging Crisis: Barriers To Entry In California Cannabis*. California Growers Association (February 15, 2018) https://d3n8a8pro7vhmx.cloudfront.net/emeraldgrowers/pages/1059/attachments/original/1519056535/An_Emerging_Crisis.pdf?1519056535 Last Accessed 2020-06-19
45. Schwab, B., Wartenberg, A., Butsic, V. *Characteristics of farms applying for cannabis cultivation permits* University of California, Agriculture and Natural Resources (September 12, 2019) http://calag.ucanr.edu/archive/?article=ca.2019a0019 Last Accessed 2020-06-19
46. *WEED GODS: Humboldt Now Has the Most Cultivation Licenses, Most Farms and Most Production Acreage in the State.* Lost Coast Outpost (October 24, 2019) https://lostcoastoutpost.com/2019/oct/24/passing-1000-mark-humboldt-county-surpasses-santa/ Last accessed 2020-06-19
47. Wilson, H., Bodwitch, H., Carah, J. *First known survey of cannabis production practices in California.* California Agriculture 73(3):119-127. (September 12, 2019) https://doi.org/10.3733/ca.2019a0015

laboratory testing for banned pesticides and other contaminants on final products.

While regenerative approaches to agriculture are site-specific, some of the major regenerative approaches relevant to cannabis cultivation include:

- **Minimization or elimination of external inputs, including synthetic pesticides and herbicides.** Eliminating these inputs, and instead adopting ecologically-tailored Integrated Pest Management (IPM) techniques, prevents environmentally harmful runoff and soil degradation.
- **Use of locally-generated organic fertilizers and composts.** Unlike most chemical fertilizers, which add nutrients to the soil immediately but fail to contribute to the long-term health of soil, organic fertilizers decrease harmful runoff and build long-term soil quality.
- **Planting cannabis in-ground and under the full sun.** Compared with alternative techniques, in-ground, full-sun cannabis agriculture creates the strongest connection between the viability of the cannabis farm and the health of the local environment.
- **The use of various techniques to improve long-term soil quality and the viability of the soil microbiome,** including use of cover cropping and low-till or no-till agriculture. Over time, these techniques can substantially improve yields and farm sustainability, lower costs, and increase organic matter retention in the soil.

Reducing Soil Erosion

The adoption of conservation measures reduces soil erosion by water, wind and tillage. Often, crop rations or changes in tilling practices are not enough to control soil erosion, so a combination of approaches or more extreme measures are necessary. The first best practice is to calculate the erosion potential prior to cultivation by incorporating the results from Water Erosion (RUSLE2) model that predicts rill and interrill erosion by rainfall and runoff, as well as the Wind Erosion Equation (WEQ) or the Wind Erosion Prediction System (WEPS). These should be done in conjunction with a field level soil evaluation that assists in the creation of a land use and crop management plan.

RESEARCH HIGHLIGHT

Purdue University is underway with a pilot study on hemp as part of a crop rotation.[48] Purdue found that "Hemp can be successfully grown in continuous rotation for several years on the same land," but they cautioned that "the risk of pest buildup, particularly root worms, borers, and rots, makes this a risky proposition."

Research Highlight: Purdue University is underway with a pilot study on hemp as part of a crop rotation.[48] Purdue found that "Hemp can be successfully grown in continuous rotation for several years on the same land," but they cautioned that "the risk of pest buildup, particularly root worms, borers, and rots, makes this a risky proposition." Purdue's suggestion was to use hemp "to diversify current rotations of bean, wheat, or alfalfa." Purdue pointed to reports from Canada, which "recommended that hemp not follow canola, edible beans, soybeans or sunflowers due to the risk of white mold and other pests and diseases."

Best practices designed to reduce erosion include:

1. **Permanent vegetative cover** is the primary way to reduce wind and water erosion forces throughout the year. Keep coverage standing with as much "air" within it as standing residue is 2x as effective as flattened residue. The effectiveness depends on the type, extent and quantity of cover.
2. **Terraces** reduce erosion by decreasing the steepness and length of the slope and by preventing damage done by surface runoff. Vegetative waterways that incorporate regional vegetation protect soil against the erosive forces of concentrated runoff from sloping lands.
3. **Contouring** enables all planting to be done across the slope, rather than up and down the slope gradient, and water is held between the ridges. Thus the downhill flow of water is slowed or stopped reducing erosion and increasing soil moisture.
4. **Cover Crop** mixtures are specific to each field and environmental condition. They should cover more than 30% of the soil after harvest and over the winter months.
5. **Strip cropping** is a very effective and inexpensive method for controlling soil erosion. Strip cropping is a combination of contouring, cover crop rotation and row crops which are grown together, perpendicular to the wind or water flow.
6. **Windbreaks**, cross wind trap strips, wind barriers, grass barriers, herbaceous and artificial barriers trap moving soils and protect soils from the effects of wind erosion in the prevailing wind direction. These practices conserve soil, water and air resources.
7. **Reduced or no till** manages the amount, orientation and distribution of plant residue on the soil surface year round while growing crops in narrow slots or tilled strips aka conservation tillage. Reduce the number of passes of tillage equipment, which reduces the soil movement, and leaves more crop residue on the soil surface.

48. "General Production Information." *Purdue Hemp Project.* 6/18/2020. https://purduehemp.org/hemp-production/general-information/

FUN FACT! One factor that affects erodibility is soil texture. Coarse texture is more susceptible than fine textured soils to impacts from climate, compaction, organic matter, microbial activity and other cementing materials.

Reduce Chemical Practices

As a general best practice, if a chemical is approved for cannabis cultivation, adhere to the product label application guidelines. Over application can cause bioaccumulation in the plant tissue, which is detectable in the final product testing.

Integrated Pest Management

As defined by The University of California Statewide Integrated Pest Management Program (UC IPM), Integrated Pest Management (IPM) is an "ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties."[49] When using IPM practices, the least toxic preventative methods are used first, such as predatory insects, and pesticides are used as a last resort.[50] It is crucial to understand the life cycle of pests and to know their natural strengths and weaknesses, so they can be exploited and used to eliminate those pests. A huge component of IPM is frequent monitoring of crops to catch problems as soon as they arise, rather than when the entire crop is at risk. To improve your IPM scheme, establish at which point economic losses appear to be so pervasive that pesticides need to be used. The UC IPM has released extensive guidance to cultivators seeking to learn more about IPM, though they do not have any materials focused exclusively on cannabis.[51]

FUN FACT

One factor that affects erodibility is soil texture. Coarse texture is more susceptible than fine textured soils to impacts from climate, compaction, organic matter, microbial activity and other cementing materials.

Indoor Cultivation Growing Media

Cannabis can be grown in a wide variety of media, each with its own advantages and disadvantages to the cultivator, as well as environmental impacts. Some examples include: Rockwool, Coco coir, Perlite, Vermiculite, Soil, Hydroponics and Aeroponic Cultivation. See Appendix A for full descriptions.

- **Rockwool** is a soilless media made from molten rocks spun into a wool-like texture and formed into rigid cubes. The manufacture of rockwool leads to the emission of volatile organic compounds (VOCs) and nitrogen dioxide (NO_2). Those environmental impacts can be mitigated through techniques such as using a closed loop system and air filtration.[52] Rockwool also is difficult to recycle, but one California producer is working on a method to recycle it. Rockwool cubes can be planted in soil or grown hydroponically.
- **Coco coir** is the fibrous material found between the inner and outer husk of coconuts and is environmentally advantageous over rockwool in many ways. It is a naturally occurring material, requires minimal processing, does not result in the emissions of VOCs, and, perhaps most importantly, it is compostable. Coco plugs can be planted in soil or grown hydroponically.
- **Perlite** is a glassy volcanic rock which expands rapidly when heated and is commonly used in potting soil around the world. Virtually all the perlite in the world is mined in a small region of Turkey along the Aegean coast.[53] Research indicates mixed results. While some studies have found that "the amount of energy consumed while producing perlite contributes a significant environmental burden," others found that it "generates relatively modest environmental impacts compared to mining and beneficiation operations for many other ores."[54]
- **Vermiculite** is a very similar product to perlite. Up until 1990, the bulk of the world's vermiculite was mined near Libby Montana, until it was found to be contaminated with asbestos and a danger to workers

49. UC IPM "What is Integrated Pest Management (IPM)?" *University of California Integrated Pest Management Program.* © 2020. https://www2.ipm.ucanr.edu/What-is-IPM/ Last Accessed 2020-6-18
50. "Agricultural IPM." *National Pesticide Information Center*. 6/18/2020. http://npic.orst.edu/pest/agipm.html
51. *University of California Integrated Pest Management Program.* 6/18/2020. http://ipm.ucanr.edu/
52. "Respecting The Local Environment." *Rockwool*. 6/18/2020. https://www.rockwool.com/west-virginia/environment/
53. Bush, A.L. "Construction Materials: Lightweight Aggregates." *Encyclopedia of Materials: Science and Technology*. 2001. 6/18/2020. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/perlite
54. Maxim, L. Daniel et al. "Perlite toxicology and epidemiology – a review." *Inhalation Toxicology*. 4/2014. 6/18/2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4002636/

and the environment.[55] The CDC admits that, absent contamination, "Based on available information, there is no clear evidence that dust from vermiculite itself causes any serious health effects."[56] It appears that the biggest dangers in processing vermiculite are to the employees, not the environment.[57]

- **Soil** is a natural and compostable growth medium with few environmental impacts, presuming it is not contaminated with petroleum, metals or other contaminants, making it an ideal medium for cultivators seeking to be as sustainable as possible. Soil should be tested prior to use to ensure it is free from contaminants. In order for soil to be considered a truly sustainable growing medium it must be reused and not disposed of after every harvest.
- **Hydroponics** is when water is used as the grow medium itself and the roots are in a chamber that can be filled with water and nutrients, or periodically is flooded with nutrient-rich water. Hydroponic cultivation is often done using cloned plants rooted in rockwool or coco coir. Research shows that, "on average, hydroponic systems use 5-20 times less water than soil agriculture."[58]
- **Aeroponic cultivation** is similar to hydroponic gardening only instead of the roots being grown in standing water or flushed with liquid water, they are misted with nutrient-infused water. Studies have found that aeroponic cultivation can save up to 95% of the water used by conventional soil agriculture.[59]

POLICY CONSIDERATIONS: LAND USE AND SOIL HEALTH

Land Use Zoning Policies

Local land use controls extend to the marijuana and hemp industries in order to protect the health, safety, and wellbeing of the public. Zoning was developed during the early 1900's as a way to protect public health by separating heavy, environmentally toxic industrial uses from residential areas. In modern times, zoning includes local regulations to separate conflicting or seemingly conflicting land uses, while also setting standards for development to ensure it blends in with the existing character and place.

Federal Cannabis Appellations

Appellations are an established agricultural tool that enables farmers to draw a boundary around a geographical region (the "appellation"), define a set of sustainable and locally-tailored standards and practices unique to that region, and legally protect the name of the appellation in marketing. Appellations are particularly well-known in the wine industry, where appellations include Napa Valley and Sonoma in the United States, and Champagne and Bordeaux in France. When appellations can be shown to meet a high level of integrity and sustainability, it can create a significant financial incentive for farmers to adopt ecologically-sound practices in order to benefit from the use of the appellation in marketing.[60] At the same time, appellations can raise awareness among consumers about how cannabis is produced, and the potential land use impacts of various approaches to cannabis agriculture.[61] There is a risk that patchwork state-by-state attempts to implement appellation-type policies would create inconsistencies that undermine the integrity of the designation. Ultimately, much of the value of appellations lies in standardization of processes that can reliably communicate a high level of product quality and integrity. While states can approximate this standardization by implementing laws that mirror those in other states, it ultimately falls to the federal government to create a single, nationally-recognized standard.

Testing Final Products

All cannabis-legal states require cannabis products to be thoroughly tested for contaminants prior to commercial sale. Generally, testing is performed by state-licensed laboratories which verify that each batch of cannabis products does not exceed quantitative thresholds for contaminants including pesticides, heavy metals, microbials, and residual solvents. In some states, such as Oregon, hemp products intended for human consumption are held to the same testing standards as cannabis products.[62] These programs have been empirically effective in reducing use of toxic chemicals and ensuring consumer safety.

Cannabis testing standards vary by state, creating potential

55. "Vermiculite." *Centers for Disease Control, National Institute for Occupational Safety and Health*. 6/21/2019. 6/18/2020. https://www.cdc.gov/niosh/topics/vermiculite/default.html
56. "NIOSH Recommendations for Limiting Potential Exposures of Workers to Asbestos Associated with Vermiculite from Libby, Montana." *Centers for Disease Control, National Institute for Occupational Safety and Health*. 6/6/2014. 6/18/2020. https://www.cdc.gov/niosh/docs/2003-141/default.html
57. "Vermiculite Health, Safety, and Environmental Aspects." *The Vermiculite Association*. 2014. 6/18/2020. https://www.vermiculite.org/wp-content/uploads/2014/09/Vermiculite-HSE-Aspects.pdf
58. Al-Shrouf, Ali. "Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming." *American Scientific Research Journal for Engineering, Technology, and Sciences*. 2017. 6/18/2020. https://pdfs.semanticscholar.org/a78e/aca7641030f0f4ac62d4946e12dfb52ed43e.pdf
59. Al-Shrouf, Ali. "Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming." *American Scientific Research Journal for Engineering, Technology, and Sciences.* 2017. 6/18/2020. https://pdfs.semanticscholar.org/a78e/aca7641030f0f4ac62d4946e12dfb52ed43e.pdf
60. https://commons.cu-portland.edu/cgi/viewcontent.cgi?article=1130&context=lawfaculty

61 Tina Caputo. *The Emerald Triangle Is Poised to Become the Napa Valley of Cannabis* Leafly (September 26, 2017) https://www.leafly.com/news/strains-products/emerald-triangle-napa-valley-of-cannabis Last Accessed 2020-06-19

62. *Cannabis and Pesticides* Oregon Department of Agriculture https://www.oregon.gov/ODA/programs/Pesticides/Pages/CannabisPesticides.aspx Last Accessed 2020-06-19

barriers to interstate cannabis markets. Strong uniform testing standards would help to ensure against both contaminated products and the use of toxic chemicals on cannabis farms.

Access to Existing Sustainable Agriculture Programs

USDA offers a wide range of programs that support agriculture through financial or technical assistance, many of which are specifically targeted to support sustainable agriculture. In February 2020, USDA announced that a number of these programs will become available to hemp farms cultivating legally under the 2018 Farm Bill.[63] However, it is unclear whether these same programs would become available to cannabis containing higher levels of THC following federal legalization. In many cannabis-legal states – whether due to stigma, legal issues, or misunderstandings about how cannabis is produced – marijuana, unlike hemp, is not classified as "agriculture" and does not qualify for farm support programs.[64, 65]

Fundamentally, cannabis farming is agriculture and should have access to the same programs and services as other agricultural sectors. From a land use and soil sustainability perspective, it is particularly essential that cannabis farms have equitable access to programs supporting sustainable agriculture, including the USDA's Conservation Stewardship Program, Environmental Quality Incentives Program, Agricultural Conservation Easement Program, specialty crop block grants, and federal organic certification.

> **NRCS**
>
> ***The U.S. is fortunate to have a government entity dedicated to the preservation and conservation of its soils, the Natural Resources Conservation Service (NRCS).***

History Highlight

The Soil Conservation Act, signed by President Roosevelt on April 27, 1935, was designed "To provide for the protection of land resources against soil erosion, and for other purposes." The driving force behind the creation of the Soil Conservation Act was the severe drought that was occurring in the Great Plains. Perhaps no event did more to emphasize the severity of the erosion crisis in the popular imagination than the Dust Bowl. Beginning in 1932, persistent drought conditions on the Great Plains caused widespread crop failures and exposed the region's soil to blowing wind. A large dust storm on May 11, 1934 swept fine soil particles over Washington, D.C. and three hundred miles out into the Atlantic Ocean."

The law had a sense of urgency and called for the protection of America's soil to "preserve natural resources, control floods, prevent impairment of reservoirs, and maintain the navigability of rivers and harbors, protect public health, public lands and relieve unemployment." In 1936, the nation further refined its soil and agricultural policy with the Soil Conservation and Domestic Allotment Act, which amended the Soil Conservation Act, in order to enhance federal-state coordination, discourage the over-use of land, assist tenants and sharecroppers, and help create stable and adequate prices for farm goods.

Organic Practices and Certification

The United States Department of Agriculture describes organic agriculture as "The application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering. Organic producers use natural processes and materials when developing farming systems—these contribute to soil, crop and livestock nutrition, pest and weed management, attainment of production goals, and conservation of biological diversity."[66]

Alternatively a new certification program specific to cannabis that would include marijuana and hemp could be developed to standardize best practices. This could not only help protect the environment, but create marketability through consumer education. There is also the opportunity for non-profit organizations and/or the private sector to set and enforce standards and best practices. Clean Green, Cannabis Certification Council, and Envirocann are current examples of such third party certification programs.

Tool Highlight

The U.S. is fortunate to have a government entity dedicated to the preservation and conservation of its soils, the Natural Resources Conservation Service (NRCS). See https://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/ for soil survey by state, soil education material, soil health and tools for conservation.

In conclusion, it's important to incorporate the land use and soil health techniques this chapter has addressed to ensure that the trajectory of the cannabis industry arcs towards environmental sustainability.

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63. *Hemp and Farm Programs* United States Department of Agriculture https://www.farmers.gov/sites/default/files/documents/USDA_OptionsforHemp-Factsheet-02062020.pdf Last Accessed 2020-06-19

64. Clarissa Spawn. *My Turn: Should cannabis enjoy right to farm protections?* Greenfield Recorder (February 23, 2019) https://www.recorder.com/my-turn-spawn-CannabisFarmingInfringement-22667936 Last Accessed 2020-06-19

65. Don Jenkins. *Marijuana grower smells chance to gain farm status* Capitol Press (January 2, 2018) https://www.capitalpress.com/state/washington/marijuana-grower-smells-chance-to-gain-farm-status/article_3a13e65f-235d-58c5-87c2-c7f6afaa7199.html Last Accessed 2020-06-19

66. USDA National Organic Program, Agricultural Marketing Service, Introduction to Organic Practices, Sep 2015

WATER

Water needs to be prioritized in decision making while drafting policy to account for the development of any new agricultural industry. The potential impacts of the cannabis industry and its water usage need to be analyzed, but also regulatory control and educational initiatives need to be leveraged in order to mitigate impacts. The necessity of protections for water resources can be considered in terms of both water quality and water quantity (e.g., use vs. availability) as cannabis cultivation has potential impacts for both.

Irrigated agriculture in the United States is the nation's largest consumer of surface and groundwater, accounting for over 90% of water use in many western states and approximately 80% nationwide.[67] Following advances in industrialization in the 1950s, agriculture has also become one of the largest sources of water pollution worldwide.[68] In general, pesticides and fertilizers contained in agricultural runoff are widely known to negatively impact water quality both in the immediate vicinity and potentially many miles from their origin.[69] As with any agricultural sector, the cultivation of cannabis has the potential to affect water quality.

ENVIRONMENTAL IMPACTS: WATER

Irrigation Impacts

The majority of the cannabis water impacts listed below can be primarily attributed to poor irrigation techniques combined with harmful agricultural practices. Over irrigation increases the need for fertilizers, fungicides, and other harmful chemicals used in industrial agriculture methodologies by removing the nutrients in the soil and creating environments for harmful fungus and molds to thrive. Improper irrigation also leads to drought conditions by regionally depleting watersheds and other sources of water while simultaneously depleting soil quality.

The issues listed below are heavily connected and often create feedback loops that cause compounding issues that increase in their detriment exponentially. An example of this would be over-irrigating a field which causes excessive topsoil runoff. This soil is now unable to hold water and nutrients as it once was, creating the need for heavier watering and application of fertilizers.

Water Use Impacts

The narrative surrounding cannabis as a water-intensive crop has largely been a result of studies of outdoor illicit cannabis farming in Northern California.[70] Because the growing season for outdoor cannabis in this region coincides with the annual late summer drought, potential reductions in streamflow due to cannabis irrigation is a widespread concern. Early work proposed that surface water diversions by illicit cannabis farming would exceed available summer baseline streamflow and completely dewater the riparian and aquatic ecosystems used by threatened and endangered fish and other aquatic species. This conclusion was based on scaling estimates of water demand by a single plant to the observed density of cannabis farms in this region. This spurred an intense debate about how much water the cannabis plant uses. Because of the wide variety of cultivation practices for cannabis, there are many valid estimates of water demand that have been cited in this debate. For instance, even among outdoor cultivation types, the arrangement of plants and alternative harvesting strategies (i.e. using mixed-light operations) significantly alters the size of plants, and thus their water demand. Water use by plants grown indoors is expected to be even less due to the controlled nature of this cultivation environment. As a result, using a single plant-based estimate to represent the water demand of cannabis is simply not appropriate. Although this practice was necessary for the purposes of estimating the impact of illicit cannabis farming, for which there is no water-use data, the results of this early work do not accurately inform water-use estimates of a regulated cannabis industry.

Disagreement about the water impact of cannabis has also often included references to other agricultural crops. Comparisons to water demand by almond farming in particular are quite common, documenting that the total acreage of cannabis is dwarfed by the almond industry and by extrapolation, its relative water demand.[71] While this comparison is valid, state and county agencies in California have adopted stringent water use policies for cannabis, given that unlike almonds, most cannabis farms are located in the remote and rugged regions rather than the traditional agricultural epicenter of the Central Valley. The key distinction is that in the former, irrigation

67. *Irrigation & Water Use* United States Department of Agriculture (Last Updated: September 23, 2019) https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/ Last Accessed 2020-06-19

68. Harris, G. Introduction: Impacts of Agriculture on Water Quality Around the World. *In Agriculture, Hydrology, and Water Quality.* PM Haygarth and SC Jarvis eds. 2002. Pp 342-344

69. Van Herpe YJP, Troch PA, Quinn PF and Anthony S. Modelling Hydrological Mobilization of Nutrient Pollutants at the Catchment Scale. *In Agriculture, Hydrology, and Water Quality.* PM Haygarth and SC Jarvis eds. 2002;Pp 243-264

70. Carah JK, Howard JK, Thompson SE, Short Gianotti AG, Bauer SD, Carlson SM, Dralle DN, Gabriel MW, Hulette LL, Johnson BJ, Knight CA. High time for conservation: adding the environment to the debate on marijuana liberalization. BioScience. 2015 Aug 1; 65(8):822-9.

71. Butsic V, Brenner JC. Cannabis (Cannabis sativa or C. indica) agriculture and the environment: a systematic, spatially-explicit survey and potential impacts. Environmental Research Letters. 2016 Apr 21;11(4):044023.

water is sourced directly from natural sources, while irrigation in the latter can utilize the extensive network of dam reservoir fed canals (and groundwater aquifers), far from sensitive and remote habitats. Therefore, it is important to consider that the further development of the legal cannabis industry will involve both development of new water use regulations and policies and water-related infrastructure to support the facilities, as well as a transition of existing farms from the illicit market to a regulated one.

Indoor vs Outdoor Water Impacts

An additional distinction must be drawn between the location of cannabis farming that initially raised environmental concerns and the development of the regulated industry elsewhere. Within California alone, the most predominant expansion of cultivated acreage is occurring in areas that have been and are currently suited for irrigated agriculture[72] (e.g. reoccupying facilities used for the defunct cut-flower industry, supplied by groundwater or municipal infrastructure). This is considering both a geographical shift in outdoor cultivation and the expansion of indoor operations, which have generally occurred in urban or agricultural centers that are supplied with water from mass storage infrastructure.

Furthermore, considering that a large amount of cannabis farming nationwide is indoors and far from watercourses vulnerable to flow reductions, the initial alarms of cannabis as a threat to water availability are not broadly applicable beyond the original context of illicit cannabis farming in Northern California. For example, the majority of marijuana cultivation in Colorado takes place indoors in urban environments due to the regulatory structure in place for licensing. This means that the majority of marijuana in Colorado is irrigated with the municipal drinking water supply and creates a different concern in terms of properly managing municipal water usage and treatment. In contrast, the majority of hemp in Colorado is cultivated outside in traditional agricultural areas.

In areas such as Colorado where the majority of marijuana cultivation is done indoors, it is important to discuss the increased demand on municipal water consumption. This heightened demand can result in reduced water availability for downstream users and associated watershed impacts, water energy nexus concerns and indirect carbon emissions from water treatment systems. Furthermore, the influent water filtration and treatment requirements result in more solid waste, energy consumption and efficiency challenges. Both indoor and outdoor cultivation can also pose wastewater and other runoff concerns such as hazardous discharges like isopropyl alcohol or butane from marijuana infused product facilities.

In summation, water impacts need to be determined and evaluated on a local level as each region is different in terms of availability, regulations, and usage needs. Whether cannabis is primarily grown indoors or outdoors in a region may be the primary determinant in how regulations need to be developed for utilizing local water resources.

Pollutants and Erosion Impacts

Large-scale irrigation projects are subject to sediment loads that are carried in returning water causing erosion that has impacts on watersheds including releasing major pollutants that result in serious environmental consequences. There are two different sources of soil erosion: (1) erosion occurring during floods that silts water reservoirs, and (2) erosion in poorly planned irrigation project areas where land capability classifications are ignored and surface irrigation methods are practiced with no land grading. Sediments originating from the erosion of fertile surface soil in agricultural areas are carried to downstream areas in returning irrigation waters.

This process not only carries potential hazardous and detrimental effects downstream but also removes the high quality topsoil containing nutrients and structure to the land. Soil erosion from irrigation causes loss of high quality soil and leads to increased erosion from other sources such as wind due to less compaction. This also results in a soil less resistant to environmental impacts and more prone to widespread ecological and meteorological damage.

Water reservoirs are another consideration. Man made small lakes, and large dams may be filled with silt load. Silt and sediment found in water reservoirs may carry pesticide residues (with serious health-hazard effects) and plant nutrients (that may cause algae blooms). Heavy metals are also carried into water reservoirs by way of soil erosion.

Fertilizer Impacts

The use of fertilizers is one method of achieving high crop yields under irrigation. However, excess or improper use of fertilizers may pollute air, water, and soil resources. A high percentage of applied fertilizer remains in the soil after the harvest of crops, although this varies depending on the fertilizer practice that is followed, crop species, rainfall, and irrigation management. Poor irrigation techniques remove nutrients from the soil and increase the need of chemical fertilizers; this creates a positive feedback loop as more water is needed to deliver artificial nutrients and more nutrients are needed due to excess irrigation leaching nutrients out of the soil.

Improper fertilizer usage combined with improper irrigation can also lead to over salinization of the soil which creates ground unsuitable for crop growth. Chemical fertilizers include high levels of salt that can create issues at the root zones of plants and must be flushed out when it becomes a detriment to plant quality and growth.

Fertilizer runoff can lead to a plethora of issues downstream including dead zones where rivers meet coastal waters and ecological issues in nationally connected waterways. Algae blooms are caused in areas where large amounts of artificial fertilizers are dumping into still bodies of water from rivers and streams. The excess nitrogen in these areas causes algae and other marine organisms to rapidly grow and utilize all available oxygen; choking out and killing anything in the affected area.

72. *Cannabis License Search* California Cannabis Portal https://cannabis.ca.gov/check_a_license/ Last Accessed 2020-06-19

Implementation of a crop and land use management plan that addresses irrigation methods can assist in reducing the creation of non-point pollutants caused by heavy fertilizer usage.

Pesticides and Monoculture Impacts

Evaporation from large bodies of water stored in dams, networks of channels, and large irrigated fields contributes to increasing humidity, which in turn creates a favorable environment for the spread of plant diseases and pests. Growers, understandably, prefer crops of high cash value under irrigated agriculture. Therefore, it is not uncommon that crop rotation is completely ignored, with the consequences that continuous monoculture of high-value cash crops has become a widespread practice under irrigation. It is also common practice in conventional industrial agriculture and illicit cultivation to apply pesticides often and heavily to protect against weeds and insects, although these pesticides are typically banned or heavily restricted under state regulatory frameworks.

Irrigation practices play a major role in the accumulation of pesticide residues encountered in water resources. Residues remaining in the soil are carried into water resources through the leaching of the soil profile with irrigation water. Vaporized pesticide residues mixed in the atmosphere may be carried long distances. Adverse environmental effects of pesticides are further amplified when there is lack of proper training of agricultural labor in the handling and use of pesticides.

Heavy Metals Impacts

Fertilizers and pesticides that are used in irrigated agriculture contain a wide array of heavy metals, including arsenic, boron, mercury, copper, cadmium, lead, nickel, and zinc. While boron is often added to the soil with irrigation water, arsenic is included in many insecticides and herbicides. Similarly, many fungicides contain mercury, copper, and cadmium. Phosphorus fertilizers may contain large amounts of heavy metals; a major source of cadmium pollution in soils. Heavy metals tend to be adsorbed by clay minerals in the soil profile and therefore are consequently less likely to be leached and mixed with groundwater. However, runoff and tail waters carrying sediments from irrigated areas often contain heavy metals that are discharged into drainage channels and then mixed with other surface water resources. The use of municipal and industrial wastewater in irrigation is another source of heavy-metal pollution in agricultural areas.[73]

Wastewater Impacts

Effluent water quality from a grow operation is impacted by agricultural inputs, such as nutrient loading and other chemicals required for cultivation, as well as erosion from over irrigation. Other contributions to water discharged from a growing operation or from a manufacturing operation include wash-down water, condensates from the heating, ventilation and air conditioning (HVAC) system and spills within the facility. Any and all of the contaminants discussed above, as well as surfactants, cleaning solutions, solvents and disinfecting agents can adversely impact water quality, fish or biota in a receiving water, or may cause an upset of a municipal wastewater system if discharged without adequate treatment and/or flow equalization.

All discharges from any commercial operation are subject to meeting specific discharge criteria for contaminants as well as for discharge rates (*i.e.*, volume per period of time). That is, the residual contamination loading to a surface water, to groundwater or to a municipal system must be below the state or local regulatory limits and the flow rate may be required to be equalized over a 24-hour period to minimize sudden impacts to a receiving water body or to the municipal system. Further, wastewater discharges may require amendment of pH and/or other water quality parameters if the final wastewater is outside of acceptable discharge limits.

BEST MANAGEMENT PRACTICES: WATER

Best management practices for water use in cannabis operations are broken down into the following: Sourcing; Use and Quality; Treatment; Irrigation; Recycling; and Discharge. Each aspect will consider indoor and outdoor grow operations separately.

Water Sourcing Best Practices

1. Research, understand and comply with local, state and federal regulations and requirements relative to water withdrawal or consumption from public supplies, surface water or groundwater. Also, determine if you are in a special watershed protection region or district.
2. Consider water use needs and capacity of available water resources when selecting a grow location. Understand what permits, allocations, or authorizations are needed to use the water resource you need for your operation, and understand all the requirements and/or restrictions that apply. Water rights are especially important to understand in the West as they do not always run with the land.
3. Research and conduct independent testing of the quality of the water resource(s) in your area.
4. For surface water sources, research and understand general agricultural water use requirements and restrictions. This can encompass general watershed area requirements, withdrawal restrictions, site design to minimize runoff and promote recharge such as buffer zones, runoff and drainage controls, erosion control, and recommended or restricted soil amendments.
5. For ground water use, research and understand allowable withdrawal rates and restrictions on use of ground water for agricultural purposes. This can encompass general watershed area requirements, withdrawal restrictions, site design to minimize runoff and promote recharge such as buffer zones, runoff controls.
6. For operations using public water supply, research and understand permits and authorizations required,

73. "Environmental Effects." *Encyclopedia of Soils in the Environment*, edited by Daniel Hillel, et al., vol. 2, Elsevier, 2005, pp. 267-273. *Gale eBooks,* Accessed 11 Mar. 2020.

restrictions on overall withdrawal rate or use during specific hours.

7. It is important to understand your local watershed, how it all works together, and how you will integrate with it in a responsible manner.
8. Municipalities should consider the source of water delivery in cases where cannabis is primarily grown indoors and can utilize options such as recycled water from wastewater systems.

Water Use and Quality Best Practices

Industry best practices for water use are intended to continuously look for opportunities to reduce water needs while minimizing impacts to local water quality. Many practices can be instituted regardless of specific growing or watering procedures and span from intake to discharge.

Water use/demand is influenced by several factors, including most significantly, indoor versus outdoor growing. Outdoor growing usage and demands are primarily associated with water availability, soil quality and type, environmental conditions, and other factors will include growing from seeds or clones, soil type, amendments used, and degree of recycling/reuse that can be incorporated into the operations.

General Best Management Practices for any grow operation include the following:

1. Minimizing water use and impacts starts with design of the operations. Incorporate a value engineering approach to minimize costs and resource use.
2. Indoor grow operations should consider their substrate and opt for growing bases with a higher water retention rate and lower evaporative potential such as living soils.
3. Specifically for outdoor grow operations, models such as the FAO-56 irrigation schedules and ET-based approach for the specific crops are readily available from the Food and Agriculture Organization of the United Nations and should be used to estimate net crop water requirements. Seasonal crop water requirements can be estimated using these models by using weather data across several years, creating a representative average yearly data set.
4. Develop a water management plan that factors in local hydrology information, such as knowledge of the watershed, river and stream system, their seasonal flows (spring runoff, floodplains) and the depth of the water table. Use this information along with land use and crop management plans to reduce the adverse effects of waterlogging and salinity, which often occur as a result of excess use of irrigation water.
5. In arid and semiarid regions where annual precipitation is not enough to leach accumulated salts to deeper zones of the soil profile, the soil surface becomes covered with a white salt crust. Therefore, the actual crop water requirement, a certain fraction of excess water, called the leaching fraction, must be included in the total applied irrigation water.
6. Adequacy of site drainage needs to be evaluated to avoid raising the water table too close to the soil surface, which can also contribute to salt accumulation in shallow soils. A solid understanding of drainage in irrigated areas is necessary to avoid soil salinization and the loss of soil fertility.
7. Monitor and track all water use. Public water suppliers may require backflow preventers and metering.
8. Establish an appropriate sampling and testing schedule to monitor incoming water quality and at the point of use following any treatment. This will vary depending on the source. Use of surface water may vary more frequently or seasonally as opposed to groundwater water or a public water supply. If a source is variable or susceptible to sudden impacts from upstream users, raw water storage may be appropriate, which can dampen/equalize variations in water quality and/or provide time to detect sudden changes in quality.
9. Ensure that the appropriate dilution rates and application schedules are followed for any nutrients or cleaning solutions that are being used during cultivation, cleaning, water treatment operations, or other aspects of water use.
10. Any water tanks or storage facilities must obtain all necessary permits from the appropriate local, regional or state agencies. Ensure a monitoring and maintenance plan is in place for all water storage.

Water Conservation Practices

Cannabis farmers may also voluntarily adopt agricultural approaches that further conserve water. Systems used in regenerative agriculture, as described in the Land Use and Soils chapter, can work to improve soil quality by increasing the absorption of water into soil and decreasing runoff through the addition of organic matter and decomposition over time. Practices such as cover cropping and mulching have shown to be effective in reducing inefficient irrigation practices. Some farmers have also experimented with dry farming, using natural moisture in the soil and minimizing or eliminating external water inputs.

Water Treatment Best Practices

When considering environmental inputs, water treatment using carbon filtration has emerged as the most efficient method to reduce contaminants — such as chlorine, chloramine, sodium and bicarbonate levels — in a facility's incoming water. Carbon filters are very effective at achieving the desired nutrient load for cannabis plants when filtering is performed according to manufacturer's specifications. Additionally, filtering leads to very low levels of waste. Only water used to periodically clean filters is disposed of, whereas sterilizing water through reverse osmosis generates substantial water losses in the brine byproduct. UV sterilization on the other hand is an effective method of avoiding contamination issues in recaptured water and is becoming an effective way of treating water from reclaimed sources.

Optimizing Irrigation

The selection of watering methods is highly influenced by an individual cultivator's personal preferences, as the benefits and drawbacks of each method are varied. While quality and yield are ultimately the most important considerations, best practice these days is to also consider efficiency and minimizing the impact on the local water resources.

In considering automation, it is generally accepted that facilities exceeding 2,500 square feet will be the primary beneficiaries of automated systems in terms of financial or product quality return on investment (ROI). However, all grow sizes can benefit from automated watering systems to control accuracy and efficiency. Increased data collection related to identification of anomalies, efficiencies, and tracking to optimize water use for the industry as a whole.

Water applied to plants should be measured during each phase of growth. This is most easily achieved when using an automated watering system. Similarly, cultivators should measure runoff to ensure that water is not being wasted, and should set a low runoff target. Ten percent to fifteen percent runoff per watering event is an efficient and achievable target.

Efficient Watering Methods:

1. Use water in a targeted, planned, and efficient manner with appropriate amounts and frequency to meet the needs of the crop without excessive water loss.
2. Select the proper irrigation system for the local climate in the grow operation area. Older systems should be evaluated for current data and improved techniques to optimize effectiveness and water usage. Current best irrigation practices employ drip, pivot or flood irrigation. New technologies such as microirrigation and subirrigation methods are available and are being used. Subirrigation is an alternative in arid and semiarid regions where the evapotranspiration rates are higher.
3. Automation of watering systems is critical to reducing water waste and decreasing variability in plant health through overwatering. If automation is not financially feasible, water nozzles and other flow reducing systems should be put in place to monitor and check flow rates.
4. Irrigation must be conducted in a manner that does not result in runoff from the cultivated area. Sprinkler systems should be capable of uniform application of water with minimal evaporative loss and minimal surface run-off. New irrigation technologies are helping to improve irrigation efficiency and to reduce the drainage water volume that requires disposal. For example, sprinkler and drip irrigation systems facilitate the fine-tuned control of fertilizer applications in order to minimize fertilizer residue remaining in the soil after the harvest of crops.
5. For all irrigation systems, establish a regular inspection cycle to identify and repair leaks prior to the planting cycle, as well as ongoing inspections during the growth cycle.
6. Irrigation system efficiency should be evaluated on an annual basis.

Irrigation efficiency in outdoor cultivation can be determined by calculating the net irrigation requirement of your field based on the needs of each crop and total number of plants. This net irrigation requirement is the total volume of water needed to satisfy your plants (from both artificial and natural sources) plus losses due to application inefficiency (evaporation, runoff, etc.). Efficiency of irrigation application is determined by taking the average net irrigation requirement and dividing it by the average volume of water applied.[74] Utilizing this calculation methodology a grower can determine if a new watering system is necessary or if their current system is adequately delivering water to the plant with minimal losses.

Water Recycling

Effort should always be made to identify and safely reuse water, where feasible. Always seek out advice from local water resource officials and from other agricultural, soil conservation, county extension services, and educational entities and organizations on recycling and reuse options being used in your area.

The biggest opportunity to recycle water is in the actual growing operations, where excess irrigation water can be collected and recycled. Recycling of "greywater" (e.g., wash water, shower water, sink water) not only may have local restrictions on recycling and reuse (such as outdoor landscaping), but can entail significant costs to remove undesirable contaminants. Recycling of greywater needs to be evaluated on a case-by-case basis and may not be feasible in many situations.

For indoor growing operations, HVAC condensate and dehumidification water may be suitable for recycling and reuse. In many instances, this water is very clean, although it is possible some contaminants from those systems may be present in the condensate and may require treatment, which could be as simple as returning to the front-end treatment system if one is present.

Captured excess irrigation water should always be sampled and tested to determine if undesirable chemicals or substances are present requiring treatment to remove. For example, over time, undesirable levels of inorganic salts, microbial matter and plant-related fungi, and other chemicals may build up or become concentrated through recycling. A best practice is to pipe collected water to a holding tank to equalize and dampen potential spikes in concentration and allow time for sampling and analysis to determine if, when and the degree of treatment needed.

The feasibility of recycling captured water will depend not only on the quality but also on the type of irrigation being used. For example, recycling may require less treatment in a drip irrigation system as compared with a spray irrigation where water is contacting the plants directly. Captured water also can also be used for other purposes other than recycling in the irrigation system, such as in wash water if not suitable for irrigation.

Several options are available to treat captured water for recycling into the operations and should be selected based on what contaminants need to be removed and the intended

74. Barnes, Edward M, and Douglas J Hunsaker. "Irrigation Systems: Water Requirements." Encyclopedia of Agricultural, Food, and Biological Engineering, pp. 119–142

use of the recycled water. Contaminants can include mineral salts, fertilizer compounds, pesticides and microbial matter such as plant-related fungi and pathogens such as Pythium, Phytophthora, Fusarium and Rhizoctonia. Depending on the quality of the water of the water to be treated and the final use, several treatment options are available that are commonly used in large greenhouse operations and outdoor agriculture:

- Filtration - Used to remove organic and inorganic particulate material. If high solids content, it may be necessary to have settling or other clarification process as a pre-treatment step. May require additional treatment following filtration depending on use (e.g., plant watering, washdown water, or discharge to a natural water body).
- Chlorine, Ozone and UV technologies - Several disinfection water treatment technologies are available for use in removing bacteria, viruses, pathogens, or other microoganisms. Chlorine treatment is available in several forms (e.g., as a gas, or as sodium hypochlorite or calcium hypochlorite). These treatments are often used in combination with filtration to remove heavy particulates prior to treatment or following treatment to remove residual particulates depending on use of the treated water.
- Copper-silver technologies - Another form of filtration that is used for disinfection and may be helpful for use against pathogens, such as pythium and phytophthora.

Options of capturing and using rainwater should also be explored. But, even captured rainwater should be tested for pH and potential contaminants depending on the local area.

Improving Wastewater Quality

Wastewater streams that cannot be reused or recycled in some way, will ultimately be discharged back to the environment - either via a municipal wastewater collection system (primarily indoor grows), surface water or recharged to groundwater. Best practices to enable the greatest degree of recycling and minimize the ultimate discharge of water from the operation include:

1. Use cleaning products as directed. Dilute concentrated products according to the intended cleaning purpose on the label.
2. Use environmentally friendly cleaners such as those rated by Green Seal, Eco Logo or Safer Choice.
3. Use filtration, carbon adsorption for water purification to avoid significant water discharges from reverse osmosis.
4. Use water nozzles to control water use in cleaning operations.
5. Avoid over-watering crops as this can lead to unintended high levels of chemicals and suspended solids in sanitary drains.
6. Do not dump any liquids or chemicals directly into sumps, floor drains or storm drains.

Considering Climate Change

A prime example of using sustainability as a risk management strategy is in consideration of Climate Change and cultivation operations ability to adapt as their local environment rapidly changes. Water resources will shift dramatically in both terms of availability and control. As the climate changes, so will local and regional water cycles which may change a cultivator's access to water and their own usage needs. A solid water usage strategy that can be readily adapted to environmental conditions will ensure cannabis operations are aware of and prepared for how climate change will impact their specific region.

The hydrologic change of climate change in terms of excess rainfall, drought, and flooding will have a drastic effect on the other impacts listed here as they are synergistic with the flow of water. Authorities must take into account a changing climate in designing strategies to mitigate the effects of nationwide cannabis cultivation and other impacts created by poor irrigation and agricultural practices.

POLICY CONSIDERATIONS: WATER

Water Use Policy

Water usage and policy has historically been handled at the state level due to its strong link to prevailing weather patterns and the geographically dependent nature of watersheds. Two primary policies are generally attributed to water usage in the United States: riparian and prior-appropriation. Riparian is most common on the east coast due to generally abundant water supply and refers to "owning any water on your land." This means that landowners have the right to collect, store, or divert water that flows through or adjacent to their property. Prior-appropriation water doctrines are more common in arid environments and prioritize water resources to areas considered of "beneficial use" which means that water is not owned by whomever's land it is running through, past, or fallen on, but rather is a common resource to be allocated by (usually) state and county level governments.

Water policy surrounding use by irrigated agriculture is most robust in the semi-arid west, and California especially, given its prominence as an international leader in agricultural production. As a result of developing under state prohibition, the cannabis industry has not shared the same trajectory of water development, management, and policy, as that of traditional agriculture in California. During the early formation of the agricultural industry, farmers organized local irrigation districts to build out infrastructure to deliver reliable water.[75] This era was followed by one in which large state and federal water projects such as the Central Valley Project and the State Water Project developed an extensive network of dam reservoirs and irrigation canals. A complex system of appropriative water rights developed to allocate a limited water supply to a growing agricultural industry.[76] Today, local agencies still represent the collective needs of

75. Hanak E. Managing California's water: from conflict to reconciliation. Public Policy Institute. of CA. 2011.

76. Thompson Jr BH. Institutional perspectives on water policy and markets. Calif. L. Rev.. 1993;81:671.

individual groups of water users to maintain flexibility and fluidity in the management of overlapping interests.[77]

Historical centers of cannabis cultivation in upper watersheds rather than valley floors do not lend themselves to centralized storage and delivery projects, thereby limiting opportunities for local or regional collective organization of water users. Because the cumulative effect of many small water users is notoriously difficult to determine,[78] there is a tremendous amount of uncertainty regarding potential impacts. Partially because of this uncertainty and the relatively sensitive watersheds in which the regulated cannabis industry was expected to develop, stringent water use requirements were implemented, including a restriction on surface water diversion for the duration of the growing season. In planning for these restrictions, the California State Water Resources Control Board offered an expedited path for growers to obtain an appropriative water right to store water[79]—a process which otherwise can be expected to take years. However, developing individual storage can still be a challenge for farmers in rugged and remote areas,[80] where few farms have access to or utilize water supplied by centralized water storage.[81] Centralized systems when utilized appropriately can ensure more balanced usage and promote access to downstream users, yet upstream ecological impacts from development must also be considered. Future study is needed to determine the impact of these water storage projects and their impact on streamflows.

Cannabis farms in California that have developed anew in regions already commonly used for agriculture have relied almost exclusively on groundwater. While this reflects the territory available with access to groundwater aquifers, it does not reflect the water resources available in those aquifers. Furthermore, the prospect of cannabis developing in regions with access to the reservoir fed irrigation networks has been precluded by local and county bans. Even if these bans were lifted, federal prohibitions on cannabis using irrigation water supplied by federal projects,[82] such as the Central Valley Project, would limit cannabis to using only groundwater. This policy also similarly covers large portions of Washington and Colorado that are supplied by federal water projects.

Additional Policy Considerations

1. Any policies on water use in outdoor growing should be based on actual water use and practices in the current legal market, rather than basing policy on inaccurate, incomplete or anecdotal information from the unregulated market.
2. Water use is very much a local issue, even regional within some states (e.g., what is seen in California) and interstate in some cases. Any federal policies should defer to local policies and not create conflicts that override local or regional watershed efforts to protect and sustain water resources.
3. Water use for indoor growing operations will be dictated by local municipal water use obligations, including well permits and water allocation/withdrawal considerations.
4. Evidence suggests that in areas where illicit growing continues to be prevalent (e.g., Northern California) overly restrictive regulation can create situations where legal operators may be penalized for practices followed by illicit operators. Programs that provide free assistance, resources, training or other incentives that may help to reduce the regulatory burden while promoting protection of water resources should be encouraged.
5. As a major threat to our natural watersheds comes from unregulated cultivation, the best solution is for regulators to work to create a system that will welcome as many cultivators as possible into the legal market by keeping barriers to entry low.

An Example of Regulatory Water Protections

Beginning in 2016, California's regulated cannabis framework has strictly required licensed cannabis farms to adopt best management practices for the protection of water resources. Key aspects of this regulatory system include:

- Requiring that any water diversions occur during the winter, when precipitation is high and streamflow is at its strongest. In the dry summer seasons, farmers are required to abide by a "forbearance period" and rely on stored water, rather than diversions, for irrigation.
- Ensuring that groundwater wells used for irrigation are not hydrologically connected.
- Establishing water rights through a Small Use Irrigation Registration (SIUR) permit, accompanied with restrictions to ensure that additional water rights do not harm river flows.
- Ensuring that roads, culverts, and other infrastructure are compatible with watershed health.

These regulatory parameters have led outdoor cannabis farmers to adopt a variety of practices to conserve water and ensure the health of local watersheds. In an attempt to avoid water diversion altogether, many farmers have invested in rainwater

77. Hanak E and Lund, J. Adapting California's Water Management to Climate Change. Climate Change. 2012;1;111(1):17-44.
78. Merenlender, A.M., Deitch, M.J., Feirer, S. Decision support tools for stream flow recovery and enhanced water security. California Agriculture. 2008;62, 148–155.
79 State of California. State Water Resources Control Board. Cannabis Cultivation Policy. 2019.
80. Dillis C, McIntee C, Grantham T, Butsic V, Le L, and Grady K. Water storage and irrigation practices associated with cannabis production drive seasonal patterns of water extraction and use in Northern California watersheds. BioRxiv. 2019;618934.
81. Dillis, C.R., Grantham, T.E., McIntee, C., McFadin, B., Grady, K.V.. Watering the Emerald Triangle: Irrigation sources used by cannabis cultivation in Northern California. California Agriculture. 2019;73(3), 1-8. DOI 10.3733/ca.2019a0011
82. Reclamation Manual, *United States Bureau of Reclamation*. 2/11/2020, 6/19/2020. https://www.usbr.gov/recman/temporary_releases/pectrmr-63.pdf

catchment systems and non-hydrologically connected wells. Among licensed farmers in California who divert directly from the watershed, diversions are required by law to take place only during the high-flow winter season and are stored in on-site water storage infrastructure for use during the summer growing season.

It is important to understand the value of water in the agricultural aspect of the cannabis industry, the sensitivities and considerations in its sourcing and the potential impacts to used water. Water usage in other aspects of the cannabis industry (processing, distribution and sales) are minor relative to farming. Consequently, the best management practices and policy considerations are directed at cannabis growing operations. In general, from a water sourcing, use, reuse and discharge standpoint, cannabis related regulation and policies should largely mirror those for general agriculture when outdoors or indoors. Policymakers are encouraged to understand their local watershed and current best management practices to incorporate them into policy and regulation, as well as include resource and financial incentives and provide ongoing education to market participants.

It is important to understand the value of water in the agricultural aspect of the cannabis industry, the sensitivities and considerations in its sourcing and the potential impacts to used water.

MASSIVE COLLAPSIBLE WATER TANK

ENERGY

As an increasing number of states legalize cannabis for medical treatment and adult-use, the industry's energy demands have increased, with cannabis cultivation and processing taking the lion's share of energy consumption. Unfortunately, managing the industry's energy appetite has proven to be a difficult task, primarily because the industry has limited historical data about energy consumption in legal cannabis cultivation. As these markets continue to grow, it is critical that states continuously track, regulate and reduce the industry's energy intensity and impact through energy efficiency and clean energy measures.

Regulations Drive Indoor Cultivation

Even as an increasing number of states have legalized adult-use cannabis in recent years, indoor cultivation has remained the preferred cultivation method, or required method, as many states do not permit outdoor cultivation. In large part, this is because controlled indoor environments (including greenhouses and windowless warehouse cultivation centers) provide cultivators with the greatest amount of control over their facility's operations and offer growers the ability to produce and harvest crops year-round. According to a 2016 study, an estimated 63% of commercial cannabis cultivation operations are conducted completely indoors, while 20% are in greenhouses.[83] For these facilities, energy costs represent thirty to sixty percent (30-60%) of total operational expenses.[84] The 2018 Cannabis Energy Report, which collected self-reported cultivation data from eighty-one cultivators representing a statistical sample of licensees, found that legal cannabis cultivation in the U.S. consumes 1.1 million megawatt-hours (MWh) annually, the equivalent of 92,500 homes.[85]

As legal production has scaled, growing techniques have evolved, and data shows that commercial cultivation methods can achieve much better energy performance than illicit cultivation approaches. Nevertheless, the ever-expanding industry requires continued and dedicated improvements in energy use and efficiency in order to scale in line with states' renewable energy, energy efficiency, and overall emissions reductions goals. Commercial grade equipment like centralized HVAC systems with integrated dehumidification, as well as cultivation methods like vertical stacking, mobile racking, and automated temperature and humidity control are popular ways to improve energy efficiency.

As more states legalize cannabis, or open their medical markets to full adult-use, projections indicate a 162% increase in electrical energy use from cannabis cultivation between 2017 and 2022. This marked uptick is a strong indicator that this emerging industry must be seriously considered in future energy planning and policymaking from a state, regional, and national perspective.[86]

ENERGY IMPACTS OF CANNABIS

As states plan for and develop policy to address the industry's energy impacts, it is critical to address and appropriately mitigate each of the following impacts:

1. Demand for electricity from cultivation facilities is increasing and challenging grid resiliency;
2. Fossil fuel-powered generators are emitting greenhouse gasses and other air contaminants, which results in an adverse impact on ambient air quality (this impact is addressed in the Air section of this paper);
3. Cultivation facilities are increasingly using renewable energy sources to run their operations off-grid, especially in regions where grid access or grid reliability is unstable;
4. Energy use intensity of cultivation facilities is dependent on cultivation approach (outdoor, greenhouse, or indoor); and,
5. Post-cultivation activities, including manufacturing and transportation, also use energy and cause greenhouse gas emissions.

Data Availability

Although accurate data on statewide energy use in the cannabis industry has been difficult to aggregate in pre-legalization years, policymakers and regulators have flagged historical estimates of the industry's energy use as reason enough to proactively mitigate this impact in their legalized markets. In California, where cannabis cultivation was estimated to comprise three percent (3%) of electricity consumption in the state in 2012 (prior

83. Marijuana Business Daily. Annual Marijuana Business Factbook: 2016.
84. Schimelpfenig, Gretchen. "HVAC for Cannabis Cultivation & Controlled Environment Agriculture." *Resource Innovation Institute.* December 2019. https://resourceinnovationinstitute.wildapricot.org/resources/Documents/RII-HVAC-Best-Practice-Guide-v9-spreads.pdf
85. Scale Microgrid Solutions and the Resource Innovation Institute. "The 2018 Cannabis Energy Report." *New Frontier Data.* October 2018. https://newfrontierdata.com/product/2018-cannabis-energy-report/
86. Hudock, Chris, 162% Increase in U.S. Legal Cannabis Cultivation Electricity Consumption by 2022, *New Frontier Data*, October 25, 2018, (last accessed June 19, 2020), https://newfrontierdata.com/marijuana-insights/162-increase-in-u-s-legal-cannabis-cultivation-electricity-consumption-by-2022/

to the state's adult-use legalization in 2018)[87] the California Public Utilities Commission undertook early efforts to mitigate the industry's energy impacts.[88]

States with longer-running legal adult-use markets are monitoring energy use as well. In 2018, Denver Colorado's Department of Public Health and Environment estimated that four percent (4%) of Denver's electricity use is consumed by cannabis operations,[89] up from two percent (2%) in 2017.[90] In all cases, the ever-increasing number of cannabis cultivation facilities in legal markets results in increased demand on electrical grids, necessitating cities, states and utilities to take steps to curtail demand.

Power Supply

Some legal commercial cultivators today are electing to supplement or completely power their operations with off-grid fuel-powered generators. Many remote cultivators require generators to power their operations because they are too far removed from grid resources or need an emergency backup energy source. These generators create excess emissions, which degrade regional air quality and contribute to climate change (this topic will be discussed more directly in the Air section of this paper). While some states have attempted to address generators, such as in California's Department of Food & Agriculture cannabis regulations, the reliance on generators, particularly by illegal growers, will need to be addressed in order to reduce the industry's dependence on fossil fuels.

As grid-tied electricity use for cultivation is projected to increase significantly by 2022, some legal cultivators choose to generate energy on-site using renewable sources, either because of limited access to utility interconnection, unattractive utility fees for commercial operations, and/or accelerated construction schedules that prevent the cultivator's ability to interconnect their renewable resources with the grid in the time needed to get their facility up and running. Offsetting electricity demand with solar photovoltaic panels and wind turbines is a value proposition to growers in regions with high electric rates or limited utility access and is a strategy that should be encouraged by policymakers and supported by utility programs through dedicated interconnection resources. When coupled with energy storage, distributed generation renewable energy resources can also provide growers with cleaner backup power, replacing the need for fossil-fuel-powered generators. This is particularly relevant for growing regions where extended periods of drought forces utilities to cycle power outages on the grid to reduce fire risk, such as the blackouts imposed on California's PG&E customers in 2019.[91]

Energy Intensity

Power source aside, the primary factor eliciting concern for the industry's high energy consumption is the energy intensity of greenhouse and indoor grow operations. The 2018 Cannabis Energy Report examined the electric energy intensity (kWh/sq ft) of outdoor, indoor, and greenhouse cultivation facilities to find ranges of efficiency performance for a statistical sample of legal commercial licensees. While outdoor facilities have a fairly narrow range of performance and very low electricity consumption, greenhouses have a wide range of electric energy intensity, with some greenhouses using as much electricity as indoor facilities. However, the study concluded that the average electric energy intensity of indoor cultivation facilities is nearly twice the average of greenhouse operations. *See* Figure 1.[92]

FIGURE 1:

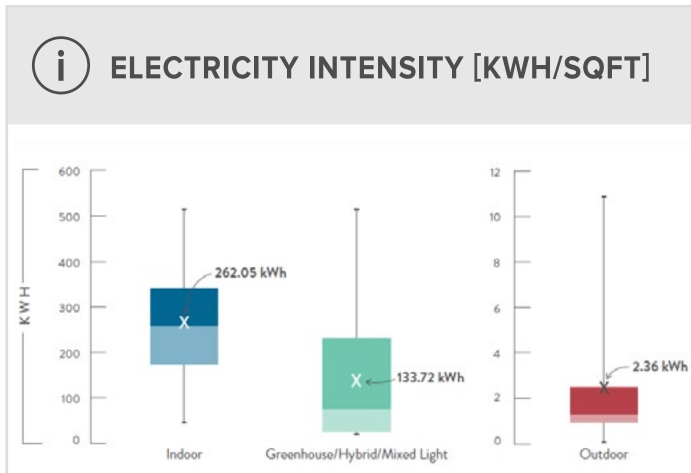

Figure 1.
Electric Energy Intensity of Sample of Licensed Commercial Cannabis Cultivators. New Frontier Data, et al., 2018 Cannabis Energy Report.

87. Durkay, Jocelyn, and Freeman, Duranya, Electricity Use in Marijuana Production, *National Conference of State Legislatures* August 2016, (last accessed June 19, 2020), http://www.ncsl.org/research/energy/electricity-use-in-marijuana-production.aspx

88. Mulqueen, April, and Lee, Rebecca, and Zafar, Marzia, Energy Impacts of Cannabis Cultivation Workshop Report and Staff Recommendations, *California Public Utilities Commission*, April 20, 2017, (last accessed June 19, 2020), https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/About_Us/Organization/Divisions/Policy_and_Planning/PPD_Work/PPD_Work_Products_(2014_forward)/PPD%20-%20Prop%2064%20Workshop%20Report%20FINAL.pdf (accessed Mar. 26, 2020).

89. Hood, Grace, Nearly 4 Percent Of Denver's Electricity Is Now Devoted To Marijuana, *CPR News*, February 19, 2018, (last accessed June 19, 2020), https://www.cpr.org/2018/02/19/nearly-4-percent-of-denvers-electricity-is-now-devoted-to-marijuana/ (accessed Mar. 26, 2020).

90. Mulqueen, et. al.

91. Fuller, Thomas, Californians Confront a Blackout Induced to Prevent Blazes, *The New York Times*, October 10, 2019, (last accessed June 19, 2020), https://www.nytimes.com/2019/10/10/us/pge-outage.html

92. New Frontier Data, et al., *The 2018* Cannabis Energy Report, *New Frontier Data*, October 2018, (last accessed June 19, 2020), https://newfrontierdata.com/product/2018-cannabis-energy-report/

While the 2018 study provided valuable insight into the industry's energy intensity, more data is needed to understand the whole-building energy intensity of cultivation facilities, accounting for not only electricity use, but also consumption of natural gas and delivered fuels, fuel used by back-up generators, and renewable energy production. Presently, there are limited resources for this data; however, a few data collection tools have emerged in recent years to fill this data gap. For example, the Resource Innovation Institute's benchmarking tool, *Cannabis PowerScore*, includes all energy sources that may be in use in a cultivation facility, so that energy use intensity in kBtu/sq. ft. can be calculated for new operations entering their data in 2020.[93]

Life-Cycle Impacts

While the ranges of energy use intensity of facilities by cultivation approach are under study, it is important to also gather data to calculate the life cycle energy impacts of the cannabis industry. This task requires accounting for post-cultivation activities, which include drying, curing, extracting, post-extraction processing, manufacturing of products, manufacturing of packaging, distribution, and sales. Many of these steps in the supply chain require fossil fuel power--most notably, transportation.

Energy Reduction Goals

Altogether, the energy consumption and electricity demands of the cannabis industry impact states' energy efficiency and greenhouse gas emissions reduction goals. It is therefore critical for agencies and utilities to help growers reduce energy consumption, manage demand, and improve operational efficiency of their cultivation facilities to ensure climate goals are met. Doing so will also enable states to control and minimize the secondary impacts of the industry's energy consumption: greenhouse gas emissions, which will be addressed in the Air section of this paper.

In order to design sustainable and effective policies, Best Management Practices must first be assessed as they are currently employed in markets across the U.S. for achieving greater energy efficiency, reducing the energy intensity of the industry, and transitioning to renewable energy resources and energy storage.

BEST MANAGEMENT PRACTICES: ENERGY

Today's cannabis industry is capable of efficiency and can utilize a range of energy sources in a variety of different cultivation environments, but it is still generally lacking in best management practices ("BMPs "). While efficient technologies are increasingly being installed to increase operational efficiency and to lower costs, facility optimization is not being achieved. It has been difficult to find peer-reviewed best practices not produced by equipment manufacturers. Thus, it is very important for the cannabis industry to come together and collaborate to find creative solutions that can serve as best practices for new and improving cultivation facilities. Luckily, the cannabis industry has great stakeholder engagement groups that support the pursuit of identifying best management practices. By bringing together multi-disciplinary experts to determine the best methods for operationally efficient cultivation operations, and advocating for effective policies and incentives that drive resource efficiency, the industry can tackle energy conservation together. However, It is critically important for cannabis businesses to participate in the stakeholder groups and share data to collectively move the industry toward sustainable practices.

Lighting and HVAC Drive Energy Use

The major drivers of energy consumption in cultivation are electric lighting and heating, ventilation, air conditioning and dehumidification systems serving facilities. These systems are inextricably intertwined and interact heavily with each other and the operational changes necessary for an efficient cultivation facility may be mysterious and complex for many growers, necessitating impartial Best Management Practices. For example, a traditional HVAC and lighting system approach could make up forty-five percent (45%) of a facility's operational costs, but a high-performance HVAC and lighting system evaluated during design could reduce operating costs to thirty percent (30%).[94]

Lighting Best Practices

As growers consider operational energy and resource efficiency to become a cut above the rest, an emerging best practice is for cultivation facilities to convert their lighting systems to light-emitting diode (LED) systems. Historically, illicit and first-generation legal commercial operations have used light fixtures with fluorescent high-pressure sodium (HPS) bulbs, as they are inexpensive and produce a spectrum of light that is sufficient for plant growth. However, despite the lower upfront first cost for HPS lighting systems, they are not energy efficient and can be expensive to operate and maintain. HPS light fixtures used for flowering stage growth commonly operate at up to 1,000 Watts each, and the bulbs need to be replaced multiple times a year.

LED lighting began to be offered to cultivators in the early 2000s, but the quality of the products was variable, and their original designs were not satisfactory to the horticultural market. Growers still have some distrust of LED light fixtures and their ability to produce the same yield as a plant grown with HPS equipment. While the marketplace has matured, not all LED light fixtures are created equal, and there are many options for growers to consider.[95]

Consider the following recommendations for the design and install LED lighting systems in cultivation facilities:

93. Resource Innovation Institute, *Cannabis PowerScore*, (last accessed June 19, 2020), https://cannabispowerscore.org/about/

94. Best Practices on HVAC for Cannabis Cultivation & Controlled Environment Agriculture, Resource Innovation Institute. 2019. https://ResourceInnovation.org/Resources.

95. Schimelpfenig, Gretchen, LED Lighting for Cannabis Cultivation & Controlled Environment Agriculture Best Practices Guide, *Resource Innovation Institute,* 2019, (last accessed June 19, 2020), https://ResourceInnovation.org/Resources/

- Design phase:
  - Ask for guidance from other growers that have moved to LED solutions
  - Plan the layout of plants to maximize light delivery and minimize walkways in spaces, to maximize utilization of the light canopy for plant growth
  - If an existing facility, measure light levels plants currently receive (in PPFD)
  - Determine target light levels for different rooms based on stage of plant growth and cultivation approach
  - Consider form factor, fixture spacing, and mounting height to achieve uniform light received by plants
  - Review manufacturer specification sheets to evaluate performance characteristics
  - Select third party-certified equipment
- Construction phase:
  - Maximize light received by plants with light and reflective wall and ceiling colors
  - Measure light levels at canopy height to confirm fixture spacing and mounting height
- Operation phase:
  - Control LED output with dimming to tune system for plants' needs
  - Revisit space temperature and relative humidity setpoints after observing interactive effects
  - Make one change at a time and document what changes you made and when, and for how long with both notes and pictures

HVAC Best Practices

Increased demand for products and cost compression in cannabis markets have led to new attitudes about efficient and optimized HVAC systems, as growers consider energy and resource efficiency to rise above the competition by reducing operations and maintenance costs through using high performance systems. Historically, illicit and first-generation legal commercial operations have used traditional HVAC equipment designed for commercial applications, and used supplemental dehumidification equipment in rooms to manage moisture.

This approach, while economical on day one, results in higher overall energy use as the HVAC equipment is not designed for the high moisture environments plants create in indoor spaces. In order to mitigate moisture, portable dehumidifiers are used in cultivation areas which injects heat into cultivation space, requiring re-conditioning of air to cool it back down. Humidity must also be controlled to maintain efficient operation of activated carbon odor control devices. One best practice for cultivation facilities is to integrate dehumidification equipment with central HVAC systems to create a more energy efficient operation.

HVAC systems not only have to deal with heat and humidity loads, but the ventilation equipment must also be protected by return air filter banks that prevent insects and particulates from impeding air flow and reducing efficiency. A maintenance program that includes monitoring and recording the pressure drop across filters and routine filter replacement should also be implemented.

Designing Efficient HVAC

Consider the following recommendations to design and install high-performance HVAC systems in cultivation facilities:

- Design phase:
  - Determine target set points for temperature and relative humidity
  - Size HVAC equipment by determining the most extreme target setpoints
  - Select a project team with expertise in cultivation applications and assign roles to understand dependencies and improve communication
  - Use integrated design approaches to maximize the potential of an upgrade or new construction project
  - Review manufacturer specification sheets to evaluate performance characteristics against design requirements
- Construction phase:
  - Know code minimums for energy performance so equipment meets permitting requirements
  - Understand the sequences of operation HVAC equipment use to satisfy target setpoints
  - Know the difference between equipment start-up, balancing, and commissioning
  - Validate how equipment will run in operation via third-party commissioning
- Operation phase:
  - Monitor airflow, temperature, and relative humidity to assess if field-measured data matches design drawings, balancing reports, and commissioning documents
  - Resolve identified commissioning issues to continue optimizing environments

LEDs Impact HVAC Design

Converting to LED lighting systems, while a worthwhile best practice, requires considerations for existing HVAC systems. A retrofit to LED will cut the heat load by about one third (⅓). Unless an existing HVAC system was designed intended for a varying load, the equipment will cycle more rapidly which could lead to temperature and humidity swings within the space, and the cycling is hard on the HVAC equipment which will impact its useful life. Ideally, the heat load of new LED fixtures should be matched closely to the heat load of the existing fixtures, which may be possible if a cultivator uses a vertical indoor cultivation approach. Otherwise, HVAC system modifications may be required. An analysis should be performed before retrofitting to LED to compare the cost of modifying the HVAC system to accommodate a reduced heat load versus total energy consumed without heat load reduction.

Future Energy Considerations

Throughout the design, construction, and operations of an indoor cultivation facility effort, there are best practices that can reduce total immediate energy demands while ensuring a more consistent environment for plant growth. Ongoing data collection and analysis will further improve results and reduce the need for future trial and error in system design and operation. With energy efficiency optimized, focus can be shifted towards implementing renewable energy plus battery storage power systems. By supplementing or replacing fossil fuel electricity generation with renewable energy and battery storage resources, cultivators can dramatically reduce the carbon impacts of their operations while aligning with state renewable energy and zero carbon emissions goals.

POLICY CONSIDERATIONS: ENERGY

There are a number of ways that federal, state and local governments can track, manage and reduce the cannabis industry's energy use intensity through policy. Effective and targeted policies and programs can be designed and implemented at any time. Here, we review the factors that should be considered in various stages of market development: prior to legalization (pre-market), in the early stages of a legal market (in market), and during the continuous improvement stage of a legal market (continuous improvement). States transitioning from medical to adult-use markets should revisit and update their policies to align with current economic and climate goals. All states should share information and effective policies and programs with each other as is done in other industries. Most importantly, market support and education should be at the forefront of a state's policy efforts, ensuring that all market participants have the information, resources and tools necessary to achieve mandated targets and goals. This support will best enable long-term, sustainable market growth.

Pre-Market Policy Considerations

Prior to legalizing cannabis, states must take into consideration several factors when drafting energy-related policies:

1. **Evaluate market size and potential growth opportunity.** States should study and understand the potential trajectory of growth for the size of their cannabis market. To appropriately size a market, states should evaluate market demand, economic competitiveness and job opportunities (determining how much supply is needed to meet demand), potential tax revenues (collected from businesses and consumers), social equity requirements and environmental impact. These considerations will best enable a state to ensure that the number of licensed facilities can meet demand and that revenues will be able to fund programs for energy rebates, renewable energy development incentives, and small business loans.
2. **Prioritize economically-viable and sustainable infrastructure.** States should prioritize the development of the most economically-viable and sustainable infrastructure. This can be accomplished by the application of zero-carbon electricity requirements and energy efficiency standards for all commercial cannabis operations, but specifically for controlled environment agriculture cultivation facilities (greenhouses and indoor warehouse facilities). States and cities can require businesses to verify compliance through the submission of construction plans, environmental permits, equipment purchases, and utility interconnection agreements.

   In order to establish appropriate standards and targets, states should refer to available data and benchmarking tools, such as the *Cannabis PowerScore*[96] and the *Blooming Benchmark.*[97] These resources can provide states with a large set of aggregate data that is voluntarily provided by cannabis cultivators, which can be used not only to inform best management practices but to help establish feasible statewide targets and mandates. States should complement energy efficiency and energy-intensity targets with compliance-tracking mechanisms, such as data collection by utilities and state regulatory agencies, and compliance should be tied to eligibility for new and renewed licenses and access to financial incentives. While all types of equipment efficiency should be considered, lighting should be a top priority. Nearly all cultivation facilities, including outdoor growers, use lighting for early growth cycles of their plants. In the aggregate, the energy use associated with lighting is substantial and can be significantly reduced through the application of appropriate efficiency standards. As highlighted in the Best Management Practices section of this chapter, standards developed by standards-setting bodies (eg: ASTM) should focus on individual fixture efficiency as well as Watts per square foot. By requiring and subsidizing sustainable development, states can help level the playing field for the amount of capital required for such development, which is critical for addressing social equity concerns and minimizing barriers to market entry. And because energy efficient and clean energy businesses will be the most economically resilient in the long-term, this support will help businesses in a given state compete in a larger interstate market.
3. **Focus on total carbon pollution, not just energy sources.** States should establish mandates for cultivators to power their operations with renewable energy *and* to employ regenerative soil practices and other net-zero-waste agricultural practices. To enforce these mandates, cities and states should track both energy use (source and consumption) and carbon pollution of cannabis cultivation so that policy adjustments can be made over time to align with state climate goals. To the extent possible and practical, outdoor cultivation should be encouraged.

   States and cities can look to examples like Boulder, Colorado's Energy Impact Offset Fund program, which requires cannabis cultivators to either offset their electricity use with local renewable energy or pay a 2.16 cent charge per kWh. Funds collected from the program

96. *Cannabis PowerScore*, (last accessed June 19, 2020), https://cannabispowerscore.org/
97. *The Blooming Benchmark*, (last accessed June 19, 2020), https://cannabisbigdata.co/blooming-benchmark/

are used to provide education to the industry for best practices in energy use and to support carbon pollution reduction projects in the city.[98] Reducing the industry's carbon pollution is addressed in other chapters of this paper, including Air and Land Use.

4. **Encourage outdoor cultivation without banning indoor. Resist banning any singular cultivation method.** Although greenhouse and indoor cultivation facilities are significantly more energy intensive than outdoor operations, they do provide growers with the greatest amount of control over their facility's operations and offer growers the ability to produce and harvest crops year-round. Furthermore, some states' climates necessitate the use of greenhouse and indoor cultivation, especially where cold/frost, moisture, and/or extreme heat/drought could devastate a growers' yield. Notwithstanding the benefits of greenhouse and indoor cultivation, outdoor cultivation should be encouraged to the extent practical because of the significantly reduced energy intensity of outdoor cultivation.

Although this list is not exhaustive, it highlights the key factors for developing proactive policies to track, manage and reduce the cannabis industry's energy impacts.

In-Market Policy Considerations

In the early stages of a new legal market, states should focus policy efforts on three areas: (1) Data Collection and Analysis; (2) Market Education; and (3) Broad Decarbonization Efforts. Of course, if the state did not adequately address energy impacts in its pre-market phase, it should focus its policy efforts on establishing a policy foundation based on the factors detailed in the previous section before shifting focus to these areas.

1. **Data Collection and Analysis.** A policy or program's effectiveness is measured by tangible results, which requires diligent data collection, sharing and analysis. As highlighted in the pre-market section, policies should be complemented by compliance and enforcement mechanisms, and data collection is an essential mechanism here.

   In addition to using the data for compliance purposes, states should analyze the data to continuously update benchmarking and to determine whether it is feasible to increase targets. States should also be willing to share data publicly and with other states directly to expedite the industry's path to maximum efficiency and minimized energy impact.

2. **Market Education.** In order for energy-related policies and programs to be successful, states should support educational programs that will guide and drive positive cultivation behavior. This includes sharing best management practices through state-sponsored and easily-accessible forums and connecting climate action goals (such as renewable energy portfolio standards, energy efficiency standards, and overarching decarbonization and emissions reduction goals) to long-term market sustainability. States should provide targeted energy efficiency and clean energy training to help business owners understand the importance and impact of state mandates, and how these requirements will enable a business to maximize its profitability over time and remain competitive in an ever-expanding market.

   In addition to educating cultivators, states must ensure that utilities have the funds, resources and tools necessary to provide cultivators with necessary energy services, including efficient interconnection processes, load management, and backup services. In the majority of markets, utilities are not equipped to manage the complicated and highly technical cultivation customer segment of the industry, creating a technical knowledge and customer service gap between utilities and their customers. The consequence of this gap is that businesses operate with less than optimal energy efficiency. By providing utilities with adequate industry education and ensuring that they are able to meet the industry's demands, states can improve the relationship between cultivators and utilities and maximize both groups' ability to succeed in meeting state mandates.

   Best practices for utility program design suggest that offering prescriptive programs for efficient lighting and HVAC equipment specific for controlled environment agricultural facilities will help utilities reach these customers better, meet savings targets, and help states achieve overarching greenhouse gas emissions reductions goals. Most states' utility programs do not offer prescriptive rebates for horticultural equipment, which means that cultivators have to participate in custom incentive programs, which can be more difficult for the customer to navigate, resulting in lower overall program participation. Additionally, cultivators may lack access to the engineering analysis and energy savings calculations required by the utilities to pre-approve equipment prior to purchase and installation. Without industry-specific low-barrier programs to focus on offsetting the cost of efficient equipment for cultivators, there is little participation from the industry, and cultivators continue to operate with inefficient equipment or bear the full burden of energy efficient upgrades.

3. **Broad Decarbonization Efforts.** Energy efficiency measures alone will not be sufficient to curtail the cannabis industry's energy impact. In order to meet state climate change mitigation goals, states must focus on aggressively incentivizing distributed generation renewable energy development as well as building decarbonization and transportation electrification across all market sectors and industries, including cannabis. States can partner with utilities to encourage cultivation customers to decarbonize

98. Cannabis Energy Impact Offset Fund, *Boulder County*, (last accessed July 18, 2020) https://www.bouldercounty.org/environment/sustainability/marijuana-offset-fund/.

their operations and limit their impact on the grid with electrification programs and support for distributed renewable energy projects, while also motivating them to conserve energy in their buildings with rebates for efficient equipment. States and utilities should ensure cannabis companies have access to and can participate in community solar gardens or similar customer-based models to offset a portion or all of their use.

Policy Considerations for Future Energy Improvements

1. **Recognition of Climate Champions.** As a legal market reaches maturity, state and local representatives can identify and recognize climate champions of the cannabis industry, much like is done with other industries. Cultivators who go above and beyond state mandates should be able to obtain voluntary certifications that recognize the most environmentally conscientious cultivators. These certifications can influence consumer purchasing power and resultantly drive and reinforce positive cultivator behavior.
2. **Social Equity Support.** At all stages of policy development, implementation and continuous improvement, states should be sure that their policies prioritize social equity, providing equitable market access to small and minority-owned businesses through dedicated funding pools, educational resources and business support.
3. **Nationwide Information-Sharing.** As highlighted in the in-market section, states should be willing and able to contribute data and information with other states to expedite the industry's path to maximum efficiency and minimized energy impact. Much like is done for other industries, a publicly-accessible online database could be created that contains regulatory information and market data for each state. Contributions could be made primarily by states and supplemented with contributions from researchers, vendors, and business owners.
4. **Utility and Supply Chain Support.** Finally, the impact of the transportation of cannabis products could be reduced by state-funded and utility-supported vehicle electrification programs and targeted federal or regional policies to reduce unnecessary transportation in the cannabis supply chain. For example, federal legalization of cannabis would lift prohibitions on interstate commerce, making it possible to transport cannabis goods throughout the country more efficiently.

To reduce the cannabis industry's energy impacts, policymakers must incorporate Best Management Practices into policy and regulation, provide structural and financial support to incentivize adoption, and provide continuous education to market participants. Altogether, these efforts will enable states to achieve their climate change mitigation goals while cultivating the long-term, sustainable growth of the cannabis industry.

SOLAR PANEL FARM

AIR QUALITY

At first glance, the cannabis industry may not appear to have a significant impact on the air we breathe. Afterall, how can growing plants be bad for the environment? However, there are many areas of the cannabis industry, including cultivation, that can result in adverse impacts to ambient air quality. Fortunately, there are measures that both the industry as a whole and individual cannabis businesses can take to reduce their overall impact on ambient air quality.

ENVIRONMENTAL IMPACTS: AIR QUALITY

The cannabis industry impacts air quality through direct emissions during cultivation and processing, as well as indirectly through emissions from associated electricity generation and transportation. Direct air quality impacts from cannabis include biogenic emissions from the plants themselves, as well as the potential for VOCs to be emitted as result of solvent use during the extraction process that follows harvest. Emission of these VOCs may not always have an immediate adverse impact, but under certain conditions, VOC emissions released to ambient air can react in the atmosphere with other pollutants to form harmful ground-level ozone pollution or secondary particulate matter.[99] Indoor cannabis cultivation operations may also have significant air quality impacts due to the reliance on fossil fuel-powered electricity generation to meet energy needs at these facilities (as is discussed in the Energy chapter). Across the industry, emissions from the transportation sector can also pose a threat to air quality. Emissions from transportation and electricity generation associated with the cannabis industry can also contribute to climate change. This section further discusses these various impacts. Later sections will address how to manage these impacts through industry practices and policy considerations.

Ozone and Secondary Aerosol Formation

Emissions of VOCs from both the cultivation and processing of cannabis can contribute to the formation of ground-level ozone pollution under certain conditions.[100] Ground-level ozone is formed through the reaction of nitrogen oxides (NO_x) with VOCs in the presence of sunlight. NO_x is typically emitted from combustion sources, such as power plants and the transportation sector, while VOCs are emitted from a variety of sources including painting and coating operations or use of VOC-containing products like cleaners and solvents. Biogenic VOC emissions from plants dominate global emissions and can comprise a significant portion of VOC emissions even in populated regions. Human exposure to ground-level ozone pollution can result in numerous adverse health effects, including acute respiratory symptoms such as throat irritation and coughing, chronic obstructive pulmonary disease (COPD), and the exacerbation of existing respiratory conditions, such as asthma. The American Lung Association compares ozone exposure to "a sunburn on the lungs."

The level of ozone formation resulting from VOC emissions varies depending on the location of the cultivation or processing operation and the proximity of other sources of pollution. Ground-level ozone formation is driven by the ratio of NO_x and VOCs in the ambient air. Areas with high background levels of NO_x pollution are considered VOC-limited which means ozone formation occurs when additional VOCs are emitted into the air. In contrast, areas that already have relatively high VOC concentrations in the airshed may not see increases in ozone resulting from increased VOC emissions. The formation of ozone is also dependent upon the presence of energy (sunlight and heat) to drive the reaction between NO_x and VOCs. For this reason, ozone formation in many regions is most likely to take place in the summertime. However, under the right conditions, ozone formation may occur in the cooler seasons, including winter. Overall, the potential for ozone formation resulting from VOC emissions from the cannabis industry is highly dependent upon the location of the cultivation and processing facilities and what best management practices are leveraged to control the emission of air contaminants.

In addition to the formation of ground-level ozone, emissions can also contribute to formation of secondary aerosols and particulate matter. Biogenic VOC emissions from cannabis plants can have high aerosol yields. In the atmosphere, these aerosols can react to form secondary aerosols and contribute to particulate matter concentrations.

Cultivation as a Source of Air Emissions

Cannabis plants naturally emit terpenes, which are a form of biogenic volatile organic compound (VOC).[101] The quantity and make-up of the VOC emissions from cannabis plants is site-

99. Future Cannabis Project. "Volatile Organic Compounds (VOCs) - Terpenes in the Atmosphere." *YouTube.com*. March 5, 2020. (last visited June 18, 2020). https://youtu.be/0kBmuaFxdvo

100. Sakas, Michael Elizabeth, *Is Pot Part Of Denver's Ozone Headache? That's What Researchers Want To Find Out*, CPR News (September 30, 2019), https://www.cpr.org/2019/09/30/is-pot-part-of-denvers-ozone-headache-thats-what-researchers-want-to-find-out/

101. Roy, Anusha, *Researchers want to know if marijuana is impacting the environment (and we don't mean the smoke)*, 9NEWS (October 2, 2019), https://www.9news.com/article/news/local/next/studying-pot-and-how-it-might-impact-the-environment/73-8342c07c-63d0-4345-97b0-b17307778f79

specific and varies by cultivar and age of plant. During the plant's growth, biogenic emissions typically reach their peak during the flowering stage. VOC emissions continue once the plant has been harvested during trimming, drying, and curing. Emissions during these post-harvest stages are expected to be higher than those during the growth of the plants.

Studies are still on-going to better understand the nature of VOCs emitted directly from cannabis plants. In particular, the State of Colorado is currently undergoing a study to analyze the type and quantity of terpenes emitted from cannabis plants and the resulting influence on localized ozone formation.[102] UNC-Chapel Hill has completed strain specific leaf-enclosure studies that have found the source strength and composition of monoterpenes emitted during cultivation.[103] These studies found that the emission rate and type of monoterpenes vary by strain and life cycle. This was further confirmed by ambient measurements of monoterpenes collected across Denver by UNC-Chapel Hill. These results showed monoterpenes concentrations 4-8 times higher than samples collected from a "background" site located at the Denver City Park. These results also showed that the composition of monoterpenes varied spatially suggesting a wide variety of emissions from various strains.

Site-specific leaf-enclosure studies that qualify and quantify both terpene and non-terpene emissions are used in the private sector to measure concentrations and predict local and regional impacts on health and nuisance air quality issues such as terpene drift.[104] These studies have shown that cannabis plants emit a diverse array of hundreds of biogenic VOCs including many non-terpenoid compounds that can be detected with specialized analytical tools. They also demonstrate that while there are large variations associated with growing conditions and plant age that need to be characterized by in-situ measurements, genetic variability is a dominant controlling factor in determining emission rates. Quantitative enclosure measurements that account for growing conditions and plant age can therefore be used to establish cultivar-specific emission factors for emission modeling studies.

Studies like these will be crucial to fully understanding the direct impact that growing cannabis has on air quality, ozone formation, and will support the identification and development of appropriate methods for mitigating these impacts.

Electricity Generation and Power Supply

Indoor cannabis cultivation requires large amounts of energy to operate the lighting and internal controls necessary to promote adequate plant growth. The electricity demand required by indoor cannabis cultivation has been equated to that used by data centers.[105] The Energy Chapter of this white paper further explores the relationship between energy use and the cannabis industry. This section will cover where that relationship results in air quality impacts.

The air quality impacts of fossil fuel-powered electricity generation can vary dramatically depending on the fuel type and power plant design. A new on-site fossil fuel power plant has the potential to generate electricity with dramatically reduced emissions of air contaminants when compared to an aging fleet of coal-fired power plants. Furthermore, an on-site power plant has the advantage of greater generation efficiency than grid-sourced power, because electricity is not lost in the transmission and distribution process. On-site power generation has the added operational efficiency of being able to capture and use waste heat for needs such as space heating, dehumidification, and deicing sidewalks.

Electricity generation does not necessarily equate to an adverse air quality impact. Renewable forms of energy production, such as wind and solar, have the potential to significantly reduce or eliminate air quality impacts generated by the cannabis industry. Renewable resources coupled with battery energy storage systems (BESSs) can further extend the time of use as well as provide back-up generation. If cannabis is to be grown indoors, facilities should consider what they can do to reduce their reliance on non-renewable forms of energy.

In addition to the main sources of power supply, cannabis cultivation facilities often have backup or supplemental power generators that are powered by diesel. Diesel combustion results in emissions of NO_x, Carbon Monoxide (CO), particulate matter (PM), and hydrocarbons, which include VOCs and hazardous air pollutants (HAPs). Auxiliary electric generating equipment such as diesel-fired emergency generators typically have much higher emissions per unit of energy generated than boilers or traditional power generating equipment. As the technology continues to evolve and costs come down, battery energy storage systems (BESSs) are becoming an attractive replacement of diesel generators.

Cannabinoid Extraction

VOC emissions may also occur during the processing of the cannabis plants to extract cannabinoids, such as THC and CBD. The extraction process is not influenced by the strain (e.g. hemp or marijuana) but instead is determined by the desired extract constituents. There are two methods of extracting cannabinoids

102. Sakas, Michael Elizabeth, *Growing Cannabis Could Lead To More Air Pollution*, Science Friday (October 4, 2019), https://www.sciencefriday.com/segments/cannabis-air-pollution/

103. Wang, Chi-Tsan, et al. "Leaf enclosure measurements for determining volatile organic compound emission capacity from Cannabis spp." Atmospheric environment 199 (2019): 80-87.

104. Wang, Chi-Tsan, et al. *Leaf enclosure measurements for determining volatile organic compound emission capacity from Cannabis spp.* Atmospheric Environment 199 (2019): 80-87.

105. Tweed, Katherine, *Marijuana Grow Ops Could Soon Rival Data Center Energy Use*, General Tech Media (September 27, 2016), https://www.greentechmedia.com/articles/read/marijuana-grow-ops-could-soon-rival-data-center-energy-use

from cannabis: mechanical and chemical.[106] Mechanical (solventless) essential oil extraction applies agitation or heat and pressure to separate the extract constituents from the plant. Solvent-based essential oil extraction uses a wide range of chemical and/or organic solvents. It is the escape of particulates from mechanical extraction and the evaporation of solvents used in chemical extraction that can adversely impact ambient air quality. Control technologies and solvent management practices can be implemented to reduce the quantity of emitted particles and gases that are released into the ambient environment.

Transportation Impacts

Due to zoning and licensing restrictions that separate cannabis businesses across the supply chain, transportation emissions can contribute immensely to the industry's overall carbon footprint. Transportation impacts may occur across the supply chain, from transporting plants between cultivation and processing facilities, to the transport of nutrients and other grow supplies to cultivation operations. The cannabis industry's transportation impact on air quality is influenced by the type of vehicles used, the type of fuels used, and the overall vehicle miles traveled. The distance between growing operations to the processing facility and final transport to the retail facility or storefront may be a short distance or may require transport over several hundred miles. Heavy-duty vehicles running on diesel that travel longer distances emit significantly more air pollutants and greenhouse gases than light-duty gasoline-powered vehicles operating at short distances. Full or hybrid-electric vehicles have an even lower air quality impact, particularly if the vehicle batteries are powered by renewable energy sources.

Carbon Dioxide (CO_2) Supplementation/ Generation

Indoor cannabis cultivation operations may use supplemental carbon dioxide (CO_2) to accelerate plant growth. CO_2 is either bulk delivered by heavy duty diesel truck or is generated on site. CO_2 generators can emit air pollutants at levels that pose a threat to human health and the environment if released into ambient air uncontrolled. Two common methods used to generate CO_2 are fermentation[107] and combustion. Colorado is testing reusing CO_2 captured from a local craft brewery's fermentation process in a marijuana cultivation.[108] Fermentation creates CO_2, hydrogen, methane, and other air contaminants. Combustion generates carbon monoxide (CO), NO_x, particulate matter (PM), sulfur dioxide (SO_2), and VOCs. Carbon dioxide supplementation has the potential to increase greenhouse gas emissions from a cultivation facility because some of the CO_2 will escape the building before it can be consumed by the growing plants. Marijuana cultivation facilities' use of CO_2 to enhance plant growth should be evaluated to determine if CO_2 emissions from this industry can contribute significantly to global climate change. Finding a local, sustainable source of CO_2, such as one that is naturally produced or reused from a byproduct of another process, CO_2 supply can reduce the air quality impacts of supplementing a cultivation with CO_2.

Climate Change Impacts

Not only do emissions from the cannabis industry impact ambient air quality, there is also a potential for these emissions to contribute to global climate change. Greenhouse gas emissions occur during electricity generation, transportation, and the CO_2 generation associated with the cannabis industry. Measures taken to reduce electricity use, improve energy efficiency, and reduce transportation impacts will all help mitigate climate impacts from the cannabis industry.

While the industry may contribute to greenhouse gas emissions, growing cannabis can also help reduce overall carbon impacts through the plant's natural ability to extract atmospheric carbon and sequester it into the soil. Carbon sequestration, as defined by the United States Geological Survey, is the process of capturing and storing atmospheric carbon dioxide, reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change. Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. This process is primarily mediated by plants through photosynthesis, with carbon stored in the form of soil organic carbon.[109] A 2002 carbon study by *Pervaiz and Sain,* found that "net carbon sequestration by industrial hemp crop is estimated as 0.67 ton/h/year, which is compatible with all USA urban trees and very close to naturally regenerated forests."[110] A 2014 analysis prepared for the Australian Parliament, found that "industrial hemp can absorb 22 tonnes of CO_2 per hectare. It is possible to grow two crops per year so absorption is doubled. Cannabis rapid growth (grows to 4 metres in 100 days) makes it one of the fastest CO_2-to-biomass conversion tools available."[111]

106. "Complete Guide to Solvent Cannabis Extracts." *Alchimia*. March 30, 2018. (last accessed June 18, 2018). https://www.alchimiaweb.com/blogen/complete-guide-solvent-cannabis-extracts/

107. Oldham, Jennifer, *Instead of releasing this greenhouse gas, beer brewers are selling it to pot growers*, The Washington Post (February 11, 2020), https://www.washingtonpost.com/climate-solutions/instead-of-releasing-this-greenhouse-gas-beer-brewers-are-selling-it-to-pot-growers/2020/02/11/cf1410ae-49c3-11ea-b4d9-29cc419287eb_story.html

108. Kakas, Michael Elizabeth, *Colorado Wants Craft Breweries To Capture The CO2 Their Brews Burp Out, And Make Some Cash From It*, CPR News (March 25, 2020), https://www.cpr.org/2020/03/25/brewing-beer-makes-co2-the-state-wants-craft-breweries-to-capture-the-greenhouse-gas-and-make-some-money-from-it-too/

109. Ontl, T. A. & Schulte, L. A. "Soil Carbon Storage". Nature Education Knowledge 3(10):35 (2012)

110. Pervaiz, Muhammad and Sain, Mohini. *Carbon storage potential in natural fiber composites*. 39 Resources Conservation and Recycling 325-340 (November 2003).

111. Vosper, James, *The Role of Industrial Hemp in Carbon Farming*, Good Earth Resources (2014), https://hemp-copenhagen.com/images/Hemp-cph-Carbon-sink.pdf

Odor Impacts

The cannabis industry is well-known for the strong odors that can accompany cultivation and processing, impacting surrounding communities. Cannabis odors are emitted from any facility that handles cannabis plants due to the release of strong smelling biogenic VOCs during plant growth. Odors are typically strongest during the flowering stage of cultivation and while processing, drying or curing plant materials. As cannabis plants mature, they release a distinctive range of odors which are partially made up of specific types of biogenic VOCs called terpenes. The dominant terpenes emitted from cannabis cultivation include: myrcene, pinenes, terpinolene, and limonene. In addition to terpenes, cannabis releases other highly odorous compounds typically present in low concentrations, such as nonanal, decanol, o-cymene, benzaldehyde, which have more potent odor impacts.[112] Odors from the cannabis industry are difficult to quantify due to relatively low thresholds for detection, and sensitivity to the odors can vary from individual to individual.

Odors pose a nuisance to surrounding communities and can impact quality of life or even livelihood. In Oregon, vineyards near a proposed cannabis cultivation sued to block the facility from beginning operation due to fears of "foul-smelling particles" from the cannabis plants tainting their grapes.[113,114] It is not clear if there is any scientific evidence to show if it is possible for cannabis terpenes to taint wine grapes, though research shows that the terpene eucalyptol can taint wine if it deposited onto grape leaves that are used in the red wine-making process; some cannabis plants do contain eucalyptol.[115]

It is important to note that the presence of strong odors does not necessarily equate to higher concentrations of air contaminants. While some terpenes are also potent VOCs, it is not always the case that strong odors equate to increased VOCs volumes and the associated air quality or health impacts. There are not currently any studies on the health impacts from directly inhaling VOCs emitted from cannabis plants.[116] The health impacts from these biogenic VOC emissions are more likely to occur when they contribute to ground-level ozone pollution, which is not directly correlated with the level of odor from a cannabis facility.

BEST MANAGEMENT PRACTICES: AIR QUALITY

Control Technology for Reducing VOC Emissions and Odors

At cannabis cultivation facilities, installing control technologies can reduce the amount of VOC emissions released from the cultivation or extraction process and can control odors in compliance with local odor ordinances. Activities in the cultivation or production cycle that release significant odors may also release elevated VOCs during that time. Therefore, many of the recommended controls for controlling odors also reduce VOC emissions. These controls are highly recommended for all cannabis cultivation or production facilities and may be required, as in Canada, where the Cannabis Act mandates that these controls be installed.

Activated Carbon

Carbon filtration is the most commonly used and recommended control technology for reducing odors and VOC emissions from cannabis facilities. Carbon filters are simple to install, effective, and reliable, so long as they are properly maintained and regularly changed. Porous carbon surfaces chemically attract VOCs and other gas phase contaminants to the surface through a process called adsorption, which is the adhesion of molecules to the surface of a solid. As the filter ages, less carbon surface area is available to trap VOCs, and the porous surface of the filter becomes saturated. Regular maintenance of the filtration system is required and should be completed according to the manufacturer's recommendations.

Carbon filters can be stand-alone units that clean and recirculate the air, or they can be integrated into a HVAC system as an air intake or exhaust filter. Typically, carbon filters are at their peak performance when positioned at the highest point in a grow space, where heat can accumulate.[117] Filter performance can be inhibited by heat and high humidity, so this control technology is better suited for facilities with environmental controls. An effective filtration system depends on the size of the cultivation space and the rate of airflow between different areas. Maintaining an optimal environment can require multiple filters, which all require maintenance and replacement resources. Carbon filters can be used in combination with other odor control technologies.

112. Rice, Somchai and Koziel, Jacek A. *Characterizing the Smell of Marijuana by Odor Impact of Volatile Compounds: An Application of Simultaneous Chemical and Sensory Analysis*. National Institutes of Health (December 10, 2015).

113. "Cannabis Case Summary: Cannabis Farms and Vineyards and Why Can't We All Just Get Along?" *Canna Law Blog.* May 9, 2017. June 18, 2020. https://www.cannalawblog.com/cannabis-case-summary-can-a-cannabis-farm-and-a-vineyard-co-exist/

114. The Associated Press, *Oregon marijuana growers face lawsuit from vineyard owner over crop's smell*, The Cannabist (11/24/201) https://www.thecannabist.co/2017/11/24/oregon-marijuana-smell-vineyard-lawsuit/93192/

115. Ezzone, Zac, *Cannabis farm applicant presents cannabis terpenes study, county looks for additional information*, Santa Maria Sun (12/18/2019), http://www.santamariasun.com/news/19255/cannabis-farm-applicant-presents-cannabis-terpenes-study-county-looks-for-additional-information/

116. Ontario Agency for Health Protection and Promotion (Public Health Ontario), *Evidence brief: Odours from cannabis production,* Toronto, ON: Queen's Printer for Ontario; April 2018.

117. Enviroklenz. "Carbon Filter for Grow Room Cannabis Odor Control." *EnviroKlenz*. August 12, 2019. June 18, 2020. https://enviroklenzairpurifiers.com/carbon-filter-grow-room-cannabis-odor-control/

The following are recommended best practices for carbon filtration systems:

- Design a carbon filtration system that meets the specific needs of your facility. It is recommended that you work with an HVAC consultant with cannabis industry experience.
- Get information from the manufacturer about the effectiveness of the filter at removing VOCs and choose a filter with an appropriate efficiency rate for the specific cultivation environment.
- Do not exceed the maximum rated cubic feet per minute rating for air circulation through the filter. If you exceed this maximum flow rate, the passing air will not have enough "contact time" with the carbon, and the filter will not be effective at removing VOCs.
- Regularly inspect your filter and replace the filter if it is releasing a smell near where the filter discharges, or if it has reached its lifespan according to the manufacturer's specifications.
- Time your filter replacement schedule so that filters are replaced in early May, which is typically the beginning of ozone season. This ensures that the filter is at peak performance for VOC removal during the high ozone season (summer).
- Using a pre-filter can help preserve the life span of your carbon filter because it can capture particles before they take-up surface area on the filter. Pre-filters should be replaced as appropriate pursuant to manufacturer recommendations.

Ozone Generators

Ozone generators are another odor control technology utilized in the cannabis industry, but they are used primarily for post-harvest sanitization purposes. Ozone generators have historically been used in industrial settings to control strong odors. However, ozone generators are potentially harmful to humans and can damage or even destroy crops because they are a direct emissions source of ozone pollution, a strong oxidizer. Using an ozone generator for odor control requires a separate "lung room" that draws air from a grow room to prevent ozone exposure. Ozone generators can be used effectively for cleaning purposes as long as plants and people are not present in the room while ozone is pumped inside. Plants and people can only return to the room once it has been purged of all ozone. Ozone is toxic to both plants and humans; therefore, ozone generators are not typically recommended.

Chemical Additives: Misters, Foggers, and Vaporizers

Misters, foggers, and vaporizers (MFV) are control technologies where chemical additives are injected or sprayed into the exhaust stream. MFV are most often used for cannabis cultivation where the odor escapes the growing facility through large roof vents because the odor controlling chemicals can be dispersed near the emission areas. The primary difference between the MFV odor control technologies is the particle size of the control technology. Mists consist of particles that range in size from approximately 50 to 300 microns in diameter. Fogs consist of atomized particles that range in size from approximately 10 to 100 microns. And gaseous vapor particles range in size from approximately 0.001 to 0.01 microns.[118]

Particle size affects the physical characteristics and effectiveness of each control technology. Mists consist of relatively large particles with the least surface area per total particles emitted. Total particle surface area increases as individual particle size decreases, with gas and vapor particles providing the greatest total particle surface area to react with odor molecules. Furthermore, larger particles settle out of the atmosphere faster than smaller particles, which results in smaller particles having more time to contact and react with the air contaminant.

Mists, fogs and vapors all operate by adding chemicals to the exhaust stream. Although most of the products consist of natural essential oils derived from plants, the addition of VOCs or HAPs to the atmosphere needs to be evaluated to determine if the emission of the particles is subject to air permitting requirements.

Another common odor control technology utilized by the cannabis industry is odor absorbing neutralizers. Odor neutralizers may be oils and liquids derived from plant extracts or synthetically manufactured. The cannabis industry trend is to use natural plant extracts. Odor neutralizers are misted, fogged or vaporized into the exhaust air at cultivation facilities to neutralize odorous VOCs, reducing their potential to form ozone. Odor neutralizers cannot be used directly within the grow room as they have the potential to impact the taste and smell of the product. The effectiveness of different technologies in the reduction of VOC emissions will vary greatly by product and contact time. Therefore, it is imperative that systems are designed and maintained for the specific environment in which they will be employed.

Masking agents and counteractive agents are also commonly used chemical odor control technologies that are also misted at the cultivation facility's exhaust. Masking agents release VOCs with a stronger odor than the VOCs emitted by cannabis, so the intention is for the olfactory system to be overloaded so that the smell of the masking agent is the only smell perceived. Counteractive agents bind with the volatile smelling compound and block them from the olfactory senses, but this does not eliminate VOCs. Both masking and counteractive agents add more VOCs to the ambient air in order to neutralize odors. These technologies are not typically recommended in urban areas and can lead to increased air quality impacts from higher VOC emissions. Businesses should carefully consider these impacts when evaluating chemical odor control technology options and choose those with the lowest net impact.

Mineral Filters

Another control option is mineral-based air filtration technology, which uses a proprietary blend of granulated minerals to remove air contaminants. One manufacturer of this type of

118. Webinar: "Cannabis Cultivation Odor Mitigation." *Byers Scientific & Manufacturing.* https://drive.google.com/file/d/15zxGlHIlw8QoKe4nC6aN_Oe64Mhh2-OP/view

filter claims that the "earth mineral technology" has advantages compared to activated carbon in the respect that performance is not adversely impacted by humidity and heat. Furthermore, activated carbon works via surface adsorption, which can reach an adsorption and release equilibrium as the activated carbon surfaces become saturated or heated. This control was previously used in military operations, but not much is known about its effectiveness for use in the cannabis industry. Therefore, it is not recommended for use in controlling odors from cannabis operations until more information is known about this technology.

Biofilters

Biofilters are an emerging odor technology for the cannabis industry. Biofilters are made of an organic medium, like wood chips, that are inoculated with bacteria that form a film on the filtration media. The odor mitigation is completed as the odorous emissions pass through the media and are consumed by the biofilm on the media. Biofilters have traditionally been used to control odors at industrial-scale agricultural operations like feedlots and municipal waste facilities. Research and development is currently being completed on biofilters that contain bacteria that will consume terpenes without harming the cannabis plants. Biofiltration is successful at treating biodegradable VOCs, but it requires a large physical footprint and careful operation control. This technology is emerging and could prove to be more cost effective and less resource-intensive than carbon filtration once it is refined in the future. However, based on the known information, this is currently not the recommended option for controlling odors from cannabis operations.

Negative Air Pressure with Integrated Treatment

A management practice that should be considered alongside control technologies is the application of containment in areas where odorous air emissions are generated. This is completed through implementing negative air pressure protocols in odor generating areas and installing an in-line odor treatment technology, such as those discussed in the sections above, prior to discharge. This management methodology would only be practical in enclosed cultivation and/or processing facilities where a minimal negative air pressure gradient can be implemented. An advantage of a facility where this type of system can be practically implemented allows for significant control of air quality both upstream and downstream of odor sources. Not only can this provide for greater emissions control, but if HEPA-type air filtration is installed upstream of the cultivation and/or processing areas, this can minimize the exposure of production areas to air contaminants such as bacteria, spores and pollen.

Cannabinoid Extraction Best Practices

Emissions of VOCs and HAPs from cannabis extraction facilities can be minimized through emission control technologies and effective solvent conservation practices, or solvent substitution. Common emission controls used in closed-loop cannabinoid extraction are condensers and cold traps. A cold trap is a device that typically operates below freezing and condenses vapors into a liquid or solid, whereas a condenser typically operates above freezing and converts some vapors into liquids. Condenser control efficiency is affected by multiple factors such as boiling point, flow rate of gasses through the condenser, as well as input, output and chiller temperatures. Closed-loop extraction systems also conserve the loss of solvents and significantly reduce fugitive emissions.

When designing a cannabis extraction process, the total environmental impact of each control device technology should be evaluated. For example, even though a cold trap will maximize the capture of air contaminants, the air pollution generated by the higher electricity demand of a cold trap may have a greater environmental impact than the reduction of air contaminants emitted from the extraction process. Extraction operations should evaluate each control device to determine the most effective method of emission reduction at their facility.

The solvents used for essential oil extraction can have an impact on the environment. 'Solventless' systems that employ only water or processes that employ supercritical CO_2 as a solvent may produce fewer toxic byproducts than systems that utilize ethanol or hydrocarbon solvents. Ultimately if materials are managed and disposed of appropriately there may be minimal impacts to the environment, but a hierarchy of systems and the materials employed should be evaluated based on their potential impacts to air quality and contribution to greenhouse gas emissions along with other operational considerations.

Solvents must be managed according to procedures that minimize fugitive or accidental emissions, which means protecting tanks and canisters from accidental puncture or tip over, ensuring they are stored at the proper temperature, identifying fugitive emission source areas and training employees in the proper use and handling of materials. Information for proper handling of solvents can typically be found on the Safety Data Sheet (SDS) for that chemical. Some best management practices for extraction facilities to follow are listed below.

Best Management Practices for Extraction Facilities to Reduce Air Emissions

- Regularly inspect and maintain all storage devices of solvents to prevent leaks.
- Conduct regular maintenance and inspection of the extraction system to ensure that it is functioning properly without direct leaks of the solvent.
- Take caution to prevent leaks during the transfer of solvents between containers and systems at all stages of the production processes.
- Never dispose of a solvent through direct evaporation or spillage, and ensure that any such solvent is always recovered and kept in a closed-loop extraction system or designated container.
- Maintain an inventory of all solvent liquids (solvent management plan), and ensure that the facility operating procedure allocates responsibility to all relevant workers to maintain the inventory and identify fugitive emission sources.
- Develop training and allocate responsibilities for staff members to ensure best practices are being implemented consistently and continually, as a part of the

routine facility operating procedure.

Electricity Best Practices

Emissions from electric generating equipment and ancillary equipment, such as diesel generators and gas-fired appliances, may be reduced through measures to improve energy efficiency at an indoor grow facility. Alternative energy sources, such as wind or solar power, should also be considered as a way to reduce emissions to ambient air and reduce the industry's overall contribution to climate change.

Emissions from electric generating equipment should be connected to adequate emission control technology. The proper emission controls will vary based on the equipment being used. Indoor cultivation facilities that are planning to use on-site electric generation to supply the energy needs of their facility should work with the manufacturer of the electric generating equipment and their state or local environmental agency to determine the appropriate emission control technology.

Carbon Dioxide Best Practices

The air quality impact from generating CO_2 for use in indoor cannabis cultivation can be significantly reduced or eliminated through the use of alternate sources of CO_2. A novel experiment in Colorado is using CO_2 captured from beer brewing for the supplemental CO_2 for indoor cannabis cultivation.[119] Cannabis cultivators who need supplemental CO_2 should consider a similar partnership that allows them to turn one business's waste into a valuable source of high-grade CO_2.[120]

Another alternative to CO_2 generation is the use of exhaust from on-site electric generating equipment. Exhaust from natural gas fired power generation can be controlled using state-of-the-art catalytic reduction. This control technology reduces levels of carbon monoxide and hydrocarbons to levels that allow for re-introduction into the plant environment. The emission-controlled exhaust from a reciprocating engine used to drive an electric generator can be utilized to provide a CO_2 enriched atmosphere to enhance plant growth, as well as employing another byproduct: heat for dehumidification. Such a system needs to be properly designed, maintained and monitored to ensure employee health and safety.

POLICY CONSIDERATIONS: AIR QUALITY

Appropriate utilization of existing policy combined with adoption of new policies and regulations can ease this burden on the industry while also ensuring adequate environmental protections. The Clean Air Act forms the basis of most state and federal air quality regulatory programs. The requirements within the Clean Air Act are set in federal law, and typically implemented or enforced by state or local environmental agencies. Existing air quality regulations generally apply to any industrial source that emit air contaminants, which would include the cannabis industry. However, there is much room for improvement upon and expansion beyond these existing regulatory frameworks. As more states and the federal government move to fully legalize cannabis, existing and future policies should be implemented in ways that are inclusive of environmental regulation.

Education and Communication

One of the biggest barriers to adequate environmental regulation is the lack of knowledge in the cannabis industry around environmental regulation and whether it applies to them. Entrepreneurs in the cannabis industry may be familiar with the requirements for obtaining a business license and building permit, but they often are unaware of the maze of environmental regulations that must be satisfied in order to operate in compliance. Even within the environmental regulatory landscape, air quality impacts are often overlooked because many air contaminants are invisible. For a business owner, navigating the environmental compliance landscape can be confusing as regulations can vary by state and local authority.

Cannabis business owners should be proactive by researching local regulations and contacting local environmental experts in order to determine regulatory applicability. This should be done early in the planning process so that appropriate air emission control systems can be evaluated and permits obtained prior to beginning construction and operation.

Air Permitting Requirements

Existing air permitting programs under the Clean Air Act can and should be applied to the cannabis industry. Air use permits grant facilities permission to emit air contaminants into ambient air. Air permits incorporate requirements that limit or control the quantity of emissions generated from industrial sources. The requirement to obtain an air permit, as well as the type of permit required, is dependent upon a number of factors including the type of equipment that will be operated, the chemical composition and quantity of emissions from the facility, and the location of the facility. It's the responsibility of the business owner to determine if their processes and activities are subject to permitting requirements before beginning construction or operation of the equipment.

Within the cannabis industry, cultivators and processors are the most likely businesses to require an air permit to operate. At cannabis cultivation facilities, emissions from growing the plants may reach levels that would typically require an air permit. However, as previously mentioned, studies are still underway to better quantify emissions from growing cannabis and therefore the cultivation itself is not likely to be subject to permitting at this

119. Ricciardi, Tiney, *Colorado hopes to make cannabis industry more eco-friendly by recycling breweries' carbon dioxide*, The Denver Post (January 29, 2020), https://www.denverpost.com/2020/01/29/colorado-cannabis-brewing-carbon-dioxide/

120. Jackson, Margaret, *Marijuana cultivator's CO2 partnership with craft beer brewer saves money, makes MJ firm more eco-friendly*, Marijuana Business Daily (February 18, 2020), https://mjbizdaily.com/marijuana-cultivator-co2s-partnership-craft-beer-brewer-saves-money-makes-mj-firm-more-eco-friendly/

time.[121] In addition, if an operation is designated as agriculture, it may be exempt from air permitting regulations.

While the cultivation of cannabis plants alone may not trigger permitting requirements, power generation and other ancillary equipment located at cannabis cultivation facilities may require an air permit to operate. Diesel power generators, boilers, hot water heaters, and HVAC equipment all have the potential to emit air pollutants at levels that require air permitting or compliance with equipment-specific regulations. Facilities should consider the potential emissions from these pieces of equipment and contact local permitting authorities before installing and operating this equipment on site. In addition, odor control technologies such as ozone generators or misting agents emit air pollutants and may be subject to air permitting requirements, depending on the scale at which they are used.

Equipment used to extract and distill desirable compounds (THC, CBD, terpenes, etc.) from cannabis may also require an air permit to operate. As discussed earlier in this chapter, extraction processes result in emissions of volatile organic compounds (VOCs). Depending on the scale of the operation and quantity of solvents used, VOC emissions generated from these processes may be significant enough to require an air permit. Mass balance is an acceptable method used to quantify annual air emissions from extraction activities. Start by estimating the amount of solvent that has been lost through evaporation. To do this, record the total volume of solvents purchased and subtract the volume that is currently in your solvent inventory, as well as the amount that has been used as product ingredients or any other trackable waste streams. Multiply the calculated amount of solvent lost to evaporation by the density of the solvent you are using (lbs/gal) and you will then have the amount of air emissions from the process. Once this information is known, the local air permitting authority should be contacted to determine whether the process requires an air use permit.

Interagency Communication

Regulatory agencies should take steps to ensure robust communication across agencies, departments, and divisions that deal with cannabis regulation. A comprehensive regulatory program should include a network of interagency communication amongst all affected state and federal departments. For example, marijuana license review should include an assessment of all applicable environmental regulations before the permit is issued. Furthermore, after the permit is issued, there should be a place for affected agencies to report on the compliance and enforcement status of each licensee. A program should also include training to increase the awareness of applicable regulations in all affected departments such as (but not limited to) agriculture, attorney general, education, natural resources, state police, transportation, and treasury. An interagency cannabis communication network should provide the ability to rapidly identify and respond to problems as they emerge and address ongoing issues related to the cannabis industry.

Cannabis Licensing Programs

In most states that have legalized recreational marijuana, cannabis operations are required to obtain an adult-use or recreational license prior to operating in the marketplace. In order to obtain an adult-use or recreational business license, the applicant must first seek approval from their city or municipality and have all building permits in place. However, what's left out of these existing licensing processes is the requirement to obtain air permits prior to construction and operation. This has already created some problems in states that have legalized recreational marijuana. For example, in Michigan and Colorado, cannabis businesses have received their adult-license and began operation before becoming aware they are also subject to environmental regulations. This oversight not only results in adverse environmental impacts but can also be costly for businesses who may have to make adjustments to their facility or even pay fines in order to comply with air permitting regulations.

As more states move to fully legalize cannabis products, states and the federal government should incorporate environmental permitting requirements into the licensing approval process. This would ensure that cannabis cultivation and processing facilities have acquired all required permits before commencing construction or operation. Furthermore, incorporating environmental compliance into licensing approval would streamline compliance for the entrepreneur and minimize unplanned expenses associated with litigation and fines.

Compliance and Enforcement Funding

Marijuana ballot proposals have rarely included provisions to fund environmental regulatory oversight, which forces each state to address funding deficiencies. The large growth of the cannabis industry nationwide is posing a challenge for state environmental agencies as they struggle to keep up. Funding to support air permitting agencies should be included in cannabis legalization laws to ensure these programs have the support they need to adequately regulate this rapidly growing industry. This is particularly pertinent in states like Michigan where there are not any fees for applying for an air permit.

Supporting Incentives

Air regulatory agencies should also consider programs for incentivizing innovation and environmentally responsible actors in the cannabis industry. The process of getting a permit and installing equipment may result in unseen expenses for those without large funds backing them. In particular, those who have previously been incarcerated for cannabis-related crimes or those with existing barriers to entering the industry may be burdened by the additional fees and time required to acquire an air permit. State or federal regulators should consider financing or assistance programs for those who have barriers to entering the cannabis industry.

In addition, states or the federal government should consider incentives for renewable forms of energy, such as solar, for the cannabis industry. Since cannabis is not fully legalized

121. Sakas, Michael Elizabeth, *Is Pot Part Of Denver's Ozone Headache? That's What Researchers Want To Find Out*, CPR News (September 30, 2019), https://www.cpr.org/2019/09/30/is-pot-part-of-denvers-ozone-headache-thats-what-researchers-want-to-find-out/

nationally, cannabis cultivators do not typically qualify for tax breaks or incentives for using solar panels or other forms of renewable energy.[122] Considering the potential for large energy use by cultivators in this industry, renewable energy incentives should be made available to incentivize the use of alternative forms of energy.

Cannabis Clearinghouse

As the legalization of marijuana and hemp progress across the United States, there is a need for federal, state, and local governments to work towards establishing a national clearinghouse, which provides a single point of information and education for cannabis entrepreneurs to learn about the applicable regulations and receive assistance with completing applications and forms. Regulators should consider developing a national clearing house, where each agency can upload laws, guidance, and other applicable documents that the cannabis entrepreneur needs to conduct business. A clearinghouse system would also provide a place for the industry to track environmental parameters, such as electricity usage and emissions generated from transportation. This would serve as a one-stop shop for determining regulatory compliance and would serve as a place to educate the cannabis industry on air quality regulations. A clearinghouse like this would expedite cannabis business development and simplify the compliance process.

Through adaptation of this framework to the cannabis industry, and proactive measures by the industry to reduce emission of air contaminants and odors, the cannabis industry has the potential to operate in a manner with a significantly reduced impact on ambient air quality.

Odor Control and Regulation

Many state and local agencies have regulations in place to limit or prohibit odors from industrial activities that adversely impact public health or quality of life. These regulations can vary broadly across state or local municipalities, but often include a process for residents to complain of foul or offensive odors and then for regulators to assess and/or confirm the presence of those odors. If odors are detected from industrial facilities at levels that adversely impact an individual's health or quality of life, the facility may face enforcement action or other penalties. There is also potential for an operation classed as agriculture to have 'right to farm' protection from prosecution for a nuisance that is the result of farming activities (*i.e.*, odor, dust). Owners or operators of cannabis facilities should educate themselves on local and state odor regulations to ensure they are operating in compliance.

Existing odor regulations should be updated to specifically address cannabis odors. Cities and local municipalities should consider adopting their own odor ordinance. When updating odor regulations to address cannabis odors, the appropriate regulatory authority should consider how odors will be assessed or quantified, what actions may be required of facilities to limit odors, and what enforcement actions may be taken against facilities in the case of a violation.

There are advantages and disadvantages to each method of measuring or detecting odors to assess compliance. For instance, in Michigan, odor investigations are performed by regulatory staff, who visit the area surrounding the industrial activity and subjectively rate the level of odor based on the level they detect. Each person may detect odors differently, thereby making this method of odor detection difficult to enforce. On the other hand, states like Colorado rely on the use of olfactometers, which are devices used to quantify dilution of the odor needed to achieve nondetection. These devices can be useful in providing some quantification of the odor detected but still are not always a reliable method of odor detection. Another option for odor detection is the use of an odor panel, which is a group of people who are presented with various dilutions of an odor sample. Use of an odor panel has its limitations for use with cannabis odors since terpenes are adhesive and may stick to the internal surface of the sample bag, thereby reducing the sample's odor intensity. More research is needed to establish non-arbitrary odor thresholds backed by science that can be used in regulatory settings.

Due to the difficulties in accurately assessing and measuring cannabis odors, odor regulations may be more effective by requiring best management practices to control fugitive emissions; for example by requiring air tight fenestrations, pressure balancing, and HVAC systems with multiple stages of VOC control that exhaust through a vertical stack that is at least 1.5 times the building height. Requirements to create an odor control plan, a malfunction abatement plan, and recordkeeping should also be used to demonstrate that the company is maintaining best management practices.

Conclusion

Existing regulatory programs provide a solid framework for the prevention of adverse air quality impacts from the marijuana industry. Through adaptation of this framework to the cannabis industry, and proactive measures by the industry to reduce emission of air contaminants and odors, the cannabis industry has the potential to operate in a manner with a significantly reduced impact on ambient air quality.

122. Milman, Oliver, *Not so green: how the weed industry is a glutton for fossil fuels,* The Guardian (June 20, 2017), https://www.theguardian.com/society/2017/jun/20/cannabis-climate-change-fossil-fuels

WASTE

> *You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.* - **BUCKMINSTER FULLER**

Best Management Practices currently within legalized cannabis are largely focused on public health and safety while disregarding environmental impacts from the waste streams generated from industrial-scale cultivation, processing and consumerism at the national level.[123] The cannabis industry generates two significant waste streams: plant by-product and consumer packaging waste. Additional waste streams generated from cannabis cultivation, processing, and sales include spent solvents, grow media, mercury-containing lighting and ballasts, vape cartridges and batteries, and other electronic waste, or e-waste.[124] The North American cannabis industry generated greater than an estimated one million tons of waste in 2019 when the impacts from resource extraction, energy use and other subsequent waste streams are considered.[125] In order for the cannabis industry to be a catalyst for change through adopting and implementing sustainable practices, a unified and innovative vision must be employed in the development of new solutions sets and guidelines that the industry can advance into the future.

ENVIRONMENTAL IMPACTS: WASTE

50/50 Plant Waste Rendering Rule

In many states marijuana waste must be rendered "unusable" and "unrecognizable" before it is then required to be mixed with non-cannabis waste to achieve a ratio of 50% marijuana waste and 50% non-marijuana waste. While states do prescribe various acceptable amendments for mixing with the marijuana waste, cultivation sites may be unable to provide sufficient volumes of non-marijuana waste to reach the necessary ratio without adding superfluous waste or having to haul in an additional waste feedstock to augment.

Using inorganics to meet unusable/unrecognizable regulations forces waste to be landfilled, whereby the 50% organic material composition decomposes under anaerobic conditions contributing to the emissions of the greenhouse gas methane.

Plant Waste Impacts

The cannabis industry by design results in a high volume of plant waste. The potential for the federal legalization of marijuana and the recent national legalization of hemp products will contribute a substantial volume of additional residual plant waste. The current primary disposal methods for marijuana and hemp plant waste are landfilling and composting; both are linear and transportation centric methods that result in greenhouse gas emissions.. Less common plant waste disposal methods include repurposing, aerobic and anaerobic digestion, or incineration. Today, most cannabis plant waste goes directly into landfills — which is not a sustainable option.

Cannabis plant waste can be composted similar to any other green waste (under proper carbon-to-nitrogen ratios). It is best for organic processing to be done in U.S. Composting Council certified (Seal of Testing Assurance or STA) compost facilities.[126] However, this composting option has its own obstacles due to limited availability and accessibility. These certified facilities often fall outside economic or environmentally effective transport distances (typically greater than 40 miles), which contributes to environmental impacts from hauling materials (as one gallon of diesel fuel produces 22.2 lbs. of CO_2).[127] There are more than 20 states with just two or less STA certified composting facilities serving the entire state and almost ten states have zero certified facilities.[128] States such as Washington that do have robust commercial composting infrastructure have reported that even with such available services, almost 90% of cannabis green waste is still being sent to landfills. This issue is not just one of material burden to landfill operations, but the inherent anaerobic (lack of oxygen) environmental conditions

123. Peterson, Eric, *"State of Hemp and Cannabis Waste"*, https://companyweek.com/company-profile/industry-report-the-state-of-hemp-and-cannabis-waste, Nov 19, 2019. (Accessed, June 2020)
124. Kennedy, Bruce, *"Cannabis Industry Generates Tons of Extra Waste"*, https://www.leafly.com/news/industry/the-cannabis-industry-generates-tons-of-extra-waste-heres-why Nov, 4 2019. (Accessed Feb 2020)
125. Cannabis Manufacturing Report
126. USCC, "Seal of Testing Assurance" https://www.compostingcouncil.org/page/STA-Requirements (Accessed June 2020)
127. EPA, 2,778 grams x 0.99 x (44/12) = 10,084 grams = 10.1 kg/gallon = 22.2 pounds/gallon https://www.chargepoint.com/files/420f05001.pdf
128. STA Certified Compost Participants, https://www.compostingcouncil.org/page/participants (Accessed June 2020)

of landfills and the organic materials' eventual decomposition and resulting air emissions. One of the byproducts of organic's decomposition in a landfill environment is methane emissions, which are a potent greenhouse gas (GHG). In 2018, the Compost Council of Canada stated: "We believe that composting should be the preferred method to process cannabis plant residuals. Landfills emit greenhouse gases (methane) with organics being responsible for 90% of these emissions."[129] In the U.S., Municipal Solid Waste (MSW) landfills are the third leading contributor to anthropogenic GHG, methane, which has a global warming potential over 25 times that of CO_2.[130] Landfill disposal of marijuana cultivation organic by-products (*e.g.*, stalk, stem, wet whole) and post hemp extraction (raffinate) is a growing contributor to GHG emissions and their subsequent environmental impacts.

National GHG Impact of Cannabis Plant Waste to Landfill: Annual Increase of ~27,876 Metric Tons CO_2 Equivalent (MTCO2-E)

Layman's terms: The environmental impact from the volume of cannabis byproducts currently estimated to be landfilled is equivalent to the emissions from more than 6,000 passenger vehicles' or more per year.

Further development of environmentally effective management and diversion solutions for plant waste will be required to keep pace with industry growth to ensure both environmental compliance and 'industry leadership' in sustainable practices moving forward.

Single-Use Packaging Impacts

"The long habit of not thinking a thing wrong, gives it the superficial appearance of being right." -Thomas Paine, 1780

Plastics are a rapidly growing segment of MSW. Plastics are found in all major MSW categories, but the single-use containers and packaging category makes up the most plastic tonnage at over 14 million tons in 2017.[131] The current U.S. recycling model for single-use consumer plastic packaging contributes heavily to the challenge of mismanaged waste entering waterways, oceans and the environment.

According to a report by the Center for International Environmental Law, if the production and disposal of single-use consumer plastics continue on their present growth trajectory, by 2030, global GHG emissions could reach 1.34 gigatons per year—equivalent to more than 295 five-hundred-megawatt coal plants.

Besides plant waste, the other significant waste stream from the cannabis industry is packaging waste, specifically disposable packaging. Single use packaging, and "Green Washing" the name of the material composition (*e.g.,* Bio, Eco, Green, Compostable, Biodegradable, recyclable) propagates waste generation. By definition and design, single-use disposable packaging is waste.[132] The solution or problem is not about how to dispose of packaging waste (*i.e.* landfill, composting, or recycling)– the central problem is the mass production of designed obsolescence, packaging designed as a waste (*i.e.* disposables, recyclables). In working to mitigate the plastic pollution crisis, the recycling model will have a limited but important role to play in the short-term, but long-term the industry needs to create less single use packaging in the first place.

The long habit of not thinking a thing wrong, gives it the superficial appearance of being right.

- THOMAS PAINE, 1780

It is estimated that the cannabis industry will have produced 1 billion units of single-use plastic waste annually by 2020.[133]

The best thing that the cannabis sector can do to improve packaging sustainability is to move beyond recyclables and innovative reusable and refillable packaging systems that support regional and national source reduction initiatives. For instance, changing material composition to higher value resin designs could increase the amount of plastics domestically recovered. This can only work if recovery systems transition away from the current recycling model that is focused on low value single-use products and the current failed bulk & bail waste diversion model where the U.S ships recyclables to China and Southeast Asia to be processed.

Recycling is Flawed

The cannabis industry cannot continue to rely on recyclable packaging as an end solution for packaging waste as recycling does not usually prevent waste or pollution. Even if consumers attempt to recycle their packaging, most single-stream recycling facilities are not able to properly sort it due to the non-traditional sizing. Some states have legalized packaging take-back programs for consumers to bring recyclable packaging waste back to the retail location for increased bulk recycling but this also has associated challenges (storage, bailing, special pick-ups, etc.). Many of the flaws with recycling packaging are

129. Gorrie, Peter, *"Recycling Cannabis Organics"*, Biocycle, https://www.biocycle.net/recycling-cannabis-organics/ July, 6 2018. (Accessed March 2020)
130. Fact Sheet - Landfill Methane, Environmental & Energy Study Institute, https://www.eesi.org/papers/view/fact-sheet-landfill-methane April 2013. (Accessed March 2020)
131. EPA, "Plastics: Material-Specific Data" https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data (Accessed June 2020)
132. https://dictionary.cambridge.org/us/dictionary/english/disposable
133. Sanchez, Rudy, "Cannabis Regulations have Created a Packaging Waste Problem", https://thedieline.com/blog/2018/10/26/cannabis-regulations-have-created-a-packaging-waste-problem Oct 26, 2018. (Accessed Feb 2020)

outside the control of the cannabis industry. After more than 40 years of public education in recycling, developments in front-end source separation and collection, and worthy efforts to develop efficiencies in back-end material recovery facilities waste sorting, the national recycling recovery rate is still only around 30%, and is challenged by bulking and bailing an adequate product (<5% contamination) for end markets.[134] Even some of the largest, most sophisticated cities in the U.S., like Chicago, still have less than a 9% recovery rate.[135] After 40 years of collecting and sorting (specifically plastics), there is a lack of quantitative evidence that this has mitigated global materials extraction or had an impact on global GHG emissions.

The first global analysis of all mass-produced plastics ever manufactured was published in 2017 and identified and synthesized dispersed data on production, use, and end of life management of polymer resins. The analysis estimates that 8,300 million metric tons of virgin plastics have been produced to date. As of 2015, approximately 6,300 million metric tons of plastic waste has been generated, only 9% of which has been recycled, 12% incinerated, and the remaining 79% has accumulated in landfills or the natural environment. If current production and waste management practices continue, roughly 12,000 million metric tons of plastic waste will be in landfills or in the natural environment by 2050.[136] Additionally, because of unregulated waste management infrastructure, the end market waste sorting in the developing world is typically done by low-wage workers in disenfranchised communities.[137] The unwanted low grade single-use plastic packaging waste is subsequently dumped or discarded, whereby it is washed into rivers, bays, and ultimately to the ocean. China and Southeast Asian countries (where "recycled" waste is shipped) dominate the issue of global mismanaged plastic waste, accounting for over 70% of the global total.[138] Mismanaged plastic waste is defined as "plastic that is either littered or inadequately disposed of."[139] To mitigate plastic waste from entering the oceans it must be recognized that the mass production of single-use disposables and the existing diversion model for "recyclable materials" are profound contributors.

Recycling could still be part of the cannabis industry's packaging waste solution in the short-term, but not the long-term with the current paradigm of heavy sort, bulk & bail, an export intensive model. Thus, this was the impetus behind the Basel Action Network, an international organization that is confronting the prevalence of marine plastics that result from the existing global waste export diversion model.[140] Through more comprehensive Extended Producer Responsibility (EPR) initiatives, there is an opportunity for the cannabis industry to mitigate waste from single-use products for more environmentally effective standardized reusable packaging design and recovery models.

"Compostable" Packaging Impacts

The practice of composting to recover nutrients from materials such as food and yard debris is beneficial when compared with alternatives such as landfilling. Additionally,single-use "compostable packaging" is a more sustainable solution to plastics but still has its flaws. Commercial composting of organic waste streams suffers from insufficient end-markets for finished products, as well as heavy contamination and greenhouse gas emission issues.[141] Single-use "compostable packaging" also introduces a broader set of environmental impacts from the upstream processes of sourcing raw materials used to manufacture organic based packaging (*i.e.* "paper based"). The hemp industry presents an opportunity to be a sustainable source of the raw fibers needed to manufacture compostable packaging.

The Oregon Department of Environmental Quality conducted a literature review of environmental life cycle assessments that included compostable packaging and found over 1,200 comparisons involving compostable packaging over the last 18 years.[142] In the majority of these comparisons, formulating and manufacturing single-use compostable materials (and then composting them) was found to result in increased environmental impacts when compared to the use of either non-compostable materials or compostable materials processed via recycling, landfilling or incineration. A primary reason for this is the potential for increased resource burden associated with producing the necessary feedstocks used in making the different types of compostable packaging. Another is that composting, unlike other end-of-life waste management alternatives such as recycling, is a relatively inefficient method of recovering nutrients for value embedded in human-made materials such as packaging. Lastly, many 'compostable' materials fail to break down (during standard processing times) in most common industrial composting systems. This means

134. Facts and Figures about Materials, Waste and Recycling | US EPA, 2017
135. Bauer, Kelly, Chicago's Dismal Recycling Rate Targeted By Mayor Who Wants To Study How Other Cities Do It Better, www.blockclubchicago.org Jan 27, 2020. (Accessed Jan 2020)
136. Geyer, Roland & Jambeck, Jenna & Law, Kara. (2017). *"Production, use, and fate of all plastics ever made"*. Science Advances. 3. e1700782. 10.1126/sciadv.1700782.
137. McCormick, Erin, et al, Where does your plastic go? Global investigation reveals America's dirty secret, www.thegaurdian.com June 27, 2019
138. Ritchie & Roser, Plastic Pollution, https://ourworldindata.org/plastic-pollution#all-charts-preview Sept, 2018
139. Patel, Prachi, Stemming the Plastic Tide: 10 Rivers Contribute Most of the Plastic in the Oceans, www.scientificamerican.com Feb 1, 2018. (Accessed Dec, 2019)
140. Basal Action Network, Plastic Pollution Prevention, https://www.ban.org/plastic-pollution-prevention (Accessed 2019)
141. A Message from Composters Serving Oregon, www.thompsonsanitary.com 2019. (Accessed 2019)
142. Mistry M, Allaway D, Canepa P, and Rivin J. *"Material Attribute: COMPOSTABLE – How well does it predict the life cycle environmental impacts of packaging and food service ware?"* State of Oregon Department of Environmental Quality. Portland, Oregon. Nov 2018. https://www.oregon.gov/deq/FilterDocs/compostable.pdf

that the processing time and conditions required in systems such as open windrow static piles, covered static piles, or in-vessel systems are highly nuanced. Because some of these single-use products fail to break down efficiently, (including ASTM 6400[143] / 6868[144] certified products), they're required to be screened out of the bulk compost which results in a potential increase in annual operational costs in the millions of dollars.[145] Subsequently, the residual uncomposted material is landfilled where the organic based materials break down anaerobically, contributing to methane emissions, which has a global warming potential 25 times that of CO_2, and is the primary environmental problem facing our planet.[146]

"What's missing from the discussion is the impact of making these (single-use) compostable items," says David Allaway, senior policy analyst at the Oregon Department of Environmental Quality. "The fact that something is compostable is a useless predictor of environmental impact." Last year, all compost manufacturing facilities that serve Oregon stated they won't accept compostable products. "These materials compromise our programs and limit many of the environmental benefits of successful composting".[147]

Lab Waste Impacts

While the waste streams of other cannabis industry sectors may have a greater environmental impact overall, state-certified marijuana laboratories performing compliance testing produce a significant amount of plastic and chemical waste due to single-use materials. Also, with the growing popularity of Good Manufacturing Practices (cGMP) compliance, many cannabis manufacturers are building internal labs to test their own products, which means the number of labs in the cannabis industry is likely to grow.

To ensure products are accurately labeled and do not contain harmful contaminants, analysts must use disposable and single-use plastics including gloves, pipette tips, racks to hold tips, sample bags and tubes. The University of Exeter estimated that 280 scientists in its bioscience department produced 267 tons of plastic waste in 2014.[148] Based on this data, a cannabis testing lab with 15 analysts could use 1,500 - 3,000 pairs of disposable gloves in a single month. Labs are rarely able to recycle these items, both because many of them are made from a mixture of plastics and because they come in contact with hazardous materials.

Testing performed in cannabis labs can involve hazardous solvents both in sample preparation and analysis. The solvents are accumulated and then transported in trucks by third-party chemical waste companies, sometimes crossing state lines and traveling significant distances. The solvents are either incinerated or treated and/or disposed of in landfills according to strict EPA regulations.

Hazardous Waste Impacts

Some cannabis products, such as vape pen batteries, may fall into the category of being hazardous or universal wastes under state or federal law, largely due to the presence of heavy metals and their use of a lithium ion battery. The designation of being a hazardous or universal waste imposes additional requirements on how those wastes must be processed. Most notably, they cannot be sent to municipal landfills. With respect to vape pen batteries, the onus is on the consumer to properly dispose of them and yet seldom are consumers made aware that the batteries have a finite life and must be disposed of in a certain way. Neither dispensaries nor manufacturers have yet to offer meaningful take-back programs that diverts these waste streams from landfills (in large part this is because cannabis regulations in many states ban the recycling of cannabis waste). As of January 2020 Colorado regulations allow marijuana dispensaries to have take-back programs for both vape waste and packaging waste and also traditional recyclers can process this waste from the marijuana industry without a special marijuana license because only trace amounts of active ingredients remain within the material to be recycled.

The solvents used in performing cannabis extractions are also considered hazardous waste and as such must be managed under the Resource Conservation and Recovery Act (RCRA). This requires characterization of waste to determine whether it is hazardous, recordkeeping of the waste generated, and a guarantee of proper disposal.

BEST MANAGEMENT PRACTICES: WASTE

Better Management of Plant Waste

- Natural Capital - promoting regenerative models and repurposing of cannabis waste.
- On-site waste processing: Anaerobic Waste-to-Energy / Bokashi / Aerobic Digestion.
- Material management models that move beyond just the landfill diversion paradigm and composting as the default disposal solutions. Reuse and repurposing of materials vs. waste disposal.

Examples of best practices and solutions for on-site "green" waste processing consist of leveraging the embedded natural capital of stalk, stem, and post extraction plant material.

1. Integration of small-scale (1k - 10k lbs./day), On-site Anaerobic Digestion (O-A.D.) of cannabis plant waste that will generate and capture methane (CH_4) (that can be used

143. https://www.astm.org/Standards/D6400.htm (Accessed 2019)
144. https://www.astm.org/Standards/D6868.htm (Accessed 2019)
145. Boiko-Weyrauch, Anna. NPR, If it says biodegradable, it might not be compostable April 12 2019. (Accessed 2019)
146. Denchak, Melissa, Natural Resource Defence Council, Greenhouse Effect 101 July 16, 2019. (Accessed 2019)
147. A Message from Composters Serving Oregon
148. Urbina, M.A., Watts, A.J.R., and Reardon, E.E., *Nature*. 528, page 479 (2015). Labs should cut plastic waste too

as energy), CO_2 (that can be used in extraction or cultivation systems), and nutrient rich fertilizer (to be integrated back into soils or cultivation). Utilization of on-site micro-anaerobic digestion for plant waste over traditional disposal methods creates a beneficial closed-loop system, providing 100% diversion and reuse. All attributes (CH_4, CO_2, fertilizer) can be regenerated back into the business operation, allowing the business to capitalize on these embedded assets and reduce waste removal costs.[149] [150] This also supports federal, state, and local waste diversion and greenhouse gas mitigation goals. It should be noted that currently this technology is well suited for the hemp extraction processors. However, federal and state regulators would need to allow O-A.D. of marijuana plant waste to qualify as meeting 50:50 mixing rules.

2. Cannabis stalks and leftover biomass contain a wealth of nitrogen and other nutrients that can be valuable to growers. The difficulty lies in accessing those nutrients, as the fibrous nature of cannabis and its high concentration of lignin prevents the plant waste from efficiently breaking down. Utilizing a microbial inoculant specifically designed for breaking down cannabis plant matter will help growers repurpose their leftover biomass as a fertilizer, reducing their fertilizer cost, waste removal costs, while also promoting higher plant yields.[151]

Marijuana Plant Waste Mixing

A common allowable method to render marijuana plant waste unusable and unrecognizable is by mixing or grinding and incorporating the marijuana plant waste with other ground materials so the resulting mixture is at least fifty percent non-marijuana waste by volume. Material used to mix with the marijuana should be segregated into two categories: *Compostable* waste and *Non-compostable* waste.[152]

Compostable mixed waste: Marijuana waste to be disposed of as a compost feedstock or through another organic waste method (for example, anaerobic digester). This material should only be mixed with certain types of waste materials to support the most effective processing methods and mitigate contamination. Appropriate types of feedstocks that could be incorporated with marijuana plant waste include: Food waste; Yard waste; Vegetable-based grease or oils; Certified compostable materials; and other organic waste categories like these aligned with local composting technologies.

Non-compostable mixed waste: *To mitigate the environmental impacts of GHG that are the result of landfill decomposition,* all measures should be employed to prevent non-compostable material from being mixed with marijuana waste because this would require disposal in a MSW landfill. To meet 50:50 rendering, marijuana waste should not be mixed with the following types of waste materials:. Paper waste, cardboard waste, plastic waste or solvents.

Improving Consumer Packaging

Source reduction - also known as waste prevention (or pollution prevention), is the elimination of waste before it is created. It involves the design, manufacture, purchase or use of materials and products to reduce the amount thrown away. Source reduction means stopping waste before it happens. Material design and management should evolve beyond the single-use disposable packaging (e.g. recyclables and compostables). The cannabis industry should move to a reusable packaging model to eliminate waste.

Transitioning from planned obsolescence single use disposable packaging is the future of sustainability and can be achieved by:

- Waste mitigation through integrating of federal standardization and specification for reusable, and refillable packaging design -- instead of inefficient multi-state and multi-regulations that propagate single-use disposable packaging waste.
- Integrate regional "Take Back" systems. Put in place well-designed EPR schemes and/or deposit systems, in collaboration with the relevant industry sectors.
- Create structure for transparency and responsibility through EPR initiatives.
- Set packaging designs and standards that support source reduction and reuse rather than propagating waste disposal.
- Re-define what "sustainable packaging" means by promoting reusable models and educating consumers that disposable is not sustainable.

The cannabis industry can lead source reduction initiatives through more regenerative and reusable packaging designs. This is done by aligning policy and regulations with material "end-of-life" (EOL) realities, regardless of the material composition. Industry needs to align packaging design and manufacturing with use of efficient market-based technologies, in combination with regenerative material flows and economic models that support *regional processing and domestic end market demand*. Efficient resource use is not the main business driver in a regenerative model. To mitigate waste in a sustainable way, packaging in the cannabis industry should integrate some form of reusable design standardization so that energy use and waste generation are minimized while also lowering any related GHG emissions.[153]

Example of inefficiency: Expending resources, energy, and subsequent volume of waste to package just one pre roll joint in a single-use disposable tube.

149. http://blueterrawastesolutions.com/
150. http://impactbioenergy.com/about/
151. Smith, Charles, Full Circle Microbes, https://fullcirclemicrobes.com/
152. Marijuana waste disposal—Liquids and solids. Washington State, www.leg.wa.gov, WAC 314-55-097: (Accessed 2019)
153. Lovins, Hunter, et al, *"A Finer Future - Creating an Economy in Service to Life"* (2019)

Example of efficiency: The U.S. Food and Drug Administration (FDA) requires that cigarettes be sold in packs of at least 20.

Note: The above example comparison does not represent reusable package design or incorporate price equilibrium considerations.

Promoting Reusable Packaging

In an effort to integrate source reduction practices, the cannabis industry should take the lead in transitioning towards design, manufacturing, and utilization of "heritage" packaging products that are robust and last longer. The cannabis industry should incorporate use of higher value materials that support regenerative material flows for easier and more efficient regional-based reuse and repurposing. This level of material management can be achieved by utilizing some form of standardized designs that supports packaging returning back into the system through take-back and deposit programs. The result is a material supply chain powered by regenerative designs with resource inputs that are utilized in connected loops rather than consumed and discarded in linear flows.[154]

To mitigate waste, the cannabis industry should integrate reusable packaging systems, such as the circular model.[155] This represents a new model for mitigating the existing environmental impacts from resource extraction, manufacturing, and disposal of single-use packaging by ending single-use with a core focus on efficient Life Cycle Inventory (LCI).[156]

Consumer and Industry Education

Understanding two fundamental realities of material composition and Life Cycle Inventory to support best practices in source reduction and waste mitigation.

1. A compostable or biodegradable product is no more environmentally effective than a petroleum-based product if, when disposed of, the conditions are not favorable or conducive to short term aerobic biodegradation. This is the reality for commercial composting systems. It does not by default become environmentally effective and instead depends on the technology used (Aerated Static, Tunnel, Covered in-Vessel, Mass Bed, Turned Aerated, Windrow, etc.) and the regional climate conditions within which the material is processed.
2. Increasing awareness around alternative material flows and their Life Cycle Inventory will help mitigate cannabis industry organics and packaging waste streams. This is possible through education, promoting system change, advancing an industry-wide shared vision for innovation in infrastructure, technologies, and end markets that are increasingly regenerative on the regional and community level.

For greater transparency and understanding of the cannabis industry's waste streams and volumes, a federal self-reporting portal for growers and vertically integrated operators to anonymously report environmental metrics should be adopted. Material management protocols should be developed for the industry to establish how to conduct integrated reporting that combines financial and sustainability reporting. "Companies with good performance on material sustainability issues significantly outperform those with poor performance on these issues, suggesting that investments in sustainability issues are shareholder enhancing."[157]

Indoor Cultivation Waste

Indoor cultivation produces organic wastes like an outdoor setting. But it also generates significant volumes of difficult to process waste like LED lights, High Intensity Discharge (HID) Grow Lights, and Compact Fluorescent Lights (CFLs). The obvious BMP for cultivators is to grow outside, climate permitting or in a greenhouse where free passive solar energy as sunlight is available. Outdoor cultivation tends to have a smaller "waste footprint" when compared to indoor (non-greenhouse) cultivation practices. When growing indoors, operators should select grow mediums that can be reused or composted and lights that can be recycled. It is not possible to recycle rockwool, but it may be possible to include it in commercial compost depending on the facility's unique policies. Producers must first consult with their local commercial composter for guidance and approval.

Vape Waste Best Practices

Through a collaborative process, vape pen manufacturers should work with their retail partners and other stakeholders to develop closed loop systems that recover vape waste for reuse or recycling. Vape recycling programs can be supported using a deposit system where consumers will get a discount at the dispensary for bringing in a used device for recycling (like with milk bottles). In order to have a functional dispensary based vape recycling program, commonly called "dispensary take-back recycling," four things are needed:

1. Vape products designed for reuse and not disposable
2. A recycler with the capability to process vape pen components/batteries
3. Viable end market for the materials
4. Laws and regulations that allow for the vape byproducts to be recycled

Vape manufacturers should consider designing the primary body of their devices with stronger materials, ideally medical grade, which can be more easily reused or recycled. An issue for many regulators, legislators, and waste management professionals is that there hasn't been an efficient way developed that fully removes cannabis residue from vape cartridges and other

154. Lacy and Rutqvist, *"Waste to Wealth"* (5), 2015
155. https://loopstore.com/sustainability
156. https://loopstore.com/the-idea
157. Eccles & Krzus, *"Sustainability and Shareholder Value"* APPLIED CORPORATE FINANCE Spring 2015. (Accessed Jan, 2019)

concentrate containers which greatly limits how these items can be managed or recycled. In addition to designing vape devices that are easier to recycle, manufacturers should create cartridges and pods that more easily accommodate opening and cleaning.[158, 159, 160]

There are currently a few recyclable vape products on the market. Waste regulations in California and other states do not allow dispensary take-back recycling (although some operators have recycling programs that may contravene state regulations). Every state has different specifications, but in many cases their waste regulations mandate that all cannabis waste must be destroyed (rendered "unusable" and "unrecognizable") and sent to the landfill. The result is no recycling or material recovery. Colorado now does allow for dispensaries to have waste take-back programs. Under federal guidelines, there should be considerations for setting a minimum standard for product design to promote reuse instead of landfill disposal.

NCIA released a white paper in January 2020 called, "The Key to Consumer Safety: Displacing the Illicit Cannabis Market Recommendations for Safe Vaping" which focuses on preventing a repeat of the EVALI/VAPI health crisis of 2019.[161] NCIA noted that "Ultimately, one thing is clear: we must stop the flow of unregulated and untested products to consumers from the illicit market." It is important to consider that unregulated sales of products lead to an unregulated waste stream, outside of regulatory control. An approach to solving this issue could be to create a licensing system that permits the greatest number of operators to engage in the legal market, rather than creating a system of limited licenses where only a small number of legal operators may exist.

Reducing Lab Waste

To reduce the environmental impact of plastic waste, labs can decrease the amount of plastic they use by switching to glass wherever possible, and or buying consumables in bulk to avoid surplus packaging. While the lab is conducting preparation and dilution methods it can strive to use the least amount of tubes and pipette tips possible. It is difficult to reuse plastics within the lab because of contamination and sterilization requirements. For tests where complete sterilization of plastics is not necessary, labs can use washing systems, such as Grenova's TipNovus to reuse supplies like pipette tips.[162] These devices allow for pipette tips to be reused 25 - 40 times.[163] In instances where sterilization is required, an autoclave can be used if the materials used are appropriate. Often, disposable materials offer cost and time benefits at an expense to the environment (*i.e.,* single-use plastics). Labs can strive to employ materials suited for reuse and integrate processes to accommodate material reuse, such as appropriate washing and sterilization.

Another best practice is to choose consumable vendors that have recycling (take-back) programs or have zero-waste manufacturing facilities. For example, Kimberly-Clark's RightCycle program allows their customers to send back hard-to-recycle gloves and single-use apparel so they can recycle them into eco-responsible consumer goods.[164]

Further, when designing analytical methods, cannabis labs should consider greener chemistry. Testing cannabis products involves a lot of solvent extractions and liquid chromatography; both of which generate significant solvent waste. While most standard chemicals are hauled to landfills (or disposed of by incineration) can release harmful compounds into the environment, greener chemicals can degrade into non-toxic compounds or can be recovered and used again in more efficient closed loop solvent recovery systems. The solvent recovery efficiency and an estimation of fugitive emissions from any chemical process can be evaluated through a Solvent Management Plan (SMP) which is essentially a solvent mass balance exercise. The Environmental Protection Agency (Ireland) has produced an Advice Note[165] that outlines the process of solvent mass balance and fugitive emissions assessment for different licensing and compliance requirements, but as well aids in the identification of areas where solvent emissions can be reduced. Whether it is done during the design stage or in an operational laboratory a SMP can identify where actual or potential fugitive emissions occur to improve processes or reduce releases to the environment.

POLICY CONSIDERATIONS: WASTE

1. For the purpose of collecting, analyzing and publishing cannabis industry data, an integrated cannabis industry tracking system should be created. For example, a designation in the North American Industry Classification System, NAICS (Formerly SIC) could be implemented. The NAICS is a standard used for collecting, analyzing, and publishing statistical data. This would provide cannabis cultivation and processing a specific designation for tracking industry data on the federal level

158 "Jetty Gold Cartridges." *Jetty Extracts*. 6/18/2020. https://jettyextracts.com/collections/jetty-cartridges#

159 "Magic Flight." *Magic Flight*. 6/18/2020. https://www.magic-flight.com/

160 "Ember." *Ember Vapor*. 6/18/2020. https://www.embervapor.com/

161. National Cannabis Industry Association, Policy Council. "The Key To Consumer Safety: Displacing the Illicit Cannabis Market Recommendations for Safe Vaping." National Cannabis Industry Association. 1/2020. 6/18/2020. https://thecannabisindustry.org/wp-content/uploads/2020/01/NCIA-Safe-Vaping-WP_Jan27_v3.pdf

162. Grenova TipNovus Pipette Tip Washing Device. https://gcbiotech.com/product/grenova/

163. Howes, L. "Can laboratories move away from single-use plastic?" *Chemical & Engineering News. Nov 3,* 2019. 97(43). https://cen.acs.org/environment/sustainability/laboratories-move-away-single-use/97/i43

164. RightCycle by Kimberly-Clark Professional. https://www.kcprofessional.com/umbraco/rightcycle.html

165. Environmental Protection Agency (Ireland). Good Practice for Solvent Mass Balance and Fugitive Emission Assessments for EPA Licensed Sites. https://www.epa.ie/pubs/advice/air/emissions/air%20advise%20no%201.pdf (2017)

[Currently there is no designated code for the cannabis industry, therefore no data or ability to frame and evaluate effective policies].

2. Integrate a national platform for cannabis industry self-reporting. For example, Colorado is working with Cannabis Big Data on a **self-reporting web portal** that will allow for better understanding of the volume and variety of waste from cannabis and hemp across the state. This allows growers and operators to anonymously self-report environmental metrics that gauge the sustainability of their operations.[166]
3. NCIA collaboration with federal and state agencies to collect data, evaluate environmental impacts and promote compliance. An example for the industry would be to integrate a Central Agency Liaison that consists of subject matter expertise representing each crucial area of the industry (*e.g.,* Land Use/Soils, Water, Energy, Air and Waste) that guides environmentally effective and economically viable initiatives focused on addressing environmental impacts holistically and promotes change that results in a sustainable cannabis industry.
4. Incentivize regenerative systems and technologies:
    - Incentivize Regional End Market Development for reusable packaging designs.
    - Create a federal Renewable Portfolio Standards (RPS) to reflect the cannabis industry opportunity to implement technologies for waste-to-energy system integration.
    - Development of regional end market demand for diverted materials could lead to more efficient resource requirements and supply specifications that supports diverted material reuse and repurposing.
5. Incentivize extraction processes that utilize careful material management, including solvent management plans. Operators could be encouraged to develop and use solventless techniques or processes that pose less risk to the environment (supercritical CO_2 fugitive emissions may contribute to greenhouse gas emissions but may be less toxic than ethanol and hydrocarbon system byproducts). Such incentives could incorporate fast-tracked permitting or reduced licensing fees.
6. Introduce or strengthen policies to promote tax credits, tax cuts, carbon credits, green certificates, and technology innovation. Model renewable energy industry's success. This could be funded through taxes, memberships, *etc.* and integrate policies that promote funding. Tax incentives could be provided for those who integrate a system for reusable packaging, waste-to energy, take-back programs, waste mitigation, *etc.*
7. Introduce standardized design and material requirements to simplify ease of reuse, and regional regenerative material flows, and countering obsolescence single use, low value, short-cycle products. Single-use products have "waste" inherent in the design, specified for disposal. Policies must consider waste's material EOL and that the current recycling and composting systems are not adequate waste solutions, but rather propagate the linear disposal paradigm. This would mean aligning policy with regenerative material flows that promote circular economy within the cannabis industry. An example could be an industry-specific ASTM federal standard for childproof packaging and aligning requirements to mitigate both environmental impacts of material EOL and safety issues.
8. Create a national cannabis sustainable packaging certification that recognizes all solutions (recyclables, compostables, and reusables) but gives the highest value towards reusable packaging due to its environmental advantages.

The cannabis industry is uniquely positioned to carve a new path when it comes to reducing the impacts of waste by integrating models for bulk sales, long-lasting reusable designs, materials and implementing take-back/return or deposit programs for packaging. However, the industry cannot be expected to take these steps on its own. Therefore, regulations must be designed around incentivizing reduction of waste while equitably enforcing non-compliance.

E-waste recycling is not a perfect system and should be a last resort for dealing with vape waste. Manufacturers' focus should be on reducing waste at all points in the product life cycle (manufacturing, retail, and disposal). The easiest way to reduce waste is to design reusable/refillable vape devices that do not use cartridges or pods. Firefly Vapor recently launched an effort advocating to amend cannabis regulations in California, Colorado, and other jurisdictions. Their advocacy has resulted in a change in regulations and statutes in Colorado which now allows for the collection and recycling of "marijuana consumer waste."[167]

Recycling should no longer be a system for supporting mass production of plastics. Source reduction policy considerations to consider for cannabis packaging to mitigate waste for a more environmentally responsible system:

- Standardization in packaging material composition and design for both state and federally legalized markets.
- Integration of source reduction strategies that decouple from the linear single use disposable model and the massive volumes of waste it generates.
- Pursuing 'upstream' re-design strategies to reduce the volume and impacts of discarded products and materials and promote low-impact or reduced consumption of single use designs.
- Improving 'downstream' reuse and repurposing of end-

166. Peterson, Eric, Industry Report: The State of Hemp and Cannabis Waste Nov 2019. (Accessed 2019)
167. "SB19-224 Sunset Regulated Marijuana." Colorado Legislature. 5/29/2019. 6/20/2020. https://leg.colorado.gov/bills/sb19-224

of-life products and materials.

Waste Mitigation through (EPR)

Waste and pollution have historically been cheaper than responsibility. Companies and manufacturers do not bear the cost of end-of-life or disposal and there is currently no incentive to design or manufacture resource efficiency into products that contribute to circular, regenerative or reusable material flows. Faced with increasing amounts of single-use waste, many governments have reviewed available policy options and concluded that placing the responsibility for the post-consumer phase of certain goods on producers could or should be an option.

EPR is a policy approach under which producers are given a significant responsibility - financial and/or physical - for the treatment or disposal of post-consumer products. Holding manufacturers accountable for the externalities — or the costs that companies don't have to pay for, but instead pass on to the wider society — including those created by greenhouse-gas emissions; air pollution; land and water pollution; depletion of water resources; and impacts on the oceans. Assigning such responsibility could in principle provide incentives to prevent waste at the source, promote innovative product design that mitigates waste and support the achievement of regional recycling and materials management goals.[168]

Non-Compliant Hemp Disposal

Per USDA Enforcement Discretion - Interim Final Rule, the disposal of hemp crops with a THC level of over 0.3% on a dry weight basis is a controlled substance that must be disposed of onsite according to the disposal methods approved by USDA. The state, tribe or the state's department of agriculture wishing to have primary regulatory responsibility have the responsibility for establishing protocols and procedures to ensure non-compliant plants are appropriately disposed of in compliance with applicable state, tribal, and federal law. States and Indian Tribes operating under approved hemp production plans must notify USDA of any occurrence of non-conforming plants or plant material and provide the disposal record of those plants and materials monthly. There is a similar requirement for producers operating under the USDA plan. Additionally, USDA will conduct random audits of licensees to verify hemp is being produced in accordance with the provisions of the rule.[169]

Non-compliant hemp should be disked or tilled back into the soil or composted over crop burning. Hemp stems retain extensive amounts of lignin's (material that is resistant to microbial decomposition) and should be chipped or mulched into finer particles accessible to the decomposition pathways. Biomass that is exempt under the Controlled Substance Act (CSAs) guidance, when applied as a standalone amendment or when combined with other forms of organic matter promotes the liberation of macro and micronutrients in soil. Due to the limited supply of global phosphorus reserves, incorporating these organic materials back into the soil is imperative and should comply with the operational guidelines that are outlined in the respective farm's operational planning documents (e.g. Land Use Plans, Nutrient Management Plans, Crop Management Plan, Conservation Soil/Agricultural Practices).

Hazardous and Universal Waste Policy

The RCRA is a federal law that regulates solid and hazardous waste with respect to generation, transportation, treatment, storage and disposal, and is often referred to as giving environmental agencies control over waste from "cradle to grave." While RCRA is a federal law, all fifty states have been granted authority to implement the initial RCRA program. Facilities generating, transporting, disposing, treating, or storing hazardous wastes are assigned identification numbers by the EPA and the numbers are used on Uniform Hazardous Waste Manifests, which must accompany shipments of hazardous waste. Common hazardous waste generated by the cannabis industry include waste ethanol and isopropyl alcohol (ignitable wastes), acetone, and other chemicals and reagents used in quality control testing. In addition, used oil and other lubricants may be generated. Once characterized as hazardous, hazardous waste must be inventoried and restrictions may exist on accumulation of hazardous waste depending on the quantity generated. Universal waste is a category of hazardous waste that is commonly used by consumers and includes pesticides, batteries, mercury-containing equipment, and lamps. Certain states have additional categories of universal wastes, such as aerosol cans, antifreeze, ballasts, paint and paint-related wastes, and electronics. Materials managed as universal wastes can be stored for up to a year and are not required to be shipped with a hazardous waste manifest and have relaxed storage requirements.

The development and adoption of 'best practice' waste management practices in the cannabis sector represent both a necessary due-diligence and a profound opportunity for the industry to pioneer and advance environmental stewardship in industry at-large, and for the cannabis industry to differentiate itself as the leading authority on the science and implementation of environmentally sound and progressive waste solutions.

The challenge before industry leaders and stakeholders is to engage an innovative and unified vision, and to develop new solution sets and guidelines which advance the industry for posterity.

168. Organization for Economic Co-operation and Development, Extended producer responsibility, www.oecd.org (2019)

169. USDA, Rules and Regulations, Hemp Disposal Activities (2019)

CONCLUSION

Environmental Sustainability in the Cannabis Industry

As the passing of the Farm Bill is celebrated and it is anticipated that the eventual federal legalization of marijuana awaits in the near future, the cannabis industry has the opportunity to establish industry standards and operating procedures that engage with the environment in ways that serve finite resources.

While many of the policy considerations presented in this white paper are intended to be specific to an environmental media or area of focus, there are some that stand out as overarching policy recommendations for improving environmental compliance and sustainability. One main recommendation of this white paper is to develop a national platform for information sharing across the cannabis industry. This platform can serve as a place for industry to report environmental parameters, such as energy use or waste generation, and would also provide a place for regulators across all levels of government to share information and guidance. This national clearinghouse would promote coordination in the regulation of the cannabis industry and hold the industry accountable to achieving environmental sustainability.

In addition to a national platform, another broad-reaching policy recommendation is to incorporate environmental best practices and regulatory requirements into existing marijuana licensing and testing processes. For instance, environmental permitting processes could be more fully incorporated into cannabis licensing programs. Currently, these programs typically operate separately, which often results in environmental permits being overlooked until well after licenses have been obtained. This can result in delays in business operations and complicate permitting processes. When states or the federal government move to legalize cannabis, they should consider structuring licensing programs to include environmental processes from the beginning.

A third and final overarching policy recommendation is to develop incentive programs for the cannabis industry. Incentives should be made available to the cannabis industry to operate in an environmentally sustainable manner. These incentives should prioritize funds provided to businesses where barriers exist to entering the market, such as small- or minority-owned businesses. These programs can be a win-win by both promoting sustainable operations within the industry and opening up the market to a greater diversity of business operations.

As additional resources are allowed to reach the cannabis industry, more businesses will integrate sustainability into their strategic planning positioning themselves to create a dialogue with stakeholders. As a result, these companies will consistently gain the ability to anticipate and react to social, environmental, economic and regulatory changes as they arise. Despite a growing number of new technologies emerging over the past few decades, the federal legalization of marijuana and hemp is an unparalleled opportunity for the cannabis industry to emerge as the leader of environmentally sustainable practices.

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APPENDIX A
TERMS & DEFINITIONS

Anthropogenic
A term used when referring to environmental change caused or influenced by people, either directly or indirectly. Example: Fossil fuels are the largest contributor of anthropogenic greenhouse gas.

Cannabis, Marijuana, vs Hemp
High-THC and low-THC / high-CBD (or other cannabinoid content) marijuana or the industrial hemp version of the plant fall under the same species, *cannabis sativa*. For the purpose of clear terminology and communication, this paper will use the words "cannabis" when referring to both high-THC and low-THC plants. The term "marijuana" will be used when necessary to distinguish the high-THC version of the plant from "hemp" that will be used to describe the low-THC / high-CBD variety of the *cannabis sativa* (L.) plant.

Disturbance
An event or its change in intensity or frequency which alters the structure or functional status of an ecosystem. Examples of disturbances that can affect soil include drought, fire, harvest, tillage, compaction, overgrazing, or addition of pesticides.

Erosion
Soil erosion involves the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity.

Greenhouse Gas (GHG)
The greenhouse effect is a warming of Earth's surface and the air above it. It is caused by gases in the air that trap energy from the Sun. These heat-trapping gases are called greenhouse gases. The most common greenhouse gases are water vapor, carbon dioxide, and methane.

Groundwater
Water contained within the soil or deep aquifers in the ground.

Hydrologic Cycle
Also referred to as the "water cycle", this explains how water moves through either a specific area or the general cycle of water in the environment.

Infiltration
Refers to the soil's ability to allow water movement into and through the soil profile. It allows the soil to temporarily store water, making it available for uptake by plants and soil organisms.

Illegal Market
When discussing the historically illegal cannabis market (often referred to as the "black market"), terms such as prohibited market, legacy, illicit, illegitimate, unregulated and underground will be used.

Irrigation
Water applied during the cultivation of crops.

Irrigation Efficiency
The net irrigation requirement of a field of crops divided by the water wasted during the irrigation process.

Leeching
The washing out of nutrients from the soil by irrigation practices.

Life Cycle Analysis (LCA)
Life cycle analysis is a method used to evaluate the environmental impact of a product through its life cycle encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal.

Monoculture
The agricultural practice of producing or growing a single crop, plant, or livestock species, variety, or breed in a field or farming system at a time.

Permeability
In soil science, permeability is defined qualitatively as the ease with which gases, liquids, or plant roots penetrate or pass through a soil mass or layer (SSSA , 2001).

APPENDIX A
TERMS & DEFINITIONS

Potable Water
Water that is safe for human consumption.

Regenerative Agriculture
A system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale. Regeneration International defines regenerative agriculture "describes farming and grazing practices that, among other benefits, reverse climate change by rebuilding soil organic matter and restoring degraded soil biodiversity – resulting in both carbon drawdown and improving the water cycle".

Reservoir
A reserve of water either created by natural sources or artificially in the form of dams and man made lakes.

Soil Fertility
Refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions. Because a soil is fertile does not necessarily mean that it will produce high-yielding crops.

Soil Organic Matter (SOM)
The total organic matter in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the active fraction), and the well-decomposed and highly stable organic material. Surface litter is generally not included as part of soil organic matter.

Soil Resilience
The capacity of a soil to recover its functional capacity after a disturbance. More specifically, resilience refers to the ability of soil to resist or recover from an anthropogenic or natural perturbation. Most soils do not offer resistance to perturbation, but are able to recover. The extent and the rate of recovery are high for a resilient soil. Resilient soils have high elasticity and amplitude, and low malleability. Some resilient soils may also be hysteretic because of inherent soil properties that influence their recovery trajectory.

Source Reduction
The elimination of waste before it is created. It involves the design, manufacturer, purchase or use of materials and products to reduce the amount or toxicity of what is thrown away. Source reduction means stopping waste before it happens.

Sustainable
The Food and Agriculture Organization of the United Nations (FAO) defines sustainable development as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry, and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable".

Wastewater
Water discharged from a cultivation operation, usually filled with enough contaminants to necessitate treatment.

Watershed
A region's water cycle as it relates to the local environment and ecology of the area.

APPENDIX B
LAND USE AND SOIL HEALTH

Physical Properties
Soil Depths within the Root Zone – typical depths 0-6 and 0-18 inches (dictated by horizon changes) and Particle Size (% Sand, Silt, Clay), Bulk Density, Porosity

Chemical Properties
pH, Electric Conductivity (EC), Cation Exchange Capacity (CEC), Total Alkalinity, Total % Nitrogen, Total % Carbon, Organic Carbon, C:N, Organic Matter

Chemical Extraction of Available Nutrients
Nitrogen (N), Phosphorous (P), Potassium (K), Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn), Sulfur (S), Zinc (Zn)

Water Soluble Macronutrients
Calcium (Ca), Magnesium (Mg), Sulfur (S), Potassium (K), Phosphorous (P), Nitrogen-Nitrate (N03-N), Ammonium-Nitrate (NH4-N)

Water Soluble Micronutrients
Boron (B), Chloride (Cl), Cobalt (Co), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Silica (Si), Sodium (Na), Zink (Zn)

Extractable and Water Soluble Heavy Metals
Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Selenium (Se), Nickel (Ni), Zinc (Zi)

Other Elements
Other elements should be added to the testing protocol as warranted by the environmental conditions. Seek professional assistance if the land has been subjected to hazardous chemical activities or there is a naturally occurring element in the parent material (bedrock).

Water Testing
Just as soil testing is important, so is testing the source water used for irrigation of the cannabis/hemp crops. Irrigation water typically comes from an underground or off-site source. The water travels either as surface water or underground water and along its path to the farm; it can encounter different environmental conditions and it can carry contaminants or elevated salts that can be harmful to the crop if not monitored.

Water testing parameters
Conductivity, pH, Calcium, Magnesium, Sodium, Potassium Carbonate, Bicarbonate, Chloride, Sulfate, Nitrate, Nitrate-Nitrogen, Total Alkalinity as CaCO3, Total Hardness as CaCO3,

Metals and Element Analysis
Aluminum (Al), Arsenic (As), Ammonium (NH4), Boron (B), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Fluoride (F) , Iron (Fe), Led (Pb), Manganese (Mn), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Phosphorous (P), Selenium (Se), Zinc (Zn)