CANNABIS ENVIRONMENTAL BEST MANAGEMENT PRACTICES GUIDE 2022

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resource innovations

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Sue Aberle, The Health Center
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Amy Andrle, L'Eagle
Dan Banks, Lightshade
Bia Campbell, formerly of Denver Office of Marijuana Policy
Meg Collins, Good Chemistry
Courtney Cotton, Denver Office of Climate Action, Sustainability and Resiliency
Anne Marie Doyle, Nuvolution
Catherine Drumheller, Oak Services, LLC
Sandra Elkind, STO Responsible
Ben Gelt, Cannabis Certification Council
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Neil Kolwey, SWEEP
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Leslie McAhren, University of Colorado
Joe Megyesy, Good Chemistry
Sheilah Ophaug, Allay Consulting
Samantha Reifer, Scale Microgrid Solutions
Susan Renaud, Denver Office of Climate Action, Sustainability and Resiliency
Marc Ross, Needle Consultants, LLC
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Joe Sullivan, Cultivate EO
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FROM THE BEST MANAGEMENT PRACTICES COMMITTEE CHAIR

From the Best Management Practices Committee Chair:

Although unintended roadblocks and structural changes to the work group delayed the intended 2022 release of this guide we are excited to present to you what we believe to be the best version of the Cannabis Environmental Best Practices Guide yet. It is through the hard work of our volunteer committee that this guide is released yearly and we want to thank all of the contributors this year for their technical revisions and reframing of the sections to follow.

This guide has been released, revised, and refreshed over the years into the complete document you find below. Although our group started as a way to proactively embed sustainability practices into the cannabis industry, it has evolved into a network of collaborative peers that support, encourage, and implement. We at the Cannabis Sustainability Work Group pride ourselves in believing that sustainability is not just a good idea, but a *necessary* idea.

We recognize our industry is impactful and in its infancy. This guide was developed to ensure that as our industry matures, the key players are equipped and emboldened to imbed sustainability from the start. It is up to these key players to lead the charge and set an example; to prove the cannabis industry can be different from all those that came before. Our industry is pioneering indoor agriculture and it is our responsibility, that no person or company is exempt from, to do right by our environment, our ecosystems, and our planet.

It has been exciting to watch our little group of passionate volunteers blossom into a movement of industry-wide change. Over my time with the group I have seen members with little backing and little hope turn their professions into ones of impact. I have seen members improve company's practices for the better. I have seen concrete and calculable progress come from those who have dedicated their busy schedules and well earned time to making just one more effort. During the past five years, faces have come and gone, but the group's purpose has remained constant: to create a more sustainable world and an equitable industry that we can all be proud of.

I hope that you find the guide not only helpful but critical; not unrealistic but grounded; not over-reaching but doable. I hope you *have* hope for our industry and for our environment. In these endeavors, as with any that intend to create systemic change, the key to progress is not to achieve *but to strive*. We hope that you continue to strive. To strive to create something better with us.

Jake Mitchell, Senior Sustainability Program Manager
at Resource Innovations & Best Management Practices Chair

"There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace."

- Aldo Leopold

News and Updates for the Colorado Cannabis Industry:

Benchmarking Requirements Coming to Denver in 2023

All buildings 5,000 square feet and larger in the City and County of Denver are subject to the Office of Climate Action, Sustainability, and Resiliency's (CASR's) Energize Denver Ordinance to increase energy efficiency and reduce greenhouse gas emissions from buildings. Small buildings (5,000-24,999 sq. ft.) are subject to prescriptive lighting or renewable requirements (with alternate compliance options in development for cannabis growers in small buildings), while large buildings (25,000 sq. ft. and larger) are subject to the Energize Denver Performance Requirements. Large buildings where energy is utilized for manufacturing, agriculture, or industrial (MAI) purposes are currently covered under the MAI Alternate Compliance Option (ACO). Stakeholder engagement with MAI stakeholders and small building owners will be ongoing into 2023. Rules and regulations for both MAI and small buildings will be finalized by the second half of 2023. Please visit the MAI page or the Small Buildings page for more information.

MAI buildings are currently exempt from the Energize Denver Benchmarking Ordinance. However, with updated rules and regulations for MAI buildings in 2023, this benchmarking exemption for MAI buildings will almost certainly be removed. MAI buildings can start looking at the upcoming requirements for benchmarking in 2023 by visiting the Benchmarking page for more information.

Colorado Energy Office Cannabis Resource Optimization Program (CROP)

This year, the Colorado Energy Office (CEO) released the Cannabis Resource Optimization Program (CROP). The program is designed to provide eligible cannabis cultivation businesses with no-cost technical assistance, including a facility audit and analysis of previous resource use, to better understand energy and water use and identify cost-effective resource management opportunities. The free assessments are available for any cultivators who are outside of Black Hills Energy, PRPA, and Xcel energy territories.

As a follow up to the on-site facility audit, CEO is partnered with the Colorado Clean Energy Fund (CCEF) and a lending institution to provide low interest financing to help program participants implement efficiency measures. Funding is currently only available for grows outside the aforementioned utility territories but will be available for all Colorado Cultivators this summer.

You can apply for the program: here.

Governor Polis Signs Extended Producer Responsibility Bill:

In June of 2022, Governor Jared Polis signed HB22-1355, authorizing a statewide Extended Producer Responsibility (EPR) program to expand recycling services across the state of Colorado. Set to launch in 2026, the program will establish the nation's first statewide recycling system for consumer packaging and printed paper that is fully producer-funded and operated. It is highly anticipated as a comprehensive strategy to address the state's abysmal recycling rate by fundamentally transforming Colorado's recycling system:

- Administered by a producer-run nonprofit, known as a Producer Responsibility Organization (PRO)
- Companies that sell printed paper, cardboard, metal, glass, and plastic packaging in the state will pay "eco-modulated" fees to the PRO
- The PRO will manage producer funds and reimburse public and private service providers for collecting and processing recyclables.

Although cannabis packaging is currently exempt from Colorado's new EPR bill, the CSWG anticipates that the policy will have a significant impact on product packaging design/sourcing decisions at cannabis companies operating in Colorado. In combination with similar policies in other states, it is likely to more broadly influence the trajectory of packaging and materials management in the cannabis industry.

You can find more information on the bill: here.

City of Denver Launches Cannabis Cares Program

A new program with the City of Denver launched this spring that recognizes cannabis companies who go above and beyond for their community. This program aims to recognize cannabis companies by awarding them "badges" in the areas of Diversity and Inclusion, Social Equity, Sustainability, Community Engagement, and Contracting with Minority Owned Businesses.

You can find more information on the program: here.

INTRODUCTION

CANNABIS SUSTAINABILITY SECTOR OVERVIEW

Under the leadership of Mayor Michael B. Hancock, Denver has committed to reducing greenhouse gas emissions (GHG) 80 percent below 2005 levels by 2050 (80x50 Climate Goal). Commercial buildings represent 35 percent of citywide emissions, and — as cannabis businesses occupy an increasing amount of commercial building space — the cannabis industry plays an important role in helping the community meet its emission reduction targets.

National and international attention is increasingly being focused on the sustainability impacts of the cannabis industry in states where cannabis has been legalized. Some cannabis businesses have initiated sustainability programs to reduce environmental impacts and have partnered with local communities for environmental and social good. However, because sector-wide baseline sustainability metrics are not currently available, overall industry sustainability performance remains unverified — leaving public perception open to individual interpretation.

In 2016, Denver Department of Public Health & Environment collaborated with local cannabis industry representatives, sustainability practitioners and regional stakeholders to create the Cannabis Sustainability Work Group. The group's mission is to promote sustainability in the cannabis industry through education, the development and dissemination of best practices,

At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

In 2018 the non-profit FAAAT (For Alternative Approaches to Addiction, Think and do tank) released a document titled "Cannabis & Sustainable Development" outlining "recommendations for the implementation of Cannabis policies aligned with international Human Rights Standards, the 2030 Agenda for Sustainable Development and the 2016 UNGASS outcome document." This document shows not only how cannabis can align with the above development goals but also how cannabis and hemp industries can contribute to goals 1 - 5, 7 - 13, and 15 - 17.

In march of this year the Securities and Exchange Commision announced the creation of a Climate and ESG Task Force that will be developing and implementing policies related to ESG activities of publicly traded companies. This will apply to cannabis companies already trading publically or wishing to trade publicly in the future. This recent development shows that ESG and Sustainability reporting is becoming more commonplace and is quickly becoming mandated through multiple levels of governments including cities, states, and federally.

The cannabis industry has the opportunity to position itself as a contributor to climate and sustainable goals while also keeping up with incoming regulations that relate to environmental impacts. This document's intention is to help cultivators and other forms of cannabis businesses understand and mitigate their impact with the most up to date technologies and methodologies

BEST PRACTICES GUIDE PURPOSE

The Guide provides recommendations for cannabis-specific sustainable practices based on an analysis of existing data from individual case studies and regional and national performance standards as well as individual technical expertise. The purpose of the Guide is to provide cannabis cultivation businesses with a snapshot of relevant sustainable practices and a starting point for process optimization techniques that facilitate continual improvement. Much of the Guide focuses on cultivation facilities because of the greater use of resources, utilities, and chemicals, as well as the greater potential for impacts to the environment. Recommendations are included for manufacturing and dispensaries where relevant. In addition, the recommendations were designed and written with Denver's energy and climate sustainability goals in mind, including the 80x50 Climate Goal.Alignment with regional stakeholders is critical to partnering for success in pursuit of social, economic and environmental sustainability. Longevity is key, and collaborating for healthy communities and holistic growth will ensure strong performance in the short and long term.

LIMITATIONS

This 2022 release is the sixth version of the Guide, which was originally released in 2017. The authors recognize that sustainability encompasses many topics, not all of which are addressed by this document. The Work Group strives to add timely and relevant new content annually.

CANNABIS CULTIVATION SIGNIFICANT ASPECTS AND RELATED IMPACTS IN DENVER

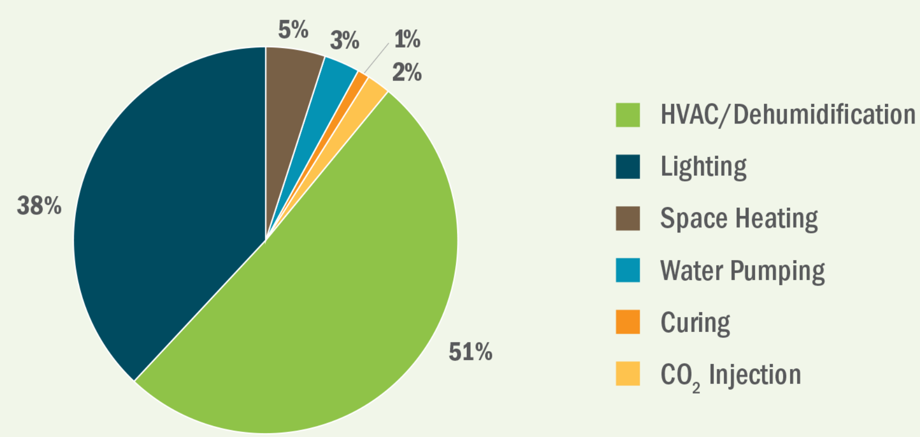
The Denver 2020 Sustainability Goals, as well as the 80x50 Goals mentioned on the previous page, help guide sustainability work in the City and County of Denver. The cannabis industry's significant environmental aspects and related impacts are listed below and highlighted throughout this document.

ENERGY
EXECUTIVE SUMMARY

Depending on the environment, growing cannabis can be a very energy-intensive process. This energy consumption is the leading driver of greenhouse gas emissions for the industry and is one of the biggest opportunities for growers to cut costs, critical in a market where decreasing wholesale prices and increasing competition are putting pressure on grows to be more cost effective to stay in business.[1]

The best time to incorporate energy efficiency and renewable energy measures into a cultivation is before it is built, but there are plenty of retrofit actions that growers can take to improve their energy usage in established facilities, as well.
During the process of designing a cultivation, one of the most immediately impactful actions one can take to reduce energy costs is to grow in a greenhouse or outdoors. However, there are important economic and risk tradeoffs with these options — such as having limited outdoor growing seasons in Colorado and the more complex architecture of a greenhouse — that must be considered when weighing how and where to build your grow.[2]

Figure 1[2]: End Use Electricity Consumption for an Indoor Grow



As shown by the above chart, lighting and HVAC are the largest loads in a typical indoor cannabis facility. For growers looking for low-hanging fruit in existing or new-build indoor facilities, tackling the efficiency of your lighting and HVAC systems is the easiest and impactful first opportunity.

Best management practices that will be covered in this report include *(in order of appearance):*

- Measurement and Verification
- Scheduling
- Lighting
- Greenhouses
- Hvac/Dehumidification and Odor Control
- On-Site and Off-Site Power Generation

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[1] *Hood, G. (2018) Colorado Public Radio, Nearly 4 Percent of Denver's Electricity is Now Devoted to Marijuana*

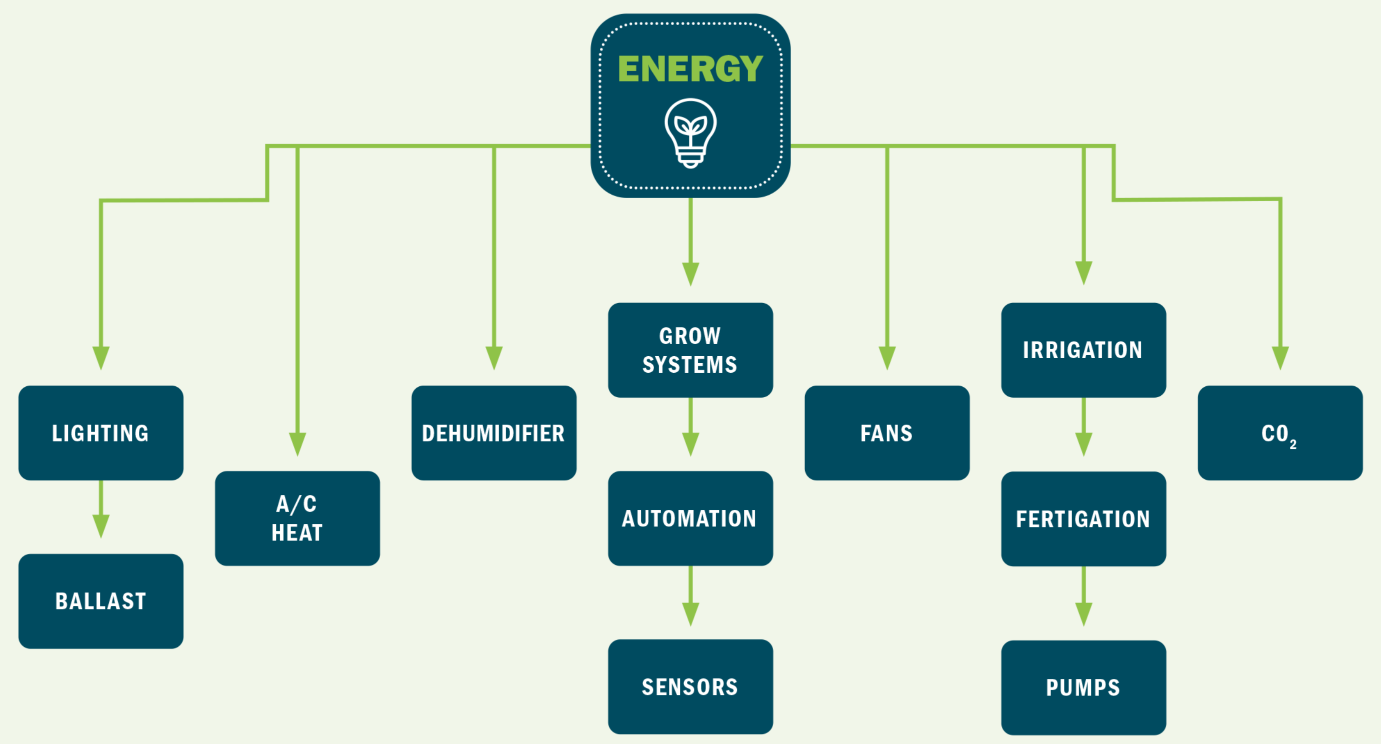
[2] *Kowley, N. (2017) SWEEP, A Budding Opportunity: Energy Efficiency Best Practices for Cannabis Grow Operations*

ENERGY EFFICIENCY & MANAGEMENT

OVERVIEW

Indoor cannabis cultivation is a resource intensive process with energy demands as the greatest contributor to the industry's environmental footprint. While growing cannabis in a controlled indoor space leads to more consistent year- round production, high energy costs and increasing price competition are pushing cultivators to get familiar with the energy impacts. Decisions relating to cultivation facility design should be driven by location specific metrics and cultivation processes. High energy use and the associated air quality and emissions contribute to negative public perception; therefore, active energy efficiency efforts can help cannabis businesses create positive improvements within communities.

Figure 2: Primary Electricity Use for Indoor Cannabis Cultivation



There are three primary reasons why cultivators should look to reduce energy profiles:

1. **ECONOMIC COMPETITIVENESS**
Energy use represents a significant portion of a cultivation facility's total operating budget. As the industry continues to mature in Colorado, the market is becoming increasingly price competitive. Organizations that reduce energy consumption, and thereby energy costs, will be better situated to succeed in this increasingly competitive market.

2. **COMMUNITY RELATIONS**
As the cannabis industry continues to grow, the electric demands of cultivation facilities could potentially lead to grid outages that affect the local community. For example, Oregon's Pacific Power has attributed seven minor community outages to grow operations.

3. **ENVIRONMENTAL IMPACT**
Electricity production is responsible for approximately one third of total greenhouse gas emissions in the United States. Over the past decade, various efforts to mitigate climate change have resulted in national electric demand remaining flat (zero percent growth).

In contrast, Denver's electricity consumption has continued to increase over the past several years due to a variety of factors, including overall community growth. Electricity use from cannabis cultivation and infused products manufacturing grew from about 1% to about 4% of Denver's total electricity consumption between 2013 and 2018. While there is no singular solution for cultivators looking to reduce facilities' energy profiles, the listed best practices are intended to provide a framework by which organizations can begin to develop a comprehensive energy management plan.

ELECTRICITY USE

2013-2018

ELECTRICITY USE FROM CANNABIS CULTIVATION AND INFUSED PRODUCTS MANUFACTURING GREW FROM ABOUT 1% TO ABOUT 4% OF DENVER'S TOTAL ELECTRICITY CONSUMPTION BETWEEN 2013 AND 2018.

MEASUREMENT & VERIFICATION

PROCESS DESCRIPTION

You don't know what you don't track. It is important for growers to understand and know how their facility uses energy in order to evaluate opportunities for improvement. Developing an appropriate M&V process will depend on both facility-specific factors (size, existing infrastructure, geography, etc.) and an organization's specific economic and sustainability goals· The following best practices are intended to provide a starting point for facility managers.

METRICS

There is currently a paucity of relevant, high quality energy data in the cannabis industry. Cultivators should measure and share facilities' energy usage data to make more strategic equipment and process decisions as well as to contribute to an understanding of the current state of the industry. One benchmarking tool is Resource Innovation Institute's Cannabis PowerScore.

Recommended metrics to track include:

Table 2: *Key Metrics to Track*

METRIC	DESCRIPTION	UNITS	NOTES	AVERAGE RANGE
Lighting Yield per Watt	Used to compare lighting technologies and strains.	grams/Watt	Measure grams of flower and trim in dry weight. Use lighting wattages, including ballasts. Measure over one grow cycle and annually.	Overall average 1.0 g/W
Total Energy Efficiency	Identifies total production efficiency; helps identify trends in building.	grams/kWh	Measure monthly and annually Use total kWhs for building.	Total dried product weight ÷ kWh/cycle = Yield per kWh
Space Utilization	Demonstrates if the cultivation space is being maximized for production.	grams/sqft	Use square footage of cultivation space only.	39.5g/sq. ft.
Lighting Intensity	Measures whether the lights are providing the desired photosynthetic photon flux density (PPFD); can help identify correct time to replace lights.	$\mu mol/m^2/s$	Measure at canopy. Measure for each type of lighting, for each stage of growth.	Refer to Table 3: Lighting Technologies for Cannabis Production
Daily Light Integral	Measures the daily accumulation of photosynthetically active radiation (PAR) spectrum light reaching the plants.	$mol/m^2/day$	Formula: $\mu mol/m^2/s$ (or PPFD) x 3600s x photoperiod (hr/day) / 1,000,000	Denver Outdoor Avg. Winter 15-30 $mol/m^2/$ daySummer 25-45 $mol/m^2/day$
Load Factor	Used to manage peak power demand; higher Load Factor reduces cost of energy.	kWh / (peak kW * days * 24 hours per day)	Use monthly electricity figures. Days equals days in billing period.	<0.60 = poor 0.60 - 0.75 = fair >0.75 = good

GUIDANCE ON COLLECTING DATA

Three levels of data, in order from least granular to most, to consider are:

Level 1 — Properly interpreting and recording

Level 2 — Requesting utility interval data, if available.

Level 3 — Installing data loggers at the building or sub-meter level.

Utility bills contain great information but are often poorly interpreted and recorded. A facility manager should break out total energy used (kW), peak demand (kW), consumption based charges, demand-based charges, and fees and taxes for each bill. Inputting this info (along with water and production data) into a standardized spreadsheet should take only a few minutes each month. **Here is a free data tracking spreadsheet template to help you get started.**

OBTAINING BUILDING DATA FROM XCEL ENERGY

Energy usage data can pertain to electricity, natural gas, steam, fuel oil, diesel, on-site solar or any other energy source. The data must cover consumption from January 1 through December 31 of the previous year. Consumption data can be collected through an Xcel Energy account, a natural gas supplier account or from past bills. Xcel Energy's My Account portal is a helpful online tool for obtaining monthly use figures and annual totals.

Xcel Energy has developed a data access portal that allows tenants and building owners to automatically receive aggregate energy consumption data imported directly into ENERGYSTAR Portfolio Manager accounts. ENERGYSTAR Portfolio Manager accounts must be set up prior to beginning the application. Visit Xcel Energy's Benchmark Guide to learn more about energy benchmarking.

- Cultivators can also install equipment to log energy data. This can be done concurrently with a Building Management System (BMS)/ Energy Management System (EMS) installation, or can be done solely for logging energy data. Installation will allow for capturing higher frequency, submetered data that can provide a great deal of insight into how a facility is using energy.

When properly configured and monitored, a robust BMS/ EMS can quickly alert a facility manager about broken, malfunctioning or needed maintenance, such as filter replacements, which can prevent energy waste, equipment failure, power loss and even loss of crop in the event of malfunctioning environmental controls. See below for more information on BMS/EMS systems.

BUILDING MANAGEMENT SYSTEMS/ ENERGY MANAGEMENT SYSTEMS

Facility managers looking for a comprehensive data solution should consider installing a BMS or an EMS. As there are many different types of BMS/EMS systems available on the market, the U.S. Department of Energy has developed a suite of Specification and Procurement Support Materials to help managers identify the right fit for each facility.

BUILDING MANAGEMENT SYSTEMS/ ENERGY AUDIT/ENGINEERING ASSISTANCE STUDY

Performing a comprehensive energy audit or Engineering Assistance Study (EAS) is often the quickest way to acquire the insights needed to develop an effective energy management strategy, but enacting this process typically requires partnering with a qualified third-party provider. Xcel's Energy Analysis Program is a good starting point for facility managers that are interested in pursuing these options and also offers several financial incentive programs to reduce an organization's out-of-pocket costs. It would benefit the operator to install submeters inside the building to collect power-usage data, such as those manufactured by e-mon or Power TakeOff. Submeters measure the power used in a specific area and/or by certain pieces of equipment, giving a more detailed picture of how and where energy is consumed in the building.

PORTFOLIO MANAGER

Because of Denver's Benchmarking Ordinance, Denver commercial and multifamily buildings that exceed 25,000 square feet are required to analyze and report their energy performance using Energy Star's free Portfolio Manager tool.
For how to set up an account, cannabis business owners and/or facility managers can refer to the City of Boulder: How-to Guide for Medical and Recreational Marijuana Business License Energy Reporting and Carbon Offset.

ENGAGE SPECIALISTS

An energy specialist, such as a Certified Energy Manager (CEM), Certified Energy Auditor (CEA), Building Energy Assessment Professional (BEAP), and others, can perform any of the above tasks for a cultivator, particularly if a grower should seek out an experienced contractor to install submeters. Interested cultivators should consider the resources available from a local trade group or association such as Rocky Mountain Association of Energy Engineers, or Rocky Mountain ASHRAE. Additionally, a specialist can perform an on-site energy audit or engineering assistance study (EAS) to reveal and evaluate energy savings opportunities. As mentioned below, Xcel Energy offers related rebates and incentives.

As the cultivation industry matures, the availability of energy, water, lighting and space efficiency metrics as related to production data becomes imperative. Individual cultivators — as well as the industry at large — should have intimate knowledge of these measures and of how particular technologies and behaviors affect resource and production efficiency.

Cannabis Specific Colorado Energy Programs:

PRPA Indoor Agriculture Energy Efficiency Program

- Free energy assessments and rebate assistance for grows in Platte River Power Authority's territory.

Black Hills Cannabis Energy Efficiency Program

- Administered by Cultivate Energy Optimization, this program will provide free energy efficiency assessments to cannabis cultivators in Black Hills Territory and offers 1-on-1 assistance for rebates and incentive procurement.

Xcel Energy Strategic Energy Management Program

- Only available to cultivations using over 1.5 GWh per year. Administered by Resource Innovations and Cascade Energy; this program not only offers both a free energy efficiency assessment and rebate assistance but is intended to build good energy management practices into the business by working with the company management and operations. Strategic Energy Management is a more holistic approach to energy efficiency and also includes enhanced incentives for cultivations in the program.

Xcel Energy Business Energy Assessments Program

- Free energy assessments and rebate assistance for small to medium sized grows in Xcel Energy territory. Administered by Franklin Energy, this programs provides a report of the buildings current level of efficiency and opportunities for improvement.

Colorado Energy Office Cultivation Resource Optimization Program (CROP)

- A free program for rural cultivators through the Colorado Energy Office to assess energy and water efficiency. This program also offers benchmarking assistance, renewable energy assessments, and rebate assistance.

SHOULD I VEG UNDER A 24HR OR 18:6 PHOTOPERIOD?

Growers often ask this question when designing their operation, but what is the right answer? The truth is, both work! By keeping the lights on for 24 hours a day, plants are exposed to 33% more light than an 18:6 schedule. This means more light for photosynthesis. However, regular periods of darkness (lights off) are important for other plant functions. Plants actually use nighttime to take in oxygen (just like people) and burn the glucose that they stored up during the day to grow in a process called cellular respiration. Ultimately, the tradeoff between maximizing light during 24hr versus giving plants a break to use their stored energy in an 18:6 schedule more or less cancels out. The most sustainable strategy from an energy point of view is to employ an 18:6 schedule. This will yield happy and productive plants while keeping your energy bill lower at the same time.

SCHEDULING

Cultivation facilities in the Denver metro area receive electric service from Xcel Energy and are billed according to total electricity consumption (kWhs) and peak demand (kW). How a facility is operated can have significant impacts on peak demand and the actual cost of energy. Managing the operation of various systems within the facility by setting staggered room schedules can significantly reduce energy costs and negative impacts on the power grid. Reducing peak demand also creates community-level environmental benefits, because energy providers utilize "peaker plants" that are generally older, less efficient and have higher emissions to provide additional electricity during times of high demand.

TIME OF USE

Many utilities are moving toward billing customers with varying rates based on the time of day they use electricity. Xcel Energy does not yet charge time-of- use billing for Secondary General rate customers (the rate category most cultivation facilities fall under). Kilowatt hours cost the same day or night, but energy can be saved by running extra equipment during cooler evening periods. If it is necessary to operate extra grow rooms simultaneously, cultivators should try to schedule those periods overnight when outdoor air temperatures are lower. This can reduce the cooling load during these times of extra production, thereby reducing energy use and saving money.

PROCESS DESCRIPTION

Energy-efficient technologies can improve both the total energy use and peak demand of a facility. Operating schedules, with the support of Smart or Intelligent Systems or Technology, play a critical role in minimizing peak demand over the month. Grow rooms, particularly in the flower stage, represent the largest sources of peak energy needs when factoring in lighting, cooling, ventilation, and odor controls. All grow room schedules should be staggered over the 24-hour period so the minimum number of rooms run concurrently. Any overlap of schedules, even for one hour or less, leads to higher spikes in peak electricity demand and higher costs.
Similarly, other energy-intensive processes, such as extraction, cleaning or electric heating, can be staggered and scheduled carefully with lighting cycles to minimize peak power demands.

LIGHTING

Lighting can be the most energy-intensive component of the cultivation environment. The design of a facility's lighting system and the types of lamps utilized in the grow process will affect both crop yield and quality. Furthermore, the lighting selection will have a substantial impact on the size of the HVAC system and the need for CO_2 enrichment and is therefore a significant driver of overall energy use in the facility. Employee health and safety should be considered in the design and delivery of indoor lighting, as well.

PROCESS DESCRIPTION

Due to the operational impact of lighting choices, a host of production-related factors must also be considered as cultivators select the appropriate lighting technology.

Lighting technologies should be measured in terms of photosynthetically active radiation (PAR), or the measure of the specific light spectrum characteristics. PAR accounts for the spectrum of light between 400 nanometers (nm) and 700nm, most of the light spectrum used for photosynthesis. Infrared (IR) and ultraviolet (UV) light spectrums fall outside of PAR readings and thus do not register with standard light spectrum measuring equipment. IR and UV light are actually classified in a range of light referred to as biologically active radiation (BAR). The concept of BAR is still new, and so for the purposes of this guide, the focus will be on PAR. The intensity of the lighting system or photosynthetic photon flux density (PPFD) is measured in micromoles per second per meter square (μmol/s-m2) and should be carefully monitored for optimal plant growth. This can be measured using a light meter with a quantum sensor.

LUMENS ARE FOR HUMANS

If you're familiar with lighting measurements, you have probably noticed that this document does not discuss some of the attributes usually important for interior lighting. The factors that determine light quality for plant growth are different from those to consider for working and living spaces. Measurements that are largely irrelevant for cannabis lighting include lumens, footcandles and lux.

EQUIPMENT OVERVIEW

Historically, the top three lighting technologies used have been T5 fluorescent, metal halide (MH) and HPS. There are now several different options to choose from, including (but not limited to): LED, light emitting plasma (LEP), CMH, and various combinations of these. LED adoption by cultivators appears to be growing. If you are considering an LED-lit grow environment, a peer-reviewed resource that may be helpful is Cultivating Cannabis with LED Lighting — A Primer: What You Need to Know.

Many of these lighting types have specific spectrums of PAR and are generally used for one stage of growth or another. Prescribing specific heights above canopy for lighting systems is not recommended, as PPFD, age of fixture, bench height and plant height will all dictate the location of the fixture.

Fixture design and optics will also dictate where the light lands, and at what photon density at various heights, so height and location of fixture should be decided on with the help of the manufacturer to optimize photon density and limit waste. There should be a perpetual review of micromole levels for cannabis and the need to adjust fixtures with the aid of a good light meter to obtain the necessary PPFD.

Lighting fixtures emit energy in the form of light, as measured in PAR or photosynthetic photon flux (PPF), and reflectors direct the light toward the canopy with varying levels of sophistication and success. LEDs tend to be directional in nature and thus generally do not require reflectors. Knowing the lighting output of a fixture alone without understanding, properly configuring and measuring the lighting intensity at the canopy will result in suboptimal lighting conditions. Below are general uses and specifications for each of these technologies [3, 4].

LIGHT TECHNOLOGY	GENERAL USE/ GROWTH STAGE	SPECTRUM	RATED LIFE IN HOURS	INTENSITY* IN PPFD	EFFICACY IN MOLES/J
T5/T8 Fluorescent	Plant propagation — mothers, clones and early veg	Broad spectrum with ability to select different color "temperatures"	20,000	150 - 500	0.84 (T8)
Metal Halide	All stages of growth (most commonly vegetative)	Broad spectrum with blue and green peaks	6,000 - 15,000	500 - 800	TBD
Ceramic Metal Halide	All stages of growth	Broad spectrum	20,000	800	1.46
High Pressure Sodium (single-ended)	All stages of growth (most commonly flower)	Broad spectrum with yellow and red peaks	5,000 - 20,000	700 - 900	0.94-1.34
High Pressure Sodium (double-ended)	All stages of growth (most commonly flower)	Broad spectrum with yellow and red peaks	5,000 - 20,000	700 - 2,000	1.70-2.2
Light Emitting Diode	All stages of growth	Broad spectrum or Single wavelengths with ability to fine tune colors, UV/Far-red options	50,000	up to 1,500	1.70 - 2.7
Light Emitting Plasma	All stages of growth	Broad spectrum plus UV	30,000	700 - 900	1.00

**Intensity is measured at manufacturer's recommended mounting height.*

***Times listed are the time it takes to reach 70-90% of original output, depending on the number listed by the manufacturer. Lights will sometimes need to be replaced before this time to maintain optimal performance.*

BEST PRACTICES

SYSTEM DESIGN

When designing for indoor cultivation, it is important to identify and understand target light levels for optimal growth. The correct measurement for obtaining best results is PPFD measured at the top of the canopy. Once an operator has determined the target PPFD, the cultivator should work with an engineer or vendor to design the system around the target. If a manufacturer cannot assist in the design and technical review, the cultivator should consider seeking a more capable vendor, or be sure to have an appropriate consultant on the team. An important consideration when designing a lighting system is PPFD uniformity. Ensuring crops receive uniform light intensity will help ensure that the crop grows uniformly. Deficiencies in light intensity often occur at the edges of cultivation spaces, such as aisles and walls. These areas often produce decreased yields due to a lack of light. Lighting vendors should provide light plans that at the very least show minimum, maximum and average PPFD of the designed area. PPFD uniformity can be improved by choosing the proper reflector type when using HID lighting, or in general by increasing the density of light fixtures. Further efficiency can be gained by using reflective coatings and paints on walls, floors and equipment to direct photons back toward the crop. In greenhouses, sensors can be used to monitor light during the day and turn lights on and off based on the amount of sunlight and the target PPFD. This is a great way to get the most out of a crop while trying to minimize electricity use.

MAXIMIZING PRODUCTION AND EFFICIENCY

Racks

Many cultivators are moving to tiered production on vertical racks or shelving. This strategy is most common in vegetation rooms where plants are smaller and require lower light intensity. Fluorescent lights or LEDs are typically used in these stacking situations because they radiate less heat and can be placed closer to plants. A common question is, “How far away from the canopy should lights hang?” While each light is different, the most important factors to consider when hanging lights are the temperature of the canopy and how many micromoles are hitting it. Ensuring the plants are consistently receiving the appropriate micromole level of lighting and the appropriate temperature level is essential for efficient growth.

Pruning

Pruning is important to maximize production. Some plants may need to be topped in the vegetative stage to keep them short and bushy. Light can only penetrate a portion of a dense canopy. Taller plants take more time to grow and ultimately produce less yield per kWh.

For these reasons, it is important to prune plants multiple times throughout the growth cycle. Typical pruning activities consist of pruning off all underdeveloped branches on the bottom third of the plant and removing large leaves that are either blocking light or not receiving light. While sometimes counterintuitive, by removing plant material, pruning allows the plant to redirect resources from underdeveloped areas to parts of the plant that will ultimately increase the overall yield.

GREENHOUSES

Greenhouses will continue to take over a large portion of the cannabis industry as regulations become more favorable. Any expansion plans should at least take into consideration greenhouse production, as it can be a much more sustainable approach although results will vary significantly based on location and design choices. With greenhouse production, lights will be needed only occasionally for supplemental light. Weather stations wired to a quantum meter should be used to ensure lights are only activating when the meter dips below the minimum micromole target. These weather stations allow for the most efficient use of electricity.

When designing greenhouse cultivation facilities, many of the system designs with regard to lighting will be different when compared to indoor cultivation. Greenhouse lighting is still based on desired PPFD, but must take into consideration how much natural light/sunlight will be obtained. Light fixture count will undoubtedly decrease in most geographies compared with indoor operations, as the lights will be used only to supplement during periods of low sunlight levels. Another aspect of greenhouse lighting system design is controllability. Many light fixtures and associated ballasts or drivers have the ability to be dimmed. There are times in both stages of growth that the plants may desire a light level lower than the full output. Therefore, cultivators can reduce energy consumption with a dimming control system. A control system can also stagger the power up and power down of any room and can help prevent unnecessary power spikes and potential damage to electrical equipment.

SEE ALSO: Appendix B: Greenhouses

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[3] *Neil Yorio. (2014) Towards Sustainable Lighting For Commercial Cannabis Production. Biological Innovation and Optimization Systems (BIOS)*
[4] *Jacob A. Nelson and Bruce Bugbee. (2014) Economic Analysis of Greenhouse Lighting: Lighting Emitting Diodes vs. High Intensity Discharge Fixtures. PLOS One.*
Additional References: Zhang, H., Burr, J., & Zhao, F. (2017). A comparative life cycle assessment (LCA) of lighting technologies for greenhouse crop production. Journal of cleaner production, 140, 705-713. doi: 10.1016/j.jclepro.2016.01.014
David Katzin, Leo F.M. Marcelis, Simon van Mourik, Energy savings in greenhouses by transition from high-pressure sodium to LED lighting, Applied Energy, Volume 281, 2021, 116019, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2020.116019.

TRELLISING

Trellis nets should be used in most grow systems to support plants as they flower, as well as when they spread branches to increase light penetration. Cultivators should install trellis netting in the first week of the flower stage before plants stretch. Consider using trellis nets that are made of natural fibers and can be composted over landfilling synthetic fibers. Installing low trellising early will help keep the plants stable and support heavier bud development. Branches should be spread and placed evenly through the holes in the trellis netting to maximize benefit. Often multiple trellises will need to be applied to the same crop over the course of flowering, depending on the size of the plants.

ADJUSTABLE LIGHT FIXTURES

It can be beneficial to have adjustable ratchets on the light depending on the technology, layout and manufacturer's recommendations. Having the ability to move the light closer to shorter plants can greatly increase the level of micromoles the plant receives. It can also be helpful to pull the lights up and away from taller plants to prevent burn. Cultivators should be sure to use non-combustible cables or chains when using adjustable lighting fixtures

LIGHTING MAINTENANCE & REPLACEMENT

Proper maintenance of lighting and lighting components is important for performance and efficiency. A dirty optic lens or reflector could reduce performance by more than 10%. Different lighting technologies have different maintenance considerations.

Bulbs: Cultivators should make sure lights are unplugged and have had at least 20 minutes to cool before cleaning or replacing. Using glass wipes to wipe down the bulb and lens is advised, if applicable. Cultivators should wipe down lights once every two months or between harvests, but should not wipe the base of the lamp or the socket. Most manufacturers recommend replacing bulbs every 12 months, along with the reflector. However, bulbs used on a 12 hours on/12 hours off ("12/12") schedule will typically have more rated life hours remaining after one year. Tracking micromole levels at the canopy level will ensure the proper amountof photons is hitting the plants and will help quantify CO2 enrichment needs. Tracking light levels and only replacing bulbs or lenses when they are underperforming is a more sustainable approach
.
Ballasts: While magnetic ballasts should be replaced every two to three years because of decreased efficiency, electronic ballasts can often perform eight to 10 years. Buying a light once consisted of purchasing a bulb, ballast and reflector separately. However, most new technology includes an electronic ballast with the reflector, so no choice needs to be made.

Magnetic: Magnetic ballasts preceded electronic ballasts, and are heavier, less efficient, and noisier than electronic ballasts. However, they may come with a longer warranty than electronic ballasts, and are less expensive and easier to repair.

Electronic: Electronic ballasts have sensitive circuitry that is more difficult to repair than magnetic ballasts. Many electronic ballasts have dimmable options that can help put less light on the plants during sensitive stages of growth. The dimmable option can also be helpful in controlling the room temperature in extreme weather conditions. As mentioned above, the electronic ballast is more efficient, creates less heat and noise, and typically lasts longer than a magnetic ballast. RFI (radio frequency interference) has been a problem with older electronic ballasts, but manufacturers have been working hard to correct that deficiency.

Cords/Connection: Cultivators should thoroughly check electrical cords for any damage, cuts or abrasions that could affect performance. Also, cords should be inspected for secure connection at the outlet as well as the fixture.

LED

Optics: Some LED manufacturers will utilize a glass or plastic optic over the diodes. These optics should be cleaned every two months with a nonsolvent cleaner and nonabrasive microfiber cloth.

Diodes: Top-of-the-line diodes are rated to maintain up to 90% of their output for 50,000 hours. That's over a decade on a 12:12 schedule (a grower will need to consider if 10% loss of light is acceptable). However, they are still relatively new, and the technology is still improving. Even if the diode is capable of lasting 50,000 hours, drivers would also need to last that long, and consideration would need to be taken for how often the optic lens would need replaced.

Fans: Some LED fixtures also include cooling fans. Most advanced LED manufacturers build lights without fans. These fans have moving parts that can fail and may need to be replaced. Cultivators should look for wet location-rated fixtures, indicated with an IP65 or higher label.

Cost of Light

It is important to consider all applicable costs when designing or updating a facility's lighting. setup. Purchase price is a small portion of the total cost over the equipment lifetime. Cost to operate, useful life, maintenance costs and disposal costs — as well as failure scenarios and associated costs — should be calculated and included in lighting decisions.

CASE STUDY

HPS TO LED CONVERSION IN VEG

The Clinic replaced 72 1000w single-ended HPS lights in their vegetative room with a mix of 6 bar and 10 bar BML (now Fluence) LED lights. There was an immediate electrical savings of 36,360W in that room. The Clinic also saw a decreased demand on their aging HVAC equipment due to the lower load in the room and ability to increase the temperature set point without detriment to the crop. In addition to the energy reduction in the room, the LED lights have actually sped up the process to get the plants to the right size and decreased the growing period by 1-2 weeks. Monitor light during the day and turn lights on and off based on the amount of sunlight and the target PPFD. This is a great way to get the most out of a crop while trying to minimize electricity use.

Resources:

- *Greenhouse Product News — Greenhouse Lighting Options*
- *ACF Greenhouses — Indoor Plant Grow Light Guide*
- *Economic Analysis of Greenhouse Lighting — Light Emitting Diodes vs. Intensity Discharge Fixtures*

SUSTAINABILITY ASPECTS AND IMPACTS:

ENERGY

- INDOOR AIR QUALITY
- ODOR CONTROL
- ENERGY CONSUMPTION
- GHG EMISSIONS
- REGULATORY COMPLIANCE
- CLIMATE
- COMMUNITY RELATIONS
- EMPLOYEE WELL-BEING
- OPERATIONAL AND COMPLIANCE BUDGETS

By the numbers:

Original Configuration	72 HPS single ended	72,000W
New Configuration	72 BML LED fixtures (36 660w, 36 333w)	35,640W
Monthly Electric Savings	36 kW 19,000 kWhs	$1,400
AC Tonnage Reduction		10 Tons

HVAC/DEHUMIDIFICATION & ODOR CONTROL

Climate control systems can account for 50 percent or more of the total energy consumption in an indoor cultivation facility.[5] Climate control consists of multiple components such as heating, ventilation, air conditioning (HVAC) and dehumidification working in harmony with emissions and odor control technology. As such, proper climate system design, installation, commissioning, and maintenance are crucial aspects of a sustainable cultivation process. Proper climate design is critical to operational efficiency and biosecurity. In many cases, climate control will be the single largest capital investment a cultivator makes after real estate. While purpose-built cannabis cultivation facilities allow for optimal climate design, the majority of indoor cultivation sites are repurposed facilities — which adds a layer of complexity to the HVAC optimization and odor control equation.

PROCESS DESCRIPTION

In addition to requiring different approaches for purpose- built versus retrofitted facilities, optimizing climate system operations will depend on myriad facility-specific factors such as size, layout, growing method, lighting system design, watering schedule, odor control needs, and local ambient conditions. Due to the complexity of HVAC and dehumidification systems, it is strongly recommended that facility managers consult with a HVAC/mechanical designer as well as emissions/odor control specialists familiar with cannabis cultivation. Engineering firms stamping mechanical designs must be licensed by the Colorado Department of Regulatory Agencies. Installing contractors operating in Denver must be licensed by the city in addition to holding a license from the State of Colorado. Facility managers may also find it beneficial to select engineering firms with specific sustainability credentials such as a Certified Energy Manager®, Building Energy Assessment Professional®, or LEED® accreditations. It is important to note that typical HVAC systems are designed for comfort cooling and occupancy ventilation. These systems can present challenges in cultivation environments that will need to be understood and addressed at the design phase. Systems specifically designed for process cooling will often address these challenges and should be considered when budget allows.

The act of cooling is simply the absorption and removal of thermal energy. This energy transfer is usually measured in BTUs (British Thermal Units) in the United States. The more energy efficient the heat exchange, the more energy efficient the cooling system.

It is important to understand the efficiency of the system as a whole for the intended purpose when evaluating any climate system.

Commonly used equipment ratings SEER (Seasonal Energy Efficiency Rating), EER (Energy Efficiency Rating) and IPLV (Integrated Part Load Value) are limited to specific uses and often specific equipment. On the surface, a high rating might make one system look more energy efficient than another. For instance, when comparing the EER rating on a 100-ton chiller and the EER rating on a three-ton mini-split air conditioner, it might appear that using 33 mini splits is more energy efficient. This is not the case, as the other components of the chiller system (fan coils, pumps, transport energy, etc.) are not accounted for in this rating. Further, adding up the running load amps (RLA) of 33 three-ton mini splits and comparing those to the RLA of one 100- ton chiller will show that the 100-ton chiller consumes significantly less energy in operation.

COOLING METHODOLOGY

EVAPORATIVE COOLING

Evaporative cooling is a low-energy cooling method in which heat is absorbed through the evaporation of water. Although this is an energy-efficient method of cooling, especially in dry climates, only certain types of evaporative cooling are applicable to cultivation spaces. Direct evaporative cooling, where water is evaporated directly into the air entering the space (typically a 100% outside air system) is not recommended for cultivation spaces due to the introduction of humidity to the space. Such systems are commonly known as “swamp coolers”.

Indirect evaporative cooling, however, can be readily applied to cultivation spaces in dry climates. Indirect evaporative cooling systems create cold, evaporatively-cooled outside air, which is passed over a heat exchanger to extract heat from cultivation space air without adding any moisture to the cultivation space.

Some indirect evaporative coolers can also operate in a “dry mode” during cold weather, allowing for naturally cold, dry, outside air to extract heat from the indoor cultivation space without any direct air exchange, water consumption, or air conditioning compressor energy consumption. When operating in a “dry mode” such systems are better thought of as indirect outside air economizers.

A third application method of evaporative cooling applicable to cultivation spaces is Direct Evaporative Pre-Air Condenser Cooling (DEPACC), when evaporatively cooled air is used to cool the air entering a normally dry air-cooled condenser, such as exist on packaged rooftop units, split system condensing units, and air-cooled chillers. Some manufacturers offer DEPACC as a factory-provided equipment option. Third party manufacturers also exist who can apply DEPACC to existing dry air-cooled equipment.

[5] *Evan Mills. The Carbon Footprint of Indoor Cannabis Production*

One important aspect to note about evaporative cooling is that it does require the use of treated city water, which is rapidly becoming a more scarce and expensive in drought stricken regions such as large portions of Colorado. While Colorado has not yet taken any steps to remove evaporative cooling systems, other areas have begun looking at doing so, and it is possible that Colorado may take similar measures in the future in order to conserve water.

Mini Splits

Small, ductless HVAC units allow for quick owner installation at a relatively low cost. These units have high-efficiency and low-ambient temperature options available. They are a viable option for small-scale facilities (less than 1,000 square feet in size), but should not be considered in large operations due to the limitation on available tonnage and, therefore, the additional space and electrical connection points required. These systems lack direct dehumidification control and are designed for comfort cooling applications, though they will provide some indirect dehumidification capability (if the space's relative humidity is high enough) as a byproduct of the cooling process. The important thing to note is that the dehumidification capability cannot be directly controlled, which means that it does not allow the cultivator precise control of the indoor relative humidity (RH).

Packaged HVAC Systems

Generally described as rooftop units (RTUs), these units are common and relatively inexpensive. The complete HVAC system comprises a supply fan, filtration (limited), compressor, condenser and evaporator contained in a single housing. Air from the cultivation space is moved through ducts to the unit's evaporator, where heat is removed, and cold air is returned to the cultivation space. This is generally an inexpensive option with mid-range energy efficiency, but can present challenges associated with excessive ductwork, redundancy, low temperature operation and requirements for building ventilation. Many existing facilities are using RTUs in ways that are far beyond the original design intent of the systems. This leads to poor performance and high energy bills. Frequently, microbial problems arise due to the inability of these systems to successfully manage the cultivation environment.

Variable Refrigerant Flow

Variable Refrigerant Flow (VRF) systems are refrigerant- based heat pump systems that allow the use of one outdoor condensing unit with multiple fan coil unit (FCU) zones within facility. Each FCU has variable cooling capacity to meet load, promoting a higher level of indoor unit zoning and distributed cooling without the ductwork that would be typical of a packaged HVAC system. Further, VRF systems, which include variable speed compressors that offer varying cooling loads, allow for variation in power consumption. With these systems, heat can be redirected to cooling zones (and vice versa) to offer energy savings.[1]

This is typically more useful in an office environment where loads vary based on external environmental conditions than in cultivation facilities where loads stay consistent. Further, VRF systems lack the latent capacities requisite for the amount of dehumidification required in cultivation facilities, and do not allow for direct humidity control. Overall, VRF is a more energy-efficient option than traditional HVAC methods, but is comparatively expensive to purchase and install; will require extensive infrastructure with multiple small compressors in VRF also carries the potential risk of leakage from exposed refrigerant piping. It is worth mentioning that indoor units often come with a "reusable" filter that will need to be cleaned and may cause some microbial issues. It should also be noted that these filters typically have a MERV rating of only between 1 and 4, far below the MERV 8 to 13 ratings generally seen for disposable media filters common in other packaged equipment, which may cause biosecurity issues in the environment.

Chilled Water Systems

Chilled water systems offer a standard solution for large-scale process cooling, data centers, large-scale buildings such as hospitals and airports, and energy- intensive manufacturing operations. In this system, the packaged water cooling machine (i.e., chiller) maintains a constant discharge water temperature (typically around 45 degrees F) from the warmer water returning from the space, thereby removing BTUs and heat load. This chilled water is then pumped indoors to distributed fan coils or air handlers throughout the space.

Chillers come in two types: air-cooled, which can be located outdoors and expel heat to the ambient air; or water-cooled, which can be located inside and expel heat to a cooling tower. Chilled water systems are typically more expensive than traditional HVAC on small and mid-sized facilities, but on large facilities they can get closer on a first cost basis to other options. Along with high energy efficiency, chilled water systems offer:

- The ability to isolate cultivation spaces without dedicating compressors to specific zones of the facility. This promotes the highest levels of system redundancy and allows for a reduction in the number of compressors needed when cultivators are 1 Most manufacturers market cooling only, heat pump, and heat recovery units under their VRF/VRV model names. So a facility owner could theoretically get a cooling only multizone split system and not have this aspect included. "flipping" flowering rooms, which reduces system cost, electrical infrastructure and peak load operation.

- A high level of installation flexibility, allowing for changing capacity within any given space without changing the central system design.

- Dedicated dehumidification control when coupled with a reheat system; dehumidification can occur without subcooling the space.

- The ability to design for redundancy, as backups can take over if one piece of equipment fails.

These benefits do come with some trade offs, which include the following:

- Increased system complexity. This can cause issues with maintenance, particularly for smaller staffs that may not have experience with water based systems or large pumps.

- The system complexity generally requires a more elaborate temperature control/Building Automation System in order to properly utilize the equipment. This can result in higher first costs.

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[1] Most manufacturers market cooling only, heat pump, and heat recovery units under their VRF/VRV model names. So a facility owner could theoretically get a cooling only multizone split system and not have this aspect included.

- Cold climates may require glycol water solutions or piping heat trace for freeze protection, which can result in higher first costs and additional maintenance costs.
- Some locations may require ongoing costs such as chemical treatments for the water to make it suitable for the chiller.
- Reheat systems for dehumidification typically require separate boilers/electrical coils. Heat recovery chillers that generate hot water for reheat coils are available, but add significant cost and complexity to the systems, and should only be used when the facility staff is familiar with the requirements and maintenance needs of them.

Water Cooled Condensers, Cooling Towers and Geothermal Systems

Generally speaking, water-cooled HVAC equipment (e.g., chillers, packaged unitary units, ground-source heat pumps) create a more energy- efficient heat removal process through the condenser and reduce operating costs substantially. Water-cooled condensers are available for both typical air conditioning packaged units and chilled water systems.

On a water-cooled condenser, the water can be fairly warm (in some cases as warm as 90 degrees F) and still be effective, so cooling towers and ground loops can be utilized in these cases. However, cooling towers typically require intensive maintenance and consume large amounts of water. Thus, they are typically not cost-effective until the total load reaches 500 to 600 tons. Onsite ponds and/or excavated geothermal loops can be useful in these cases, assuming the capacity for heat absorption is available.

DEHUMIDIFICATION METHODOLOGY

Cultivation facilities are notoriously high-humidity environments due to the massive amounts of water being added to the space. Ultimately, the water that is applied to plants is transpired by the plants and then needs to be removed from the space. The needs of dehumidification equipment will change as the parameters in the room change. The warmer the rooms can be kept during lights off periods, the more efficiently dehumidification equipment will operate.

Standalone Dehumidifiers

Standalone dehumidifiers typically consist of small, free- hanging (plug and play) dehumidification units used to supplement the dehumidification offered by the cooling system during lights-on periods and as the primary source of dehumidification during lights-off.
Standalone dehumidifiers are more energy intensive than larger-scale dehumidification methods due to the use of small compressors, and output is limited by temperature parameters in the space (the lower the temperature, the less output the units produce). Generally, standalone dehumidifiers carry the lowest up-front cost and are the easiest systems to integrate, but due to their plug-and-play nature, they can be difficult to integrate with other climate control equipment, and generally result in the highest operational cost and lowest efficiency of all available dehumidification options.

Reheat

Without a standalone dehumidifier to achieve dehumidification, AC systems often cool the air below the desired temperature, and then reheat the cooled air as needed. There are several methods to accomplish this reheat.

For smaller grows, generally it is more energy efficient to use standalone dehumidifiers than to rely on a standard AC system with electric or fossil-fuel reheat for dehumidification.

However, chilled-water systems with heat recovery and AC systems with integrated hot gas reheat can provide cooling and dehumidification very efficiently for medium size or larger grows.

Electric reheat: Electric heat strips are utilized to produce heat. Electric reheat is not energy-efficient, and standalone dehumidifiers will save energy compared to this option.

Natural gas or propane reheat: Natural gas or propane is used to produce heat in order to reduce the ambient-air relative humidity. More advanced air handlers (in chilled water or standard HVAC systems) will often have this as an integrated option, or this function can be achieved with stand- alone gas heaters.

Hot-water reheat: Common in chilled water systems, hot water is supplied to fan coil units through a gas-fired boiler system. Advanced systems can vary the flow rates of hot and chilled water to achieve environmental set points in the most efficient way, saving energy.

Chilled-water system heat recovery: A chilled- water system can be designed to perform the needed reheat by using recovered heat from the system's condenser coil (basically, the heat removed through CO_2 the dehumidification process is reinjected into the airstream prior to distribution to the room.) The cooled and dehumidified air is reheated through a heat exchanger with the water heated from the condenser.

Hot gas reheat: Some more sophisticated rooftop AC systems come equipped with an additional outdoor condensing coil for reheat. This additional coil and the associated controls allow the system to reject heat to the outdoors when cooling is required in the space (lights- on periods), or to use the other condenser coil for reheat when there are minimal sensible cooling needs (during lights-off periods).

Desiccant

Desiccant dehumidifiers use desiccant media to absorb moisture from the space by rejecting the added moisture to an exhaust air scavenger airstream. For this system to work optimally, the desiccant media is heated on the exhaust side so that the moisture can be released outside to the environment, and the desiccant is reused. Desiccant humidifiers require the lowest amount of energy and can operate in a wide range of temperatures, but can be cost prohibitive and are generally only used on large-scale facilities.

Economizers

"Economizer" is another term for free cooling, utilizing the outdoor ambient environment to assist with temperature management of the cultivation space.

Air-side economizers are units that utilize ventilation as a cooling method when ambient temperatures are below the set point in the cultivation space. While air-side economizers are an energy efficient solution, they must be applied carefully and properly in cultivation environments to avoid creating problems with enrichment, biosecurity and odor control, and should only be implemented with the assistance of an experienced cultivation mechanical design professional (See "Ventilation and CO2" section for additional details). Where air side economizers are used, it is recommended that air filters with a minimum rating of MERV 13 be used, and where extra peace of mind is desired, those filters should be coupled with a MERV 8 pre-filter. While alternative filtration technologies such as Ultraviolet Germicidal Irradiation (UVGI) can be used in series with these filters, it is not recommended that it be used in place of higer level media filters.

Indirect air-side economizers, where cold outside air (typically during winter) is used to cool cultivation space air is a safer approach. Cold air is passed through an air-to-air heat exchanger (such as a flat-plate or heat-pipe) to pull heat from the cultivation space without actual mixing or injection of outside air into the controlled environment. When used during sub-freezing outside air temperatures, indirect outside air economizers must still be carefully controlled to avoid the buildup of frost on the indoor side of the coil, but such controls are often integral to the equipment and can be provided by the manufacturer. In dry climates, when coupled with indirect evaporative cooling, indirect outside air economizers can greatly extend the quantity of "free-cooling" hours and capacity throughout the year *(See "Evaporative Cooling" section for additional details).*

Water-side economizers (or fluid coolers) can be utilized in both chilled water systems and in water- cooled condensing units and allow for free cooling without ventilation. When utilized in chiller systems, water-side economizers can reduce wintertime energy consumption dramatically by bypassing the compressors entirely when temperatures drop below 40 degrees F, utilizing cold outdoor temperatures to chill the water. On water-cooled condensers (in certain geographies) fluid coolers can be utilized in place of cooling towers for the condensing water loop.

AIR MOVEMENT

Air movement over the plant canopy is critical for transpiration of moisture and the prevention of pests and fungus. Cultivators should examine cubic feet per minute (CFM) per watt when evaluating canopy fans and emissions control technology for efficiency. Destratification fans are important to energy efficient climate management, particularly when ceiling heights exceed 10 feet. Destratification fans create vertical airflow and ensure that heat and humidity trapped at the plant canopy reach the ceiling, where the cooling and dehumidification equipment is typically located and can exhaust heat and moisture.

Airflow and airspeed both need to be studied more closely in controlled cannabis environments so that the industry can create baseline standards; however, the baseline generally accepted for most crops for airspeed is 1 m/s.

VENTILATION AND CO2

In many CO2-enriched environments, ventilation or air- side economization may waste significant amounts of CO2 (which can conflict with the energy code and efficiency efforts overall).

Cultivators should carefully weigh efficiency gains associated with ventilation against CO2 waste to determine accurate costs and greenhouse gas emissions associated with both. Limiting ventilation can also be helpful to biosecurity efforts and in minimizing exposure to contaminants, possibly reducing reliance on pesticides or fungicides. Although common, gas-fired CO2 generators should not be used in modern indoor grow facilities. Generators contribute high levels of waste heat while operating and many are not vented properly, leading to dangerous indoor environments. Bottled CO2 is a better substitute practice.

DESIGN STANDARDS

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) publishes commonly accepted HVAC standards for architects and engineers. As a starting point, facility owners may benefit from familiarizing themselves with ASHRAE 90.1, Energy Standard for Buildings. ASHRAE has also published an Advanced Energy Design Guide Series2 focused on reducing energy building use, which is available as a free PDF download. It should be noted that most areas in Colorado have adopted the International Energy Conservation Code as well as the International Mechanical Code as their legal building codes. While these do share similarities with ASHRAE 90.1, it is still important for facility owners to work with a consulting engineer with experience in applying the legal codes to buildings in order to ensure the building is actually code compliant in the eyes of the state.

[2] *ASHRAE Advanced Energy Design Guides: https://www.ashrae.org/technical-resources/aedgs/aedg-free-download*

BEST PRACTICES

One of the most common mistakes made by business owners is failure to invest in regular HVAC system maintenance. Due to the nature of indoor grows requiring nearly 24/7/365 space conditioning, the upfront investment in high efficient equipment can make economic sense. While initial system design and equipment procurement are critical, all HVAC systems require regular maintenance to ensure peak operating efficiency. Periodic inspections should be completed, during which time filters should be inspected and replaced, condenser/evaporator coils should be cleaned and electrical connections should be checked.

The U.S. Environmental Protection Agency (EPA) recommends semi-annual maintenance checkups for all commercial HVAC systems.

As described above, selecting the most energy- efficient HVAC and dehumidification systems is highly dependent on operational factors, including the size of the facility and the budget. Below are some general energy efficiency recommendations:

- For very small facilities, mini-split systems can be an efficient HVAC option.
- For larger facilities, variable refrigerant flow and chilled water systems offer higher efficiency and redundancy compared to standard packaged systems.
- If using stand-alone dehumidifiers, cultivators should consider pints per kWh when evaluating for efficiency. Cultivators should also pay attention to performance curves — dehumidifiers are rated at Association of Home Appliance Manufacturers (AHAM) standards of 80 degrees and 60 percent humidity, but some manufacturers publish output at 86 degrees and 80 percent humidity, which can be misleading if it not being compared using a common reference.
- Chilled-water systems with heat recovery and AC systems with integrated hot gas reheat are the two most energy-efficient options for achieving integrated cooling and dehumidification. Water from these systems is relatively clean and can be reintroduced to the fertigation system with minimal filtration.
- Desiccant dehumidification can be highly efficient, but costly.
- Cultivators should seal spaces to reduce CO2 loss, improve biosecurity and reduce odors emanating from the facility.
- Cultivators should keep rooms warmer at night to manage latent load. This is because plants will still transpirate to some degree during the night cycle when the lights are off, and the evaporative cooling effect produced by this can actually cool and humidify the space.
- When possible, cultivators should provide shade for outdoor condensing units to reduce operating temperature and extend life. However, it's important that provision of shade does not interfere with air flow around air cooled condensers, as interference with airflow can result in diminished capacity.
- Consider calculating your canopy's emission load as the baseline before installing the proper number of mitigation units to provide the exact number of required air exchanges to effectively sequester cannabis emissions at the rate they are emitted off the plants.

TAX IMPLICATIONS:

Boulder County Energy Impact Offset Fund & Credit Program

The Boulder County Energy Impact Offset fund requires commercial cannabis cultivators to either offset their electricity use with local renewable energy or pay a 2.16 cent charge per kWh. The fees from this surcharge are then placedinto the Boulder County Energy Impact Offset Fund. This fund, in turn, has been used to educate and support best in industry practices with regards to energy usage as well as for funding other carbon-pollution reducing projects such as and low-income renewable energy. Boulder County cannabis cultivators participating in the EIOF fund are also eligible for an EIOF credit program to free up cultivators' capital to invest in energy efficiency and renewable energy. Under the EIOF program, eligible cultivators can receive a credit against future EIOF fees for these out-of-pocket energy efficiency upgrade costs.

Resources:

- ASHRAE, Air Conditioning, Refrigeration and Heating Institute. See sample Preventative Maintenance schedule in appendix
- National Renewable Energy Laboratory — Solar Energy Basics
- Environmental Protection Agency — CHP Benefits
- National Renewable Energy Laboratory – Commercial & Industrial Solar Best Practices
- U.S. Environmental Protection Agency — CHP Project Development Steps
- Xcel Energy — Distributed Generation Guidelines
- Boulder County Marijuana Energy Impact Offset Fund RILA Best Energy Management Matrix

ENERGY SUPPLY

OVERVIEW

While the previous section discussed best practices pertaining to energy demand reduction, a comprehensive energy management strategy should also consider opportunities for supply-side improvements. Nearly all cultivation facilities in Denver receive electricity directly from the grid. For Xcel Energy customers, this means that the electricity being consumed in Denver facilities is generated using a mix of technologies as outlined below.

Table 4: Xcel Energy — Power Supply Mix for Colorado Customers

XCEL ENERGY – 2020 POWER SUPPLY MIX FOR COLORADO CUSTOMERS[6]		
	Total Generation Mix (%)	Median Lifecycle CO_2 Emissions (grams/kwh)[7]
Coal	25.8%	1001
Natural Gas	37.3%	469
Wind	30.6%	12
Solar	4.7%	46
Hydroelectric	0.8%	4
Other*	0.8%	-
*Includes biomass, oil and nuclear generation		

On-Site Power Generation:
One approach for facility managers looking to make supply- side improvements is on-site power generation. While a host of onsite generation technologies exist in the marketplace, two of the more common on-site options for cultivators to consider are solar photovoltaic (PV) and combined heat and power (CHP). While the economic, environmental and resiliency benefits of these technologies will vary depending on facility-specific factors, one advantage all on-site generation options share is the elimination of transmission losses8. Roughly 5 percent of grid-generated electricity is lost in the transmission and distribution process. Onsite renewables such as PV may offset only 10% to 15% of a facility's energy consumption, unless an area other than the roof footprint of the cultivation building is available to host PV panels.

Off-Site Power Optimization:
The second approach is entering into a alternative energy supply contract with a utility company. As discussed more specifically in the topic breakout, Denver businesses have multiple clean-energy procurement options. While utilizing this approach does not typically have the same economic or operational benefits associated with on-site generation, offsite optimization likely represents the simplest alternative for cultivators looking to reduce the environmental impact of their facilities.
As with the demand-reduction strategies presented in the previous section, there is not a one-size-fits-all solution to supply-side energy management. While the following best practices are intended to provide a starting point for discussion, facility managers are strongly encouraged to consult with a licensed professional prior to acting.

[6] *Xcel Energy — Energy that Works for Colorado*
[7] *IPCC Renewable Energy Sources and Climate Change Mitigation*
[8] *U.S. Energy Information Administration*

ON-SITE POWER GENERATION & STORAGE

Power generated on-site, commonly referred to as distributed generation (DG), can deliver economic, environmental and operational benefits to cultivation facilities in certain situations. Two DG technologies cultivators should evaluate are solar photovoltaic arrays (Solar PV) and natural gas cogeneration systems (Combined Heat & Power, or CHP). While these on-site generation options can result in excellent returns for facilities, implementation is a complex process and requires technical expertise, detailed coordination with the local utility, and careful financial planning. Cultivators should consult with an experienced technical specialist as part of the assessment process.

PROCESS DESCRIPTION

Performing a desktop feasibility study (also known as a qualification study) is typically the first step in the on-site power-generation procurement process. Facility managers should retain a technical specialist to perform this study, which is provided free of charge by many on-site power generation specialists.

While there are many approaches to desktop feasibility studies, the process typically requires facility managers to fill out a brief survey and provide six to 12 months of utility bills. Using this information, specialists can build a high level model that provides a "ballpark" economic, environmental and operational impact assessment.

If the desktop feasibility study indicates an attractive value proposition, the next step is performing a Level 1 Feasibility analysis. The EPA provides a sample Level 1 Feasibility Analysis for facility managers to review; in the event a project proceeds, a Level 2 Feasibility Analysis is subsequently performed.

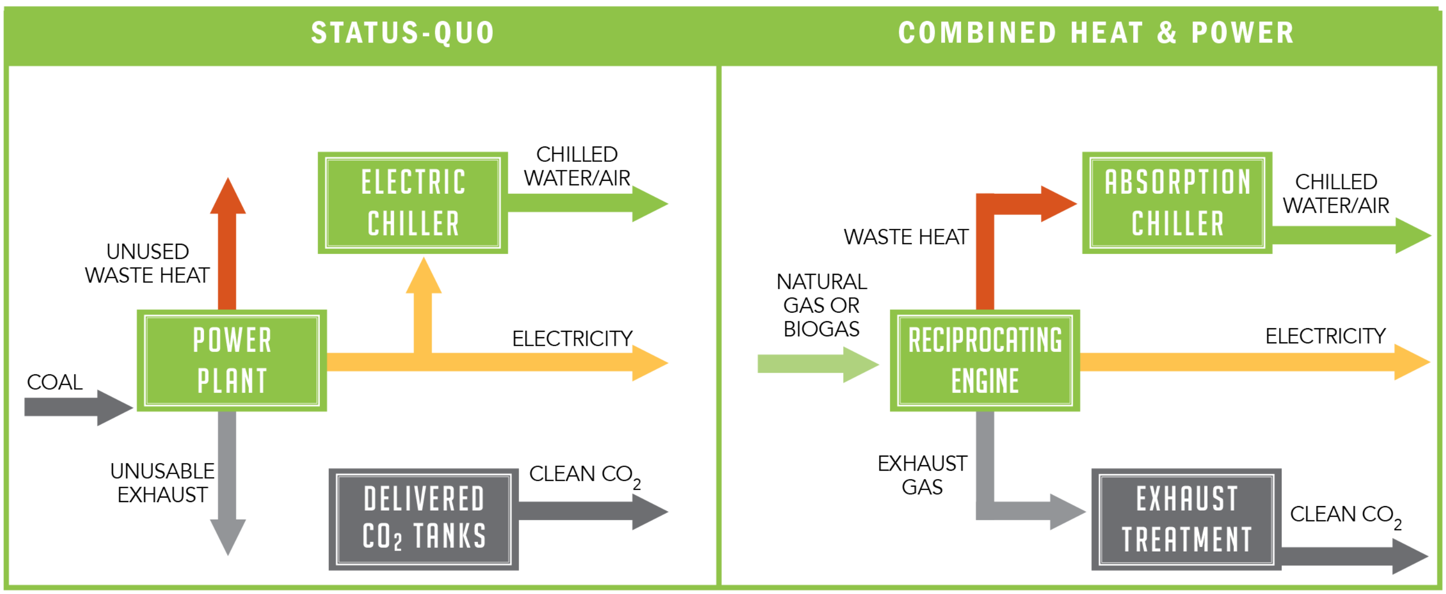
During this process, project-specific design engineering is accomplished, equipment options are formally evaluated and detailed financial analysis is completed. Following the conclusion of the Level 2 Feasibility Analysis, the project team is typically ready to submit necessary permits, with construction beginning shortly thereafter.

Table 5: No-Carbon and Low-Carbon Energy Sources for Cultivation Facilities

ENERGY TYPE	NOTES
Solar PV	Solar Photovoltaic Systems (Solar PV), convert sunlight into usable electricity. Solar panels use sunlight to generate electricity, and inverters convert that electricity from variable direct current (DC) to alternating current (AC) at the correct voltage, frequency, and phase needed to tie into the facility's electrical infrastructure and the larger electrical grid. For cannabis cultivation facilities, these systems will most frequently be installed on the building's roof, though some properties might be able to benefit from solar system installed on the ground (ground-mounted) or in the facility's parking lot. Because the economic returns from on-site solar systems are typically dependent on utility-specific regulations, facility owners should consult with utilities prior to project design.
Cogeneration (CHP)	CHP systems use a natural gas generator (engine, turbine, or fuel cell) to produce electricity and repurpose the waste products to offset the facility's HVAC and CO2 needs. When done properly, this process can reduce a cultivation facility's emissions footprint by 25 percent to 45 percent, generate attractive economic returns and serve as reliable source of power during grid outages. While CHP systems offer an exciting value proposition, these systems also feature comparably complex technology and require significant technical expertise throughout the design, build and maintenance phases. Cultivators looking to benefit from CHP technology should enlist a qualified third party to guide the process.
Wind	Small wind turbine systems can be installed alone or in conjunction with solar photovoltaic systems. The small size and variability of energy produced by these systems makes them most applicable for supplementing another power source. The amount of energy small wind turbines can provide depends on the site, size and height of the turbine, but small wind systems for commercial buildings typically generate 20 kilowatts to 100 kilowatts. To determine the amount of wind energy available at a site, installing an anemometer for at least 12 months prior to system purchase is recommended. Wind power is not commonly used in metropolitan areas as permitting and conformance with local zoning and building codes may prove challenging.

Financial planning for cannabis businesses can be different from traditional businesses. Many financial stimuli from local, county, state and federal entities exist to accelerate the adoption of energy-efficiency measures and renewable technologies, and they should be thoroughly leveraged. However, for a cannabis business, it would be wise to consult with financial specialists before making assumptions about tax treatments with regard to renewable investment tax credits, utility rebates, and operating expense deductions versus capital expenses (depreciation).

Figure 2: Comparison of energy inputs and associated outputs of standard or grid energy use versus a Combined Heat and Power (CHP) system.



OFF-SITE ENERGY SUPPLY

Community Solar

An alternative for cultivators looking to reduce the environmental footprint associated with electricity production is to explore off-site energy supply opportunities. Denver facilities served by Xcel Energy should investigate the Solar Rewards Community program, commonly referred to as solar gardens.

PROGRAM DESCRIPTION

Colorado was the first state to offer community solar opportunities for customers of investor owned utility companies, and Denver grow facilities can benefit from renewable energy production situated and managed off-site.

Customers "subscribe" to a portion of the solar array and benefit from the array's output over medium- and long-term contracts.

Any entity with an Xcel electric account can benefit from this arrangement, including building owners, renters or managing parties. Recently, community solar developers have been hesitant to contract with the cannabis industry. It is important to continue reaching out to developers to assist in the evolution of this portion of the clean energy industry.

BEST PRACTICES

In Denver, electricity consumers can also choose to independently contract with the owner/operator of a qualified solar array. Under this arrangement, a third party builds a community solar system and sells the electrical output to Xcel. Xcel then credits the customer for that electricity on the customer's monthly electric bill, commonly referred to as net- metering. It is important to note that cultivators may or may not save money by participating in this arrangement, as agreements are made directly with the owner of the community solar array. The utility simply acts as a facilitator in this arrangement.Contracts are generally longer-term, where monthly electric savings outweigh financing costs leading to positive cash flow for the customer.

Utility Green Pricing Program, Unbundled RECs and Direct Purchasing

Other options for off-site generation is opting for your utility's green pricing program. Such programs are usually sold at a premium but allow customers to voluntarily sign-up for additional renewable electricity content, therefore reducing your carbon emissions and allowing you to make claims about using renewable electricity.
Xcel Energy's Windsource® program is an example of a utility green pricing program. Windsource® is Green-e® Energy certified, therefore meeting the environmental and consumer-protection standards set forth by the nonprofit Center for Resource Solutions. Learn more at www.green-e.org.

Sourcing unbundled Renewable Energy Certificates (RECs) is another way to source offsite renewable electricity. A REC represents the environmental attributes, but not the electrons, of 1 megawatt hour (MWh) of renewable energy generation on the electricity grid. They are used to track when and where renewable energy is generated, who it is sold to, and who is using it. While RECs are an additional cost to your electricity, they allow you to make marketing claims about using renewable electricity when paired with electricity you get from a shared grid. Green-e® Energy certification ensures RECs come from newer generators that meet strict environmental standards and that the sellers are third-party audited.

You can find Green-e® Energy certified REC products at www.green-e.org/certified-resources.

The final option, direct purchasing, is when purchasers buy renewables directly from a third-party owned generator. These usually come in the form of a physical power purchase agreement (PPA) or a financial PPA (often called a virtual power purchase agreement). This option is not available in all states, depending on regulations. PPAs can have financial risks and rewards. Learn more about this and other renewable electricity purchasing options in the EPA's Guide to Purchasing Green Power.

REBATES

Rebates are offered by the majority of utility companies to customers in their territories that can reduce their energy usage. These rebates can be significant, often accounting for 25 – 50% of a new technology purchase and 25 to even 100% of a lighting upgrade.

Utilities provide rebates for one simple reason: it is cheaper to reduce energy in their territories than it is to create new power generation (i.e. build new power plants and transmission lines). This means that although the rebates are substantial, it is in the best interest of the power company to provide them. Additionally, most utilities include it as a fund you pay into as a percentage based on your monthly bill. This means that rebates are YOUR money already, so you should be taking advantage of it.

Rebate programs come in two different forms: prescriptive rebates and custom rebates. Prescriptive rebates are a set dollar amount that you are paid based on the equipment type, such as $15 dollars per LED bulb replacing incandescent. Custom rebates are where the majority of indoor agriculture rebates fall; these rebates are often based on a dollar amount given per kWh reduced. Custom rebates usually range from $0.15 – $0.30 per kWh reduced which means that you will often have to calculate the energy savings of your new technology based on historical equipment.

https://www.epa.gov/greenpower/guide-purchasing-green-power

This is where it starts to get tricky when applying for a rebate; often if your calculations are far off from the actual savings, your rebate will get rejected. Once you submit a rebate with your calculations, utility engineers will calculate the actual savings and either reject or adjust the rebate based on their own calculations. This means you need to provide the proper documentation and information in order to justify your calculations.

It becomes even more complex if you are completing a new construction project, where instead of replacing equipment you instead choose to install energy efficient technologies at the beginning of your facility build out. In this case the utility calculates your rebate based on what is called an "assumptive or hypothetical baseline". This baseline reflects the energy usage would be in the facility if you had gone with traditional equipment instead of more energy efficient equipment.

With lighting this is often done with PPFD maps which show how many HPS or Metal Halide lights you would need in order to achieve the same light levels as the LEDs. Other equipment such as HVAC or fans is based on the facility needs with less efficient equipment (i.e. how many oscillating fans are required to get the same airflow as a single destratification fan). Oftentimes the baseline is determined by local building codes such as required insulation thickness which is then compared to how much "better" your build will be (i.e. code requires a R value of 10 but you are going with R value 20). The upside to this process is that the rebates are often significantly higher and avoid upfront cost of less efficient equipment.

Now that you understand the different types of rebates that are available let's look at how to actually secure rebates:

1. Look on your utility's website for different rebate programs, make sure you are looking under "commercial" rebates.

2. Identify which program is best for your needs. If this is difficult due to multiple different programs your utility offers, call the utility company's rebate or "energy efficiency" division. (Phone number will often be listed with the rebates)

3. Determine if your project requires pre-approval. Custom rebates often require a pre-approval in order to secure the funds for your project. This means submitting the rebate BEFORE you purchase the equipment. Many programs will deny your application if you have already purchased.

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4. Fill out the application, compile your supporting documents, and calculate your energy savings.

    - Although this process can seem intimidating, most utilities already have workbooks built that will calculate your savings for you by simply entering your old and new equipment.
    - Supporting documents often include a W9, equipment spec sheets, and quotes.
    - If you have to create an "assumptive baseline" (see above) you may need to reach out to your equipment vendor to provide the necessary data.
    - For lighting projects this often means acquiring PPFD maps for the space both for the new lights and for the lights you are "replacing".
    - For HVAC this usually requires performance curves or numbers related to EER or SEER.

5. Submit your project for pre-approval.

6. Wait to hear back if your project was approved

    - If your project is not approved, you can almost always resubmit based on the reasons the prior application was denied.

7. Order and install equipment after pre-approval is complete.

8. Submit for payment.

As you can see the heaviest lifting when applying for a rebate is on the front end and acquiring pre-approval. Companies often opt to use a professional service to help them submit rebates since the process can become so complex. Let's look at a real-world example of the most difficult type of rebate "new construction custom rebates":

You are considering purchasing LED lights for your new indoor agriculture operation. You would like to purchase 100 lights for your new facility. Your utility company offers a custom rebate of $0.35 for every kWh you save. Since this is a new construction the rebate will be based on how many traditional lights you would need in order to reach the same lighting levels as the LEDs. You go to your lighting vendor and have them build PPFD maps showing both the assumptive baseline and the lighting layout for your new LEDs. Their maps show that for every 650W Heliospectra MITRA LED you would need 1 High pressure sodium light. The calculation to determine the energy savings would look something like this:

Baseline Energy Usage:
150 (LEDs) x 1 (assumptive baseline) = 150 HPS Lights

1 HPS Light = 1100W input power

1100W x 150 = 165,000 watts / 1000 = 165 kWs

12 hours per day (runtime) x 1165 kWs = 1980 kWhs per day

1980 kWhs x 300 (growing days) = **594,000 kWhs**

per year New Energy Usage:

150 LEDS x 650W input power = 97,500 total watts / 1000
= 97.5 kWs

12 hr. per day (runtime) x 97.5 kWs = 1,170 kWhs per day 1,170 kWhs x 300 (growing days) = **351,000 kWhs per year**

Energy Savings:
Assumptive Baseline (594,000 kWhs) – New Baseline 351,000 kWhs) = (243,000 kWhs saved x 30% in HVAC savings) + saved energy usage = **315,900 total kWhs saved**

Total Rebate: 315,900 kWhs x $0.35 = $110,565

Resources:

- Xcel Energy — Solar Rewards Community
- Colorado Energy Office Community Solar Information

WATER

EXECUTIVE SUMMARY

Central to all agricultural operations, water is one of the most key inputs. With water making up more than 90% of the mass of fresh cannabis weight, it becomes clear that delivering it effectively and efficiently is crucial to any savvy cultivator. Beyond the plant itself, farmers have a more intimate understanding than most of how important water is as a shared resource in a fragile ecosystem that is prone to extreme drought conditions. The water that is used to irrigate indoor cannabis crops is the same water that comes out of your faucet at home. After being used in the cities, it is allowed to flow east into the watershed shared by the eastern part of Colorado, as well as neighboring states, such as Nebraska and Kansas, where it will be used to water their crops and supply their homes. When the various needs that society has for this precious resource are taken into consideration--not-to-mention the pressures of population growth, climate change, and other factors that affect water availability and quality--effectively and efficiently using water becomes even more critical. In this section, the topics of water both as an input and an output in cannabis cultivation will be discussed, as well as the topic of how to manage the water inside of the cultivation area.

As a raw material, water used for irrigation must first be checked for its suitability to use on crops. Luckily, water delivered in the Front Range is of uniquely high quality due to the purification process of nature's water cycle, as it comes primarily from Rocky Mountain snowmelt. All water, though, should be checked for impurities. Impurities come in many shapes and sizes, but are largely thought of in a few categories: elemental (e.g., salts and heavy metals); microbial (e.g., E. coli) and manmade (e.g., pesticides and industrial chemicals). Growers should take routine water samples at least twice a year and send them to labs to monitor water quality.

If quality is found to be out of spec, a grower should use technologies that filter and sanitize the water (e.g., carbon filtration, reverse osmosis, ultraviolet light treatment) before applying it to their crops.

Once the water is deemed suitable, the next big challenge is delivering it to the plants efficiently. There are several approaches to irrigation, and each one has technology that can aid the grower. From low-tech hand-mixing nutrients and hand watering plants, to high-tech automated fertilizer dosing and delivery, a grower will have to make choices that strike a balance between capital and operating costs as well as plant performance and sustainability goals. Often, the most efficient systems are both best for the plants and have the lowest operating costs. Increased yields and decreased bottom lines are great ways to pay back the investment needed to use these sometimes more initially expensive solutions.

After the water is delivered to the plant, it usually shows up again in two main streams: leachate, or water that has flowed past the plant and not been taken up; or condensate, water that has transpired through the plant or evaporated into the farm and condensed inside of the dehumidification equipment. Both streams tend to flow to the drain that ultimately leads away from the facility and off to a local wastewater treatment plant. At this point, a farmer can either choose to utilize technology to reclaim and recycle that water so that it can be used again for irrigation, or to make sure that it is of a suitable quality to be sent on to the wastewater treatment site, where it will be processed to be used again for another application.

WATER USAGE & QUALITY

WATER OVERVIEW

Indoor cannabis cultivation within Denver and surrounding municipalities is currently reliant on the municipal water distribution system for irrigation and operational effluent discharge. As such, there are specific process points of environmental impact, including net consumptive use (= influent – effluent), filtration and treatment, and effluent discharge water quality.

In general, the environmental impacts of municipal consumptive water use include state-specific issues, such as increased urban demand resulting in reduced water availability for rural agricultural production and associated watershed impacts; water-energy nexus concerns; and indirect carbon emissions associated with municipal water treatment systems. In addition, for indoor cultivation operations, influent filtration and treatment requirements result in solid waste generation, energy consumption and efficiency challenges, while effluent water quality is impacted as a result of the agricultural inputs required for cultivation. The flow of water through a typical indoor cannabis cultivation is presented below.

While consumptive water use and water quality have been preliminarily identified as significant aspects for indoor cannabis cultivation, it is important to note that these concerns are not unique to the cannabis sector. Neither a sector-specific water-use baseline nor production unit theoretical minimum is currently available. However, the implementation of proactive operational efficiency and monitoring practices can readily address the potential water use and quality environmental impacts, while setting the stage for leadership in process integration of progressive technologies for use and cost optimization. The sustainability impacts of water use and quality include:

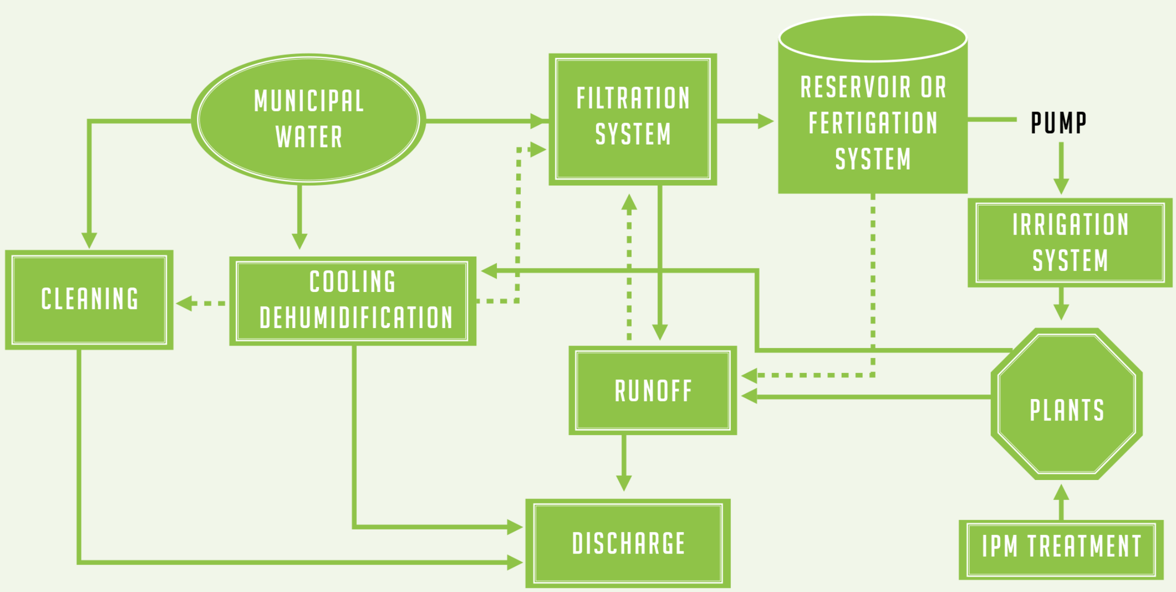
Economic Competitiveness

The introduction of water-use efficiency measures can lower operational costs by reducing direct resource purchase (i.e., lower volume equals lower cost). In addition, water-use efficiency may also result in lower levels of consumables use due to a reduction in influent treatment volume and less wear and tear on process equipment

Community Relations

As discussed above, concerns about municipal consumptive water use in Colorado include increased urban demand resulting in reduced water availability for rural agricultural production and associated watershed impacts; increased energy usage for operational influent treatment; and indirect carbon emissions associated with municipal water treatment systems. By proactively integrating water-use efficiency techniques and effluent water-quality monitoring, a cannabis cultivation operation can demonstrate the commitment to integrated resource management and community partnering that is required to cultivate strategic relationships with municipal leadership and neighborhood residents — all while anticipating regulatory changes.

Figure 3: Water Flow for Cannabis Cultivation Facilities



[9] *Electric Power Research Institute (EPRI). 2002. "Water and Sustainability (Volume 4): U.S. Electrical Consumption for Water Supply and Treatment — The Next Half Century. See also https://www.theclimateregistry.org/*

Environmental Impact

There is a direct link between water and energy. Water and wastewater utilities account for approximately 5 percent of overall U.S. electricity use, resulting in significant greenhouse gas (GHG) emissions9. In addition to energy impacts, there are regional water resource concerns from the cannabis industry — such as loss of agriculture in rural areas, and biodiversity and watershed impacts of piping water outside of its native watershed. Proper water management within a cultivation facility can result in reductions in GHG emissions and negative watershed impacts.

The following topic-specific sections will provide guidance and recommendations for water filtration and purification, irrigation methods and automation, wastewater recycling and improving wastewater quality for an indoor cultivation facility.

ESG and Water

Water scarcity is a severe risk to the cannabis industry with increased frequency of droughts and wildfires due to climate change. These physical risks can lead to increased regulations at the state and municipal level. Already in California, cultivators are prohibited from diverting surface water for the purposes of irrigation during the dry season limiting growers access to water

(https://www.waterboards.ca.gov/water_issues/programs/cannabis/cannabis_water_rights.html#:~:text=The%20Cannabis%20Policy%20prohibits%20cannabis,31%20of%20each%20calendar%20year.).

Water is an essential resource for cultivators therefore there has to be systems in place to conserve water or collect water earlier on to mitigate this risk. Limits on water usage by states is likely to increase as the effects of climate change become more frequent and extreme. In Colorado, there have already been efforts to find solutions to the looming water scarcity risk. This has included authorization to use reclaimed water for cultivation by the Code of Colorado Regulations and approval by the Water Quality Control Division of the Colorado Department of Public Health and Environment and the local water provider (https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=8439 (pg 104)). Part of addressing ESG concerns is recognizing these risks to better protect your business but also to protect our limited natural resources that are facing threats due to climate change.

The best part of recognizing these risks early on is the ability to turn these risks into opportunities. Implementing the following best management practices to limit water use and increase water recollection allows the issue of water scarcity to be an opportunity. Not only will the risks of water scarcity be less for your business but the costs of water will be less, your businesses environmental impact will be less, and your business will be more resilient for the future. ESG allows the cannabis industry to assess the risks and opportunities of water and prepare for them with best management practices.

BEST PRACTICES

Industry best practices for water use span from tap to drain and can substantially reduce water needs while improving water quality. Many practices can be instituted regardless of specific growing or watering procedures
.

WATER FILTRATION & PURIFICATION

To meet the demands of rapid maturation and high yields for indoor cannabis production, the applied water must meet strict specifications. A cultivation facility's incoming water — regardless of whether it is tap water or well water — should be tested by a trusted analytical lab, such as the Colorado State University soil and water testing lab, to understand if additional filtering is necessary prior to plant application.

Similarly, excess process water captured via flood trays or through HVAC condensate will exhibit different characteristics, requiring the need for analysis and purification before subsequent applications. There are multiple ways to improve the quality of incoming water including carbon filtering, reverse osmosis and UV sterilization.

PROCESS DESCRIPTION

According to the Colorado State University Cooperative Extension, irrigation water should be evaluated for four basic criteria:

1. Total soluble salt content (salinity hazard)
2. Relative proportion of sodium cations (Na+) to other cations (sodium hazard)
3. Excessive concentration of elements that causes toxicity or ionic imbalance in plants
4. Bicarbonate anion (HCO3-)
5. Concentration as related to calcium (Ca++) plus magnesium (Mg++) cations

When it comes to a facility's incoming water supply, salinity hazards and sodium hazards are of particular concern. It is important to test water quality prior to watering crops.

In some cases, incoming water may not meet the strict specifications for optimal plant growth; therefore, some level of purification is needed. Water to be applied to plants should be purified and nutrified on demand or purified and held in storage tanks until nutrients can be added prior to application to the crop. Water can be purified using several different methods including carbon filtration, reverse osmosis and UV sterilization. However, it is worth noting that reverse osmosis results in about 40 – 60% water loss in the treatment process, so it is not recommended for efficient water use.

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.

Resources:

- Colorado State University — Soil and Water Testing Laboratory
- Denver Water Quality Reports
- Example of water testing report

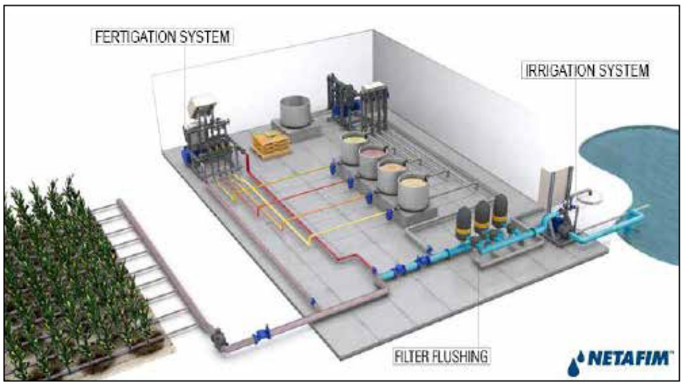
IRRIGATION METHODS & AUTOMATION

Accurate irrigation is essential to the growth of healthy plants and the overall performance of a cultivation facility. Inefficient water use not only wastes this precious resource, but also can harm the plant; cause facility damage by encouraging fungal growth; and create worker safety hazards and add extra load to the HVAC system, wasting energy. A variety of irrigation methods are used in today's cannabis industry. Selecting both the right method for a given facility and following good operational practices for that method are equally important for achieving optimal efficiency and plant growth.

BEST PRACTICES

Seven different methods are commonly used in indoor cultivation facilities: flood tables, aeroponic systems, wick systems, nutrient film technique (NFT), water culture systems, drip irrigation and hand watering.

Figure 4: Irrigation & Fertigation System Diagram.
Source: Netafim



FLOOD TABLES

Flood tables are very popular in agriculture and horticulture greenhouses. Generally used with seed trays, plug trays or small pots, flood tables (also known as ebb and flow tables) work by periodically flooding the entire tray with nutrients while pots wick up the water through the drainage holes. This method can be more difficult with large pots. Most often with the flood method, tray water not absorbed by the plants is run through a pipe to a holding tank to be reused. Typically, the recycled water will be treated to kill any water-borne plant pathogens (e.g., Pythium, Phytophthora, Fusarium), which can be done chemically or through UV light exposure. Flood tables use a lot of water per irrigation cycle, so this method is best used when the majority of the water will be absorbed or when the cultivator is prepared to sanitize, renutrify and reuse the water. Flood tables are often used with rock wool mediums, and the runoff is captured in a tank directly below the tray to be sanitized and re-nutrified in place.

AEROPONICS

Many cultivators use aeroponic systems, such as an EZ-Clone machine, for propagation. Aeroponic systems utilize spray nozzles to mist the stem or roots with a nutrient solution. Cultivators using large-scale aeroponic systems are more likely to use a channel system in which the roots of many plants are enclosed within a channel and spray misters line the inside of the channel. Another method is the bucket system, in which nutrified water and air are maintained in buckets, into which the roots grow.

WICK SYSTEMS

Using a wick, the plants pull nutrient solution up from a reservoir through capillary action. This system is better suited for smaller plants. Heavy feeders like cannabis can lose weight and yield if the wicking process is too slow.

NFT SYSTEMS

The Nutrient Film Technique (NFT) consists of a very shallow nutrient solution that cascades downward in a tube or tray toward the reservoir, where it is reused. It is most commonly used on smaller plants with a short crop cycle, and cannabis plants are very sensitive to interruptions in electricity and the water cycle. This system allows only a relatively small space for cannabis roots to thrive, which can impact crop performance.

DEEP WATER CULTURE SYSTEMS

In water culture systems, the plant is held in a basket just above the nutrient solution and the roots hang down into the nutrient solution. The roots do not suffocate because the reservoir is continuously aerated. This allows the plant to receive an ideal amount of nutrients, as well as oxygen.

HAND WATERING

Watering by hand using hoses or watering cans is a common watering method used at cannabis cultivations.
Many growers prefer the hands-on aspect of hand mixing and hand feeding each plant. However, this method allows for the largest margin of error and is the most labor intensive. Nutrient mixingby hand can easily vary by day or by employee, leading to inconsistent final solutions. The total volume of water being applied to each plant can vary greatly, especially if staff are inattentive.
Nevertheless, most cultivation operations use the hand- watering method at some stage of plant growth. Cultivators must have good standard operating procedures and employee training for hand watering to minimize mistakes.

DRIP WATERING

Drip irrigation is widely considered the most water efficient way of irrigating a crop. Nutrified water is pumped through irrigation tubes and drip emitters to each plant. Many options exist for flow volumes and types of emitters. Cultivators should consult with an irrigation specialist to help determine the correct emitter based on water pressure, length of irrigation runs, container sizes, number of plants to be irrigated at once, etc. Drip irrigation allows the cultivator to fine tune how much water is given to each plant.

Drip irrigation is usually accompanied by a fertigation system that automatically injects nutrients into the water line according to specifications and can be run on programmed time schedules.

LIVING SOIL SYSTEMS

A Living Soil System3 is method of plant production utilizing inputs derived from plant, animal, and naturally occurring mineral origins with the intent of increasing diversity and abundance of ecological soil organisms over time. A Living Soil system requires no flushing of nutrients at any point of the life-cycle — therefore significantly reducing the amount of water usage in an indoor, outdoor, or greenhouse cultivation.

BEST PRACTICES

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. It is generally recommended to select the most efficient method(s) that fit within the budget and expertise of facility staff. However, any facility exceeding 2,500 square feet in size should seriously consider an automated watering system. Clear standard operating procedures and frequent training of staff with irrigation responsibilities are essential to ensuring that the chosen system operates optimally. Table 6 below highlights some of the benefits and drawbacks of the three most commonly used irrigation methods:

AUTOMATION

Automated watering systems are highly recommended to help control accuracy and efficiency and to increase data collection, as well as for the ease of mining that data. Cultivators mining the most data for anomalies, efficiencies and tracking will continue to stay on the cutting edge of the industry. Automated data collection ensures that real- time data is collected daily. Several major manufacturers currently offer environmental and fertigation packages that tie into one software program, allowing for a streamlined data collection process and easy, intuitive data mining. Production is all about repeatability, and data collection helps ensure repeatability. Data collection also helps improve procedures by targeting issues and concerns.

Table 6: Irrigation Methods for Indoor Cannabis Cultivation

IRRIGATION METHOD	EFFICIENCY	BENEFITS	DRAWBACKS
Hand Watering	Low	· Eyes on all plants during watering · Gives grower "hands on" feel · No high-tech equipment required	· Inconsistency of volume per pot · Inconsistency between employees responsible for task · Labor-intensive
Drip	High	· Automated · Precise volume of water · Allows cultivator to water a large number of plants at once	· Potential clogging of dripper · Manual inserting/removal of dripper when moving plants · High cost to install and maintain · More technical, with high learning curve
Flood Tables	Medium	· Automated · Less chance of under-watering plants · Easy and inexpensive to build	· Large amounts of water used at once · Increased humidity if reservoirs do not have lids · Manual labor to clean and refill reservoirs

[3] *Resource: Definition of Living Soil*

MEASUREMENT

The water applied to plants should be measured during each phase of growth. This is most easily achieved when using an automated watering system as described above. Similarly, cultivators should measure runoff to ensure that water is not being wasted, and should set a low runoff target. Ten percent to 15% runoff per watering event is a highly efficient target. Salt levels in the media should be monitored at these low runoff levels to ensure crop quality. Ongoing measurement against this target will help maintain overall water efficiency and identify factors that affect water use, such as employee turnover, schedule changes and equipment changes.

What measurements should I take when monitoring irrigation?

- Ascertaining pH is critical for nutrient uptake. Being outside of range can cause nutrient deficiencies.
- Electrical conductivity (EC) measures the amount of fertilizer in your nutrient solution or root zone. Controlling this value determines how much food you are feeding your plants.
- Volumetric water content (VWC) is the amount of water in the media relative to maximum capacity. Use this number to make sure your roots are getting enough water, but aren't staying too saturated.
- Temperature is critical for root health and function. Too cold and the plant won't eat; too warm and the roots become susceptible to disease.

Need to add Living Soil to this list and differentiate between what you have defined here and Living Soil. I also think giving examples of soil-less mediums should be defined and explained and how they are different from Living Soil - based on the general confusion and how many professional growers I have tell me they are growing in soil when they are not. There is a lot of confusion in this area so clarifying what we can would be really helpful.

Include under Benefits for Living Soil:

Living Soil systems require no flushing of nutrients at any point of the life-cycle - therefor significantly reducing the amount of water usage in an indoor, outdoor, or greenhouse cultivation.

Table 7: Grow Media Comparison

GROW MEDIA	DESCRIPTION	BENEFITS	DRAWBACKS
Mineral Soil	Often thought of as "dirt," soil can vary greatly depending on its composition.	Natural Contains nutrients Easily amended	Not sterilized and may contain pests Very heavy (worker safety) Low steerability Loose media requires more work to keep facility clean. Not all soil is the same, selecting the right kind with the right amendments can be challenging
Rockwool	Made by melting rocks and spinning the molten material into fibers.	Lightweight Inert, so grower can control nutrients Manufacturing process ensures material is clean High steerability	Natural high pH, requires conditioning before use. One time use Fast drainage leaves plants prone to wilting if not managed properly. Not compostable or re-usable and not a recommended sustainable practice."
Coco Fiber	A fibrous media made from the husks of coconuts.	Natural Easily amended Medium steerability (depends on thickness of fibers)	Not sterilized and may contain pests Very heavy (worker safety) Loose media requires more work to keep facility clean.

ELECTRICAL CONDUCTIVITY

Many growers are feeding plants based on specific electrical conductivity (EC) levels identified by the nutrient line they are using. It is important to frequently monitor the EC levels of both the nutrient water being given to the plants and the EC level of the planting medium with either probes or a handheld device. Cultivators have had success with very high EC levels and very low EC levels.

- Averages for vegetative growth: 1.0 – 2.5 EC
- Averages for flowering growth: 2.0 – 4.0 EC

Growers should test runoff frequently to determine if any salts are building up in the medium. Total volumes of water applied to the plant to create runoff may hinge on these numbers. If the plants are able to absorb all of the water and nutrients provided, frequent flushing may not be necessary. While production goals will often drive the target EC for feeding plants, it is important to remember that fertilizer use is another area where cultivators can look to improve their sustainability impact. Many fertilizers are mined from the ground, and some nutrients, such as phosphorus, are being depleted at a rapid pace. Avoiding overfeeding by keeping ECs on the lower side of a target range; recycling and reusing irrigation runoff; and using environmentally friendly sources of nutrients are a few examples of how growers can minimize their impact when it comes to fertilizers.

Resources:

- Home Hydro Systems: Aeroponic Systems How to Grow Marijuana: Aeroponics
- Current Culture H20: Hydroponic System Info

Drip Irrigation Resources:

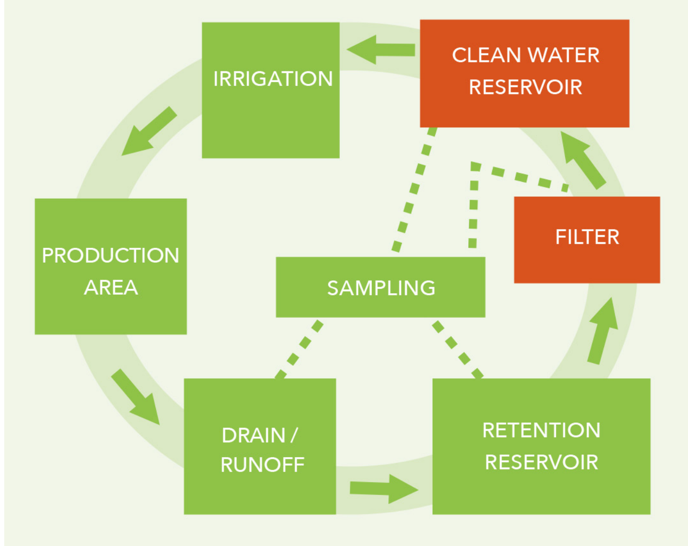
- Irrigation Tutorials: The Basic Parts of a Drip System
- Irrigation Tutorials: Drip Irrigation Design Guidelines
- Procedure for flushing plants: American Agriculture: Flushing Potted Plants

WATER RECYCLING

Cultivating cannabis in controlled indoor environments provides multiple opportunities for water efficiencies and water recycling. Virtually all excess water runoff and water vapor can be captured and delivered back to the beginning of the watering process.

Note: This water reuse practice is not to be confused with Denver's updated graywater regulations. Graywater — which includes wash water, shower water and sink water — can be applied only to outdoor landscapes, not reused indoors or applied to consumable crops. Water applied to cannabis plants through hand watering, flood trays or drip methods can be easily captured in two complementary ways.

Figure 5: Irrigation water recapture process



PROCESS DESCRIPTION

First, applying water onto plants generally produces some amount of excess water that can be captured and piped back to water storage tanks. This excess water should be filtered and sterilized again to avoid contaminants and then stored for the next round of watering. The second water recycling method involves capturing HVAC condensate.
Healthy cannabis plants naturally transpire a majority of the applied water after each watering cycle through transpiration. This water vapor passes through the cultivation room's HVAC equipment and condenses back to relatively clean liquid water that can be directed to a facility's water storage area to begin the water process anew.

BEST PRACTICES

Water should not be a single-pass ingredient for cannabis production. Cultivation facilities equipped with water storage can easily incorporate water- recapture methods into existing cultivation practices for reuse.
Water can be captured as follows:

- As excess runoff while watering: Best accomplished when all runoff water is contained in drain lines or ditches
- As HVAC condensate and dehumidification water: Often very clean (almost reverse osmosis quality); however, it should be checked for heavy metals that can leach off the cooling coils.
- Pipe captured water to a holding tank for reuse.

Recaptured water may need to be purified again. There are several options available, but method selection should be based on what the cultivator is trying to remove from the irrigation water. Cultivators should look for technologies that kill waterborne pathogens such as Pythium, Phytophthora, Fusarium and Rhizoctonia.

Options include:

- UV technologies, which are very popular in the greenhouse/nursery industry.
- Copper technologies, which are helpful for use against Pythium and Phytophthora Electrochemically Activated Water (ECA).
- Water storage located immediately upstream of the water-filtering process.
- Chemical treatments, such as ozone and hydrogen peroxide, simultaneously disinfect and raise the oxygen levels within the water.

Subsequent rounds of watering should first be pulled from this storage tank before requiring any new "tap" water to be drawn. This recaptured water can make up the vast majority of the next watering cycle's water.

IMPROVING WASTEWATER QUALITY

Certain practices in cannabis production can lead to unintended high levels of contaminants in a facility's wastewater discharges. Such contaminants can add stress to treatment facilities and can be largely avoided.

PROCESS DESCRIPTION

Purifying water using reverse osmosis generates significant volumes (at least a 1:1 wastewater to water ratio) of brine which must be discarded to sanitary drains. The concentration of brine (high in salts and minerals) creates difficulties in removal at water treatment plants. It is best to avoid the reverse osmosis process altogether and use other water filtration methods (see Water Filtration and Purification above). High concentrations of cleaning agents in wastewater are difficult to process as well. When cleaning cultivation rooms and associated equipment, cultivators should use cleaning products according to the manufacturer's specifications. Concentrated cleaning solvents should be diluted appropriately as described on the label.

A higher concentration of solvent does not necessarily clean better and will lead to poor indoor air quality and difficulties in processing the wastewater.

BEST PRACTICES

Cultivators should:

- Use cleaning products as directed; dilute concentrated products according to the intended cleaning purpose on the label.
- Use environmentally friendly cleaners such as those rated by Green Seal, Eco Logo or Safer Choice.
- Use filtration for water purification to avoid significant water discharges from reverse osmosis.
- Use water nozzles for any cleaning operations to avoid excess water use.
- Avoid over-watering crops as this can lead to unintended high levels of chemicals and suspended solids in sanitary drains.
- Refrain from dumping any liquids into storm drains.

ADDITIONAL CONSIDERATIONS

Storm drains empty directly into local waterways. There is no treatment to storm drain effluent. In fact, by law, nothing is allowed to be dumped down storm drains — only rainwater and snow melt. Cultivators can help keep local streams clean by not dumping into storm drains, keeping property free of litter and using dry, absorbent cleanup methods for liquid spills outdoors.

Resources:

- CASR Rules and Regulations Governing Graywater Treatment Works
- Greenhouse Management — 10 Tips for Recycling Irrigation Water
- Greenhouse Product News — Grower 101, Water Disinfection
- Greenhouse Management — Disinfecting Recycled Irrigation Water
- Clean Water 3 — Treatment Technologies
- Examples of UV purification products: Hortimax Growing Solutions Superior Aqua Systems
- Examples of copper purification products: Aqua-Hort
- Priva Vialux Line Water Disinfection Examples of ECA products: Horti-Daily Royal Brinkman
- Green Seal Eco Logo
- EPA Safer Choice

Figure 6:
Example of piped drainage from trays

Figure 7:
Piped drainage running into floor sink

Figure 8:
Example of coarse filter on tray to keep large debris out of recycled water

Figure 9:
Sediment Filter

Figure 10:
Hortamax Vitalite UV Filter

Figure 11:
Brinkman ECA System

Resources:

- DDPHE Rules and Regulations Governing Graywater Treatment Works
- Greenhouse Management – 10 Tips for Recycling Irrigation Water
- Greenhouse Product News – Grower 101, Water Disinfection
- Greenhouse Management – Disinfecting Recycled Irrigation Water
- Clean Water 3 – Treatment Technologies

Examples of UV purification products:

- Hortimax Growing Solutions
- Superior Aqua Systems
- Examples of copper purification products:
- Aqua-Hort
- Priva Vialux Line Water Disinfection
- Examples of ECA products:
- Horti-Daily
- Royal Brinkman

WASTE MANAGEMENT & DIVERSION

EXECUTIVE SUMMARY

The cannabis industry generates waste and can benefit from the adoption of sustainable waste management practices. There are four general waste categories that cannabis operators must deal with: Plant, universal, hazardous, and non-hazardous waste. How these waste streams are managed is impacted by cannabis and non-cannabis regulatory frameworks, as well as external factors which collectively can present barriers to landfill diversion as discussed below.

Currently in Denver, landfilling is the main form of waste disposal, with recycling and composting used to a lesser extent. Following the simple progression of reduce, reuse, recycle can have a positive effect on business performance by reducing costs. Therefore, cultivation facilities should aim to reduce, reuse and compost as much as possible. Cannabis operations should consider the sources of the resources used and purchase items that are made from natural, compostable or recycled materials, when available. For example, an operator can send low- THC organic waste (stalks, stems, fan leaves and rootballs) directly to a certified waste or composting facility without 50/50 mixing or rendering unusable/ unrecognizable. Dispensaries can now collect consumer packaging for composting, recycling and reuse (with sanitization and inspection steps).

The ideal goal is for the industry to ultimately design operations that reduce the amount of waste generated by aiming for zero landfilling of waste, designing packaging that adheres to local guidelines for reuse, recycling, and composting, while minimizing material inputs through recycled content, and or by implementing package collection take-back programs.

Introduction

The value chain of the cannabis industry is composed of upstream agricultural production and manufacturing as well as downstream distribution and retail channels for an array of cannabis products. As we have seen, the process of bringing cannabis products to market–particularly with the indoor cultivation model–can be energy, water, and material intensive. It can also result in significant emissions to the environment and solid waste streams that are strictly regulated by state law, as in the case of high-THC content plant waste, or managed by cultivations, dispensaries, and consumers through available waste services and infrastructure including hauling services, public receptacles, recycling centers or “MRFs” (Material Recovery Facilities), industrial composters, and landfills.

Currently, neither the state of Colorado, nor the city of Denver publish industry-specific numbers for waste in the cannabis sector. However, the statistics that are available paint a rather dismal picture with broader implications for materials management in Colorado and across the country. In 2022, Colorado recycled and composted a mere 16% of its "MSW" municipal solid waste. At half of the national average MSW diversion rate of 32%, Colorado ranks among the lowest states in the country for recycling and sends the vast majority of its MSW–95% of which is estimated to be recoverable with existing infrastructure–to landfills.[1] Per capita, Coloradans generate twice as much waste as the average US citizen. So, even the highest MSW recycling rates in our state–which exceed 50%–are tempered by high generation and taken alone, tell an incomplete story. It is clear that strategies of source reduction and reuse must accompany recycling if we are to make genuine progress.

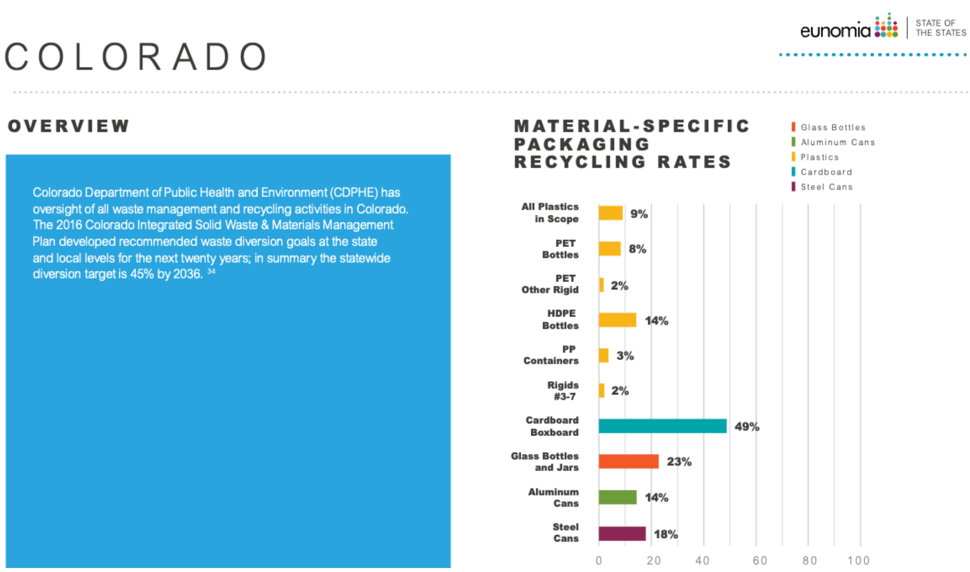
A recent study on recycling of Common Consumer Packaging Materials ("CCPM") in the United States provides additional insight into Colorado's mediocre record in diverting CCPM from the trash bin.[2]

This graphic shows that the majority of CCPM–including high-value PET plastic bottles, aluminum and steel cans, and glass–are recovered at surprisingly low rates.

Despite the lack of industry waste data and acknowledging that the cannabis industry, like any other, has limited control over consumer behavior to ensure that products are disposed of properly at the end of their use life, the state figures suggest the majority of cannabis-related consumer waste ends up in landfills.

To a large extent, the lack of public access to recycling services in Colorado–only 30% of the state's residents--dictates the poor results that we continue to experience in our state. Thankfully, a new Extended Producer Responsibility ("EPR")*4 bill–the first in the nation to be fully funded by packaging producers–and policies and programs in Denver and other municipalities across the state promise to dramatically improve access and change the materials management landscape for the better.[3]

Before delving into how the cannabis sector can contribute to improved outcomes for sustainable materials management in and beyond Denver, it's helpful to settle on a definition. According to the EPA, sustainable materials management (SMM) is:[4]



[1] Eco-Cycle and COPIRG, 2022, The State of Recycling and Composting in Colorado (2022): 6th annual look at recycling and composting in Colorado. available at: https://pirg.org/colorado/foundation/resources/the-state-of-recycling-and-composting-in-colorado-2022/#:~:text=In%202021%2C%20Colorado%20landfilled%20almost.more%20than%20the%20national%20average.

[2] Eunomia and Ball Corporation, 2021, The 50 States of Recycling: A State-by-State Assessment of Containers and Packaging Recycling Rates. available at: https://www.ball.com/getattachment/37f5f87f-d462-44c5-913f-d3075754741a/50-States-of-Recycling-Eunomia-Report-Final-Published-March-30-2021-UPDATED-v2.pdf

[3] Colorado Department of Health and Environment, 2023 Extended Producer Responsibility Program. available at: https://cdphe.colorado.gov/hm/epr-program

[4] U.S. EPA, 2023, Sustainable Materials Management, available at: https://www.epa.gov/smm/sustainable-materials-management-basics

...a systematic approach to using and reusing materials more productively over their entire life cycles. It represents a change in how our society thinks about the use of natural resources and environmental protection. By examining how materials are used throughout their life cycle, an SMM approach seeks to:

- Use materials in the most productive way with an emphasis on using less.
- Reduce toxic chemicals and environmental impacts throughout the material life cycle.
- Assure we have sufficient resources to meet today's needs and those of the future.

The crux of this approach is a sea change in how we treat materials in America; not as waste, trash, or rubbish, but as valuable resources that we must use as efficiently as possible. Anyone familiar with the concepts of Zero Waste and Circular Economy will recognize similar principles to extend product utility, design out waste and toxics, and employ materials in ways that contribute to rather than degrade environmental integrity. How to systematically translate such principles into practice in the cannabis sector is the key.

In the sections that follow, we will address sustainable materials management in the contexts of product packaging, facility operations, and discuss the larger framework of policies, services, and infrastructure that dictate how the industry interacts with our waste management system. Along the way, we will assess opportunities and barriers–including some that are unique to the cannabis industry–and make recommendations to:

1. Know your "waste": familiarize your entire staff with municipal guidelines, conduct trainings, regular audits, track, and report;[5]
2. Clean up existing waste streams by phasing out problem materials (in designs, and procedures);
3. Adapt sourcing to local guidelines and services to support and not hinder recoverability
4. Engage an expert and work with reputable materials management services;
5. Design for "higher level strategies" of source reduction through recycled content, reuse other Circular Economy/Zero Waste strategies.

We will seek to prioritize recommendations for sustainability while considering practicality and simultaneously dispel some of the confusion and–in some cases–misinformation that persists about materials in our society. Our hope is to empower industry stakeholders with actionable information, options, and resources to contribute positively to the collective change we all wish to see.

OVERVIEW

There are four general waste categories that cannabis operators must contend with: plant, universal, hazardous, and non-hazardous waste. How these waste streams are managed is impacted by cannabis and non-cannabis regulatory frameworks, as well as external factors which collectively can present barriers to landfill diversion as discussed below.

Currently in Denver, landfilling is the main form of waste disposal, with recycling and composting used to a lesser extent. Following the simple progression of reduce, reuse, recycle can have a positive effect on business performance by reducing costs. Therefore, cultivation facilities should aim to reduce, reuse and compost as much as possible. Cannabis operations should consider the sources of the resources used and purchase items that are made from compostable or recycled materials, when available. For example, an operator can send low-THC organic waste (stalks, steams, fan leaves and root balls) directly to a certified waste or composting facility without 50/50 mixing or rendering unusable/unrecognizable. Dispensaries can now collect consumer packaging for recycling and reuse (with sanitization and inspection steps), and composting, subject to local guidelines and access to composting services/facilities.

The ideal goal is for the industry to ultimately design operations that reduce the amount of waste generated by aiming for zero landfilling of waste; designing packaging that adheres to local guidelines for recycling and composting, minimizing material inputs through recycled

[5] U.S. EPA, 2023, Instructions on Conducting Waste Assessments. available at: https://www.epa.gov/smm/instructions-conducting-waste-assessments

content, and or by implementing reuse strategies with take-back programs for product packaging.

Positive environmental impacts can be significant when sustainable waste practices are chosen. Taking this further, we might begin to not think in terms of waste, but instead of planning, designing, and operating intentionally to reduce waste and to think in terms of reusing, regenerating, and recycling everything. The sustainability benefits of waste reduction include:

Economic Competitiveness:

Solid waste reduction efforts can save money through reduced materials procurement and disposal costs. Also, the implementation of water and energy efficiency strategies can also result in solid waste reduction. Don't throw your profit margins in the trash — instead, implement environmental efficiencies.

Community Relations:

Waste reduction and diversion can reassure neighborhood residents that a cannabis cultivation operation is a responsible environmental partner, committed to the health and wellbeing of the local area. In addition, because land-use impacts and greenhouse gas (GHG) emissions are reduced, a progressive solid waste management program can dovetail with municipal goals, such as the City of Denver climate, energy and land use sustainability goals.

Environmental Impacts:

Waste reduction and diversion results in lower volumes of municipal solid waste (MSW) and subsequently lower embodied energy, landfill gas (LFG) emissions, and landfill leachate.
The goal is to keep the waste management hierarchy top-of-mind: reduce, reuse, re-purpose, recycle, regenerate. The Ellen MacArthur Foundation frames it this way:

"The circular economy is based on three principles, driven by design:

- Eliminate waste and pollution
- Circulate products and materials (at their highest value)
- Regenerate nature

It is underpinned by a transition to renewable energy and materials. A circular economy decouples economic activity from the consumption of finite resources. It is a resilient system that is good for business, people and the environment.[6]

BARRIERS

Significant obstacles to sustainable materials management exist in the cannabis industry. Thankfully, many are surmountable. A combination of increasing awareness and cost-effective options can help the industry make progress. Please see the resources in each section and references at the end of this chapter to help guide your sustainability journey.

Barriers are mentioned throughout this chapter, but here are some of the key issues organized according to the materials management hierarchy:

- **Reduce**
  - single-use packaging model;
  - child protection requirements;
  - reduction efforts may result in "burden shifting", e.g. efforts to reduce single-use plastic may increase use of other materials, or add to upstream or downstream impacts (i.e. outside of the use phase)

[6] *Ellen MacArthur Foundation, 2023, What is a circular economy? Available at:* https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

- **Reuse**
  - product health and safety requirements;
  - cost and complexity of take back programs;
  - lack of support services model in the cannabis sector;
  - potential for burden shifting (e.g. increased transportation emissions associated with reuse model);
  - potential liability risk;
- **Recycle (/Compost)**
  - general lack of industry awareness and/or confusion on how to design product packaging and manage it for recyclability;
  - marketing of packaging products that do not meet local guidelines or market requirements for recyclability;
  - confusion about materials that are labeled as recyclable or compostable, but are really not;
  - local guidelines/services that do not consider/incorporate cannabis packaging;
  - product health and safety requirements contribute to hybrid packaging that presents challenges for the customer to "recycle right";
  - a dearth of reporting to verify recycling efforts;
  - disagreement on how to accurately assess the environmental impacts associated with recycling;
  - a proliferation of packaging products that sub-optimize for a specific material or attribute (i.e. bio-based, biodegradability, PCR, aluminum vs. plastic vs. glass, etc.), but otherwise fail due to a misalignment with existing infrastructure, services, and end-markets;
  - misleading and/or false marketing claims (i.e. greenwashing) associated with packaging products in the cannabis sector.

Again, please see the Resources at the end of each section as well as the References at the end of the chapter. In particular, the Sustainable Packaging Coalition[7] and Association of Plastics Recyclers[8] provide expert guidance on product packaging design and support a systems approach to solving sustainable materials management issues facing the cannabis sector.

PLANT WASTE MANAGEMENT

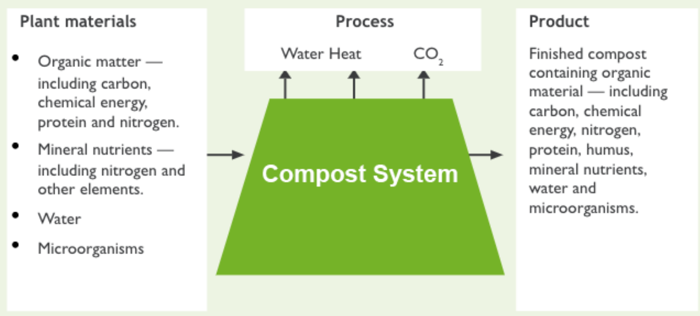
Plant waste materials represent a significant component of the cannabis production waste stream. This waste stream consists of all unusable plant matter including stalks, stems, fan leaves, root balls, etc. Currently, there are low rates of waste diversion from landfilling, which is the most common option in the Denver area. The ideal is that all plant matter is reused, recycled, or composted to create a soil amendment. The revised regulation changes that now allow for direct composting of low-THC organic plant waste from cultivation operations should encourage greater diversion to the regenerative options outlined in this section.

Waste pickup is a great solution for this biomass as it can be used to create other products before being composted. Cultivations should side-stream stalks, steam, fan leaves and root balls for direct composting. Composting can take place on the licensed operator's property, but it is more commonly carried out at a certified compost or waste operator's facility. Unusable plant material can create valuable agricultural inputs to the compost stream while maintaining compliance. In general, food scraps and yard trimmings are all compostable in commercial compost facilities. A Living Soil System for cultivation can reduce waste generation by eliminating the need to throw "soil' or grow media away after each harvest.

[7] *Sustainable Packaging Coalition, 2023, All resources archive including sustainable packaging white paper, design guides for reuse, recyclable, recycled content, and compostable, position papers, and materials recovery system analysis, available at: https://sustainablepackaging·org/resources/*

[8] *Association of Plastics Recyclers, 2023. APR Design Guide· available at: https://plasticsrecycling·org/overview*

Figure 12: Composting process diagram



Alternatively, plant and food waste can be processed on- or off-site using Bokashi fermentation or anaerobic digestion. However, these and other options as listed in MED regulations below can present some logistical and compliance challenges and may not be available in certain areas.

"Any of the following may be used as more sustainable alternative methods to render regulated marijuana waste unusable and unrecognizable. The methods below do not require a 50 percent mix with non-marijuana waste:

On-site composting, anaerobic digestion, pyrolyzing into biochar, or biomass gasification. If using one of these options, please refer to Rule 3-230(E)(2) of the Marijuana Enforcement Division's Colorado Marijuana Rules, 1 CCR 212-3."

In summary, implementing best practices for organic waste management can reduce the environmental impact of a facility by creating valuable agricultural inputs while maintaining compliance.

BEST PRACTICES

Cultivation facilities' waste is mainly generated from unused plant material, agricultural inputs, equipment, and product packaging and can be categorized as either organic, recyclable, universal, or hazardous waste. Although cannabis waste is strictly regulated, this section will outline compliance best practices that minimize the industry's environmental impacts from waste.

For facilities in urban settings, compost collection is likely the most common option for managing organic waste. Cultivations should side-stream low-THC plants components (stalks, steams, fan leaves, and root balls) for direct composting without mixing.

Paper or cardboard that cannot be recycled due to contamination may be discarded with the high-THC compostable materials.
(Important: Check your jurisdiction's local composting guidelines or with your compost hauler to be sure of what is accepted in the compost stream.) Common sources include paper towels from restrooms, handwashing stations and kitchens, shredded paper, and soiled or wet cardboard. These materials can help contribute to compliance with MED requirements for mixing high-THC plant waste.

Cultivators should place separate receptacles for compostable materials throughout the facility anywhere the waste is generated. Cultivators should always include descriptive signage (photos of compostable materials are helpful), and it is generally a best practice to co-locate a compost bin with each trash and recycling bin. Employees may not be familiar with compostingpractices. Providing regular training to all staff on which items belong in each bin is important to ensure that recyclable matter is not contaminated with other types of waste.

ADDITIONAL CONSIDERATIONS

Incorporating composting into a facility requires an additional waste receptacle outdoors. Cultivators should ensure that there is adequate space for the receptacle, and that it meets MED requirements for security and control requirements.
Marijuana waste that can support the rapid growth of undesirable microorganisms should be held in a manner that prevents the growth of these microorganisms as required by MED Rule R504 Health and Safety Requirements.

Resources:

- A1 Organics Composting Cannabis Waste Guide
- A1 Organics Hold on Compostable Products in the Compost Stream
- Certifiably Green Denver Composting Resource Sheet
- Bokashi Fermentation Method and Resource

UNIVERSAL & HAZARDOUS WASTE

Hazardous and universal wastes are present in most cannabis cultivation and extraction facilities. Reducing and managing these wastes can reduce risks to employees and the environment and is essential for maintaining compliance. Source-reduction and substitution represent the best opportunities for reducing risk and saving money on hazardous waste management and disposal.

PROCESS DESCRIPTION

Regulatory requirements for any given business depend upon the quantity of hazardous waste generated. Universal wastes are a subset of hazardous wastes that have reduced management standards as defined by federal, state and local laws, regulations, rules or other requirements. Most hazardous wastes commonly generated by cannabis facilities are considered universal wastes. These include mercury-containing lighting and ballasts, many types of pesticides or other chemicals used in the cultivation process, certain solvents or other chemicals used in the production of marijuana concentrate, marijuana soaked in a flammable solvent for purposes of producing a marijuana concentrate, electronics (e- waste) and batteries.

Cultivators must determine which regulations apply to the waste before disposal, including making a hazardous waste determination. It is important for each operator to determine what generator category they fall into. Some small-quantity generators may be exempt. Using organic pesticides instead of synthetic chemicals will help reduce hazardous waste. Vendor selection can also reduce your generated waste; for example, ordering LEDs instead of mercury filled lighting fixtures will help. Facilities should have a written collection and disposal plan for used light bulbs and used batteries.

Cultivators should consult with the Hazardous Materials and Waste Management Division's Customer Technical Assistance line at 303-692-3320 with any questions about hazardous waste. Hazardous wastes must be disposed of properly by a registered hazardous waste transporter shipping to a hazardous waste treatment, storage and disposal facility (TSDF).

CONSIDERATIONS:

Prior to beginning any marijuana-related operations, cultivators should consider the following:

- Is a plan in place for dealing with solid and hazardous wastes generated during operations?
- What quantities of waste will be generated, and what are the various waste streams?
- If the operation is generating hazardous waste, has the cultivator determined which is the appropriate generator category and what rules may apply?
- Conditionally exempt small-quantity generator (CESQG).
- Small-quantity generator (SQG).
- Large-quantity generator (LQG).
- Is there a waste storage plan addressing storage methods and locations and length of time the waste may be stored?
- What readily available materials could be used to render marijuana plant material and marijuana products unusable and unrecognizable?
- Where will the waste be sent, and how will it be transported?
- Will any composting of marijuana- related waste occur on-site?
- What licensing and permitting requirements will apply to this operation?

Resources:
- CDPHE Generator Assistance Program
- EPA Resource Conservation and Recovery Act (RCRA)
- Colorado Hazardous Waste Generator Handbook
- CDPHE Solid Waste Regulations

BEST PRACTICES

- Planning usage of pesticides and chemicals. Purchasing materials in smaller quantities and buying no more than a one-year supply of product. This helps avoid excess material expiring or becoming obsolete as regulations change.
- Preparing only the amount needed for each applcation.
- Managing hazardous waste to minimize the potential for a release to the environment and ensuring proper recordkeeping. (e.g., store in a sealed and labeled container with secondary containment in a locked area.)
- If applying or handling pesticides, lawfully adhering to all pesticide label instructions. It is also recommended that at least one employee has obtained a CDA Private Applicator license. More information can be found at www. colorado.gov/pacific/agplants/private-pesticide-applicators.
- Selecting ideal lamps and ballasts.
- Purchasing lamps and ballasts with the longest burn time possible to reduce the frequency of replacement.
- Considering LED lighting, which does not become hazardous waste at the end of its life.
- Recycling universal waste lamps, ballasts, e-waste and batteries with a qualified recycler.

Resources:
- Hazardous Waste Management and Guidance
- Marijuana Enforcement by the Colorado Department of Revenue
- Mercury-Containing Lighting Universal Wastes
- CDPHE Generator Assistance Program
- EPA Resource Conservation and Recovery Act (RCRA)
- Colorado Hazardous Waste Generator Handbook
- CDPHE Solid Waste Regulations

Packaging and Materials

Deciding on what packaging to use is critical for all retail sales of cannabis products. The information below is intended to help guide this decision, taking into consideration the sustainability implications both upstream and downstream and providing best practices for cannabis business operators. Upstream considerations are all the inputs that go into creating the packaging itself. Downstream considerations are what happens to the packaging once the consumer discards the package. We also want to stress that any packaging decision is one based on sustainability impact tradeoffs. There are no silver bullets to a single-use packaging model and all decisions will have negative environmental impacts. With that said, certain packaging decisions will have a less negative impact than others or help bolster and support a current waste management system. We want you to leave with a guide to inform your decisions and know what questions to ask. In the section that follows, we present the different material types used in cannabis packaging and inform on the end-of-life scenarios. Lastly we present some options for best practices.

Cannabis is packaged in a myriad of different options. Commonly seen in the industry are folding cartons, rigid containers, flexible bags, jars, vials, pouches, trays, tubes etc.

The following are the main material types used for cannabis packaging. Paperboard, Metal, Glass, and Plastic. Within each of these categories, there are subcategories of material types, i.e. different types of plastics, metals, glass, and paper. To understand the impact of each material type, you should look at the individual material type and its characteristics. The end-of-life options for these material types include: Recycling, Composting, and Landfilling, and in some jurisdictions, incineration. The final two options are the least desirable from the standpoint of sustainability. As a packaging purchaser, you will take into account some of these considerations as well as the price point you are trying to hit, the brand look and feel as well as, shelf appeal, and product storage requirements.

Glass

Recyclability: Glass can be repurposed and recycled infinitely without degrading the quality. Almost all glass contains some percentage of recycled content, about 30% in most cases. Sourcing packaging that contains some percentage of recycled content helps support the recycling industry and is encouraged. Please note that not all glass is the same, and some glass-like Borosilicate glass contains additives that make it harder to break and resistant to heat changes, but also render it unrecyclable, and a contaminant in the recycle stream. When deciding on glass, make sure to choose one that is recyclable. Painted glass also may not be accepted.

Reusability: One of the sustainable aspects of glass is that it can be reused and, if transported and handled properly, is very durable and long lasting. Ideally, the cannabis industry would have a reuse model for packaging. Still, because of regulations, distribution models, sanitation hurdles, and a variety of other roadblocks, we have yet to see widespread adoption of reuse models. Regardless, the consumer can reuse glass packaging for a variety of personal uses depending on the type of packaging. Reusability should be encouraged because it reduces waste in landfill and keeps materials in use.

Non-Toxicity: When glass does end up in our natural environment and outside of our waste capture systems, it is free of harmful chemicals and toxins that cause negative environmental impacts to our ecosystems.

Energy intensive: The production and recycling of glass is energy intensive in comparison to other materials. The high temperatures required to produce glass require energy that contributes to increased greenhouse gas emissions and natural resource depletion depending on the energy source used in manufacturing or recycling. Weight and shipping considerations: Glass is heavy. Hence, shipping and transporting glass is energy intensive and increases life cycle carbon emissions. Oftentimes glass also must be packaged with plastic for protection during transport. This should be considered in the sustainability footprint of the glass itself. Glass breakage in shipping is also common, so packaging loss should be a consideration.

Mixed materials: Often, glass cannabis packaging is paired with a plastic locking mechanism to seal the product and meet child-resistant requirements. Ensure that the packaging you choose is easy for the customer to recycle and that they are informed about separating mixed materials for recycling.

Metal

Recyclability: Like glass, metal is infinitely recyclable. Commonly seen metals for cannabis packaging are aluminum, steel, and tin. It is also an ideal material type for the recycling system. In general, it is easy to capture and does not have many contaminants. The recycling system for metal is strong and has the highest rates among all cannabis packaging materials.

Durability: Metal is a safe bet for protecting cannabis products. It is strong and resistant to cracking, shattering, or degrading. It is easy to transport, and depending on the form factor, it can be a lighter-weight option than some other products. Extractive and energy-intensive: Beyond being another energy-intensive manufacturing process, mining metals used to create metal packaging is both energy intensive and destructive to natural environments. While metal ranks well for its downstream attributes, it ranks low due to heavy upstream impacts. Consequently, ensuring metal packaging is recycled is paramount to avoid mining of virgin metals for single-use packaging. Cannabis businesses should strongly encourage their customers to recycle metal packaging.

Product freshness: Metal oftentimes must be combined with other material types to create a good seal. Metal on metal does not provide the moisture barrier cannabis products require, so consider the implications of any additional materials employed and whether or not they will hinder recyclability.

Paperboard

Variety of renewable materials: Paperboard is a broad category with several different feedstocks. Paperboard can be sourced from renewable resources like trees and hemp plants. These various feedstocks will have different impacts. You can also look for paperboard with some percentage of recycled content. For all paper types, ask questions about the sourcing of the feedstock and if they are using certified sustainable and ethically sourced feedstocks that have strict requirements against deforestation and other harmful processes.

Recyclability: Paperboard is commonly recyclable. However, there are also important things to avoid rendering paper packaging unrecyclable. In particular, avoid coatings and films. These will most likely impact the recyclability and cause contamination issues. Some child-resistant paperboard options are effectively hybrids composed of mixed materials. Make sure to choose a paperboard and employ printing that supports recyclability. For example, avoid plasticized labels and use plant-based inks.

Lightweight: Paperboard is usually a lightweight option and can be folded during shipping to reduce the space needed for shipping and storage. Folding paperboard cartons can be assembled in-house unlike rigid plastic glass and metal packaging options.

Water Usage: The production of paperboard products is extremely water intensive. The water required to grow the trees and hemp plants, as well as the water required to produce paper, is taxing on the environment.

Chemicals used in production: While paperboard is often seen as a natural product, its production uses chemicals. Look to use feedstocks that avoid chemicals like bleach or employ coatings including fluorinated compounds (e.g. PFAS, PFOAs, etc.). Such chemicals can leach into the natural environment and pose serious long-term threats to human and environmental integrity. Look to source from manufacturers and distributors that are transparent about their supply chain and can substantiate their practices with certifications and/or third party verification.

Limited uses for certain cannabis products: Paperboard makes a great secondary layer but often has to be combined with a primary package to seal and keep the product fresh. This can create packaging redundancy and complicate recycling efforts due to their hybrid nature. Consider the overall impact and implications of multiple layers of packaging when a single layer can be used instead.

Plastic

Recyclability: Petroleum plastic is recyclable. Not infinitely like glass or metal, but is lightweight, durable, can be recycled several times, or upcycled into long-lasting products including building materials and other consumer products. With that said, there are significant and systemic obstacles to making plastic recycling effective and more sustainable. Unfortunately, the limitations of the current waste management infrastructure combined with our profligate use of plastic, result in a broken system that needs support and change to work.

As a plastic purchaser, it is important to understand the different characteristics of your plastic. You might hear common terms: Rigid, Mylar, Flexible, Bio-based, Petroleum-based, Plant-based, Hemp-based, Compostable, Biodegradable, Recycled content, or PCR. All of these will fall into one of the number 1 to 7 categories, the de facto identification for different plastics in our recycling system. Unfortunately, many plastics that display a 1-7 resin code and “chasing arrows” symbol are neither desired, processed, nor lack end markets at many recycling facilities. Flexible packaging like Mylar is a mix of several material types that make it extremely difficult and costly to recycle and, like plastic bags and films, are not accepted in municipal systems. Further complicating things are that many packaging products labeled as “biodegradable” or “compostable '' are mistaken for petroleum plastics and placed in recycling bins. These contaminate the recycling stream and will either be landfilled or lower the quality of commodities to plastic end-markets.

Typically, packaging that displays the #1, #2, or #5 resin code is the desired type of petroleum plastic for recycling centers and plastics markets. Using cannabis packaging that includes some percentage of post-consumer recycled content is another way to support the recycling industry. For quality and/or safety considerations, virgin plastic is used much more extensively than recycled content. Despite increasing demand for (and regulations that require) post-consumer recycled content, the recycling industry lacks stable end markets for many material types, and the vast majority of plastic packaging ends up in landfills. It is important to check with your local MRF to confirm they can process the packaging type you are using and have access to an end market.

Lastly, the size of the package may determine its recyclability. Often smaller packages will fall through plastic sorting machines causing them to be sent to a landfill. This is an unfortunate reality of the recycling process and needs to be addressed. Certain pigments, especially black, pose challenges for automated sorting technology in recycling centers and result in increased landfilling of plastics.

Easy to transport: Plastic is typically lightweight and durable in transport. Many proponents of plastics will point to the limited upstream impacts of plastic packaging due its transportability. However, the end of life management options for many plastics–particularly plastic materials that do not conform with municipal recycling guidelines–are limited. So, from a life-cycle perspective, there is a significant trade-off.

Product storage: Due to the regulations around child-resistant packaging and a need for moisture barriers, plastics have become a common choice for the cannabis industry. Depending on the plastic type and overall design, plastic packaging can provide prolonged shelf life for a variety of cannabis products. Increasing shelf life and maintaining product quality should be a top priority of anyone packaging cannabis products.

Harmful Toxins: Both petroleum-based and compostable plastics can contain harmful chemicals like phthalates and BPA. These are harmful to us and the natural environment. Look to avoid plastics that contain these and other chemicals that pose significant ecotoxicity and/or human health risks.

Produced from non-renewable resources: Petroleum-based plastic uses fossil fuels, chiefly natural gas, as a feedstock. Fossil fuels must be extracted, transported, and refined. Even when plastics are made from plant-based feedstocks, there is often a reliance on fossil fuels in the cultivation and transportation process. Plant-based feedstocks may also be derived from food crops traditionally intended for human and/or livestock consumption. The single-use model around low-cost plastic packaging has created a situation where our dependence on nonrenewable resources will continue to strain the environment until we build systems that can reduce our need and dependence on non-renewable resources. Choosing material types that support and address systemic sustainability in a holistic manner is key.

Plastic waste in our environment: Due to the nature of plastic and our severely challenged global waste management and recycling system, much of the plastic packaging we use ends up in landfills or the natural environment. Current issues with microplastics and toxicity in ecosystems need to be addressed and it starts with avoiding the generation of unnecessary and non-recyclable single use plastic packaging in the first place.

Complications with compostable and "biodegradable" packaging: Several new plastic types and compostable plastics have been developed in recent years and are being used in the cannabis space. While there are potential benefits to many of these new material types, many require specialized systems to manage them correctly. Compostable packaging has been limited in the cannabis industry due to the wall thickness needed to meet regulations; most of the options will not meet industrial compost facility standards.[9] Biodegradable packaging lacks definition and end-of-life options.[10] These are not desired in landfill, recycling facilities, or compost facilities. Consult your municipal guidelines to select packaging that can be accepted at an industrial compost facility, recycling center, or landfill.

Best Practices and Recommendations

Reduce material usage and excess packaging: Due to regulations, the need for shelf appeal, and the nascent nature of cannabis packaging, we find that a great deal of cannabis packaging used could either be reduced or eliminated altogether. When choosing what packaging to use, ask yourself if this extra layer is needed or if you could find an option that reduces the overall material used. If the packaging company you are working with does not have the right size or offering, someone else might. Ask your supplier if they know of any other options that might fit your needs. We understand the importance of shelf appeal and meeting regulations for packaging.

The point here is to explore all options and make sure you are considering the amount of material you are using and if it could be reduced or removed in place of a single-piece option.

Consider upstream impacts of your packaging: All packaging comes from somewhere and strains the natural environment no matter what you choose. You should look at the environmental impact of feedstocks used to produce your packaging. The amount and type of energy used in production. The shipping distance and method used. Ask your supplier questions about all these things. They should be transparent about what the product is made of, where it is made, and the energy sources being used. You should also ask for documentation to ensure they do what you are told is true or current.

Consider the downstream impacts of your packaging: Probably the most confusing aspect of cannabis packaging is what happens to it once it is disposed of. The first reason this is so difficult is that waste systems and end-of-life options vary state by state, and even within the state, you might find variation from county to county. What is recyclable in one region might not be in another. This is complicated because even if it is technically recyclable, there might not be an end market for recycled material. The material will be sent to a landfill if there is no end market. Just because something is recyclable doesn't mean it will be. Mixed material types, different colors, and sizes all affect recyclability. As an operator, it is up to you to understand your local guidelines and choose a package–not just a material type–that is designed for recovery and recycling.[11, 12] For example, #7 plastics might carry a recycling symbol, but because this is a catch-all category, it will have no end market and will contaminate recycling streams (and reduce the market value) of more desirable post-consumer plastics.

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[9] Colorado Department of Health and Environment, 2023. Materials management resources, available at: https://cdphe.colorado.gov/sw-materials-management

[10] Sustainable Packaging Coalition, 2023, SPC Position Against Biodegradability Additives in Petroleum-Based Plastics, available at: https://sustainablepackaging.org/resources/

[11] Municipal guidelines: City of Denver
- *Accepted for Recycling*
- *New Changes to Compost Collection Guidelines*

[12] Regional guidelines: Boulder County / Eco-Cycle
- *Composting*
- *Recycling*
- *Recycling Dirty Dozen*

Compostable packaging presents a similar issue: Just because something is compostable doesn't mean it will be composted, or that it won't degrade the quality of the resulting soil amendment and potentially affect soil integrity.[13] Access to compost facilities is comparatively limited across the United States, and we have seen a recent trend in Colorado where compost facilities and/or municipalities no longer accept compostable products of any kind.[14] High levels of contamination in compost streams by non-compostable packaging and materials including both bio-based and petroleum-based plastics, paper products, and metals has forced a revision in composting guidelines to protect the integrity of the compost system and ensure a high-quality product that is free from "trash". Check to see if there is a compost service where you live and if it will accept compostable packaging.

Compostable and biodegradable packaging in landfills are not seen as desired end-of-life solutions. Landfill operators do not want compostable or biodegradable products in a landfill. When these products break down, they release carbon and methane. Emissions capture at Colorado landfills is limited and, for the most part, reduces methane emissions only partially. About half (54%) of the 22 landfills reporting currently have "active gas collection systems" installed. However, many systems have extremely low capacity compared to the reported GHG emissions, and may not even be consistently operated. The Larimer County Landfill reported the largest amount of GHG emissions (consisting of nearly 100% methane at ~196k mt CO2e) but recovered only 20% in 2021. A look at the facility's annual emissions shows a continued increase despite having an emissions capture system in place.[15]

Labels and inks: Often missed by operators is the impact of the labels and various inks and foils used in printing. Consider the material type used for your label and the inks. Operators ask customers to remove labels before recycling. Putting a callout on the label that says please remove before recycling is encouraged. When considering non-label options learn about the impact of ink foils and glosses used to create a certain look. This may reduce the recyclability or impact the environment if it ends up outside a traditional waste system.

Ask for certifications: As an operator, it is your responsibility to validate the claim being made by your packaging supplier. Ask for certifications. Ensure they are for the specific product you are buying and not just the material itself. If a company is using recycled content, ask to see proof that what you are buying uses the amount of recycled content being claimed. The same goes for compostable products. Your packaging may be made of compostable materials, but the package may not biodegrade effectively due to the wall thickness, material composition, or because it is not intended for home composting.

Encourage take-back programs: By nature, single-use packaging will always impact the environment. As consumers, we should look for ways to reduce the amount of single-use packaging used. One solution for this would be a take-back and reuse model. For many reasons, take-back programs are difficult for the cannabis industry. For example, child-resistant requirements make it difficult to reuse packaging. Many in the industry believe that these requirements get in the way of reusability. As an industry, we should consider whether non-activated products must be put in child-resistant packaging. This could open up new types of packaging that would support reuse.

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[13] Godofredo Solano, Diego Rojas-Gätjens, Keilor Rojas-Jimenez, Max Chavarría, Rosaura M. Romero, Biodegradation of plastics at home composting conditions, Environmental Challenges, Volume 7, 2022, 100500, ISSN 2667-0100, available at: https://doi.org/10.1016/j.envc.2022.100500.

[14] A1 Organics, 2023. Press Release on Compost Guideline March 27, 2023, available at: https://a1organics.com/wp-content/uploads/2023/02/A1-Organics-NEWS-RELEASE-Changes-in-the-SSO-Stream-Fin.pdf

[15] U.S. EPA, 2023, EPA Facility Level Information on Greenhouse Gases "Flight" Tool. available at: 2021 Greenhouse Gas Emissions from Large Facilities.

Resources:

- Compostable Product Certifications
    - North America: Industrial Composting Certifications
        - CMA (Compost Manufacturing Alliance)
        - BPI (Biodegradable Products Institute)
    - Europe: Industrial Composting Certifications, Home/ backyard Composting Certifications
        - TUV Austria https://www.tuv-at.be/green-marks/.
        - Din Certo https://www.dincertco.de/din-certco/en/main-navigation/certificates-and-registrations/overview-certificates-and-registrations/
- Association of Plastics Recyclers APR Design Guide
- Sustainable Packaging Coalition
- SPC Design for Recycled Content Guide
- Municipal guidelines: City of Denver
    - Accepted for Recycling
    - New Changes to Compost Collection Guidelines
- Regional guidelines: Boulder County / Eco-Cycle
    - Composting
    - Recycling
    - Recycling Dirty Dozen

INTEGRATED PEST MANAGEMENT

EXECUTIVE SUMMARY

Pest control is a critical component of cannabis cultivation. The goal of an Integrated Pest Management (IPM) program is to prevent, reduce, or maintain pest populations at non- damaging levels by utilizing a combination of structural, environmental, cultural, and biological controls in conjunction with compliant and responsible pesticide applications if necessary. The philosophy of IPM offers a sustainable framework for cannabis pest management by eliminating unnecessary pesticide applications, focusing on pest prevention, and combining multiple means of control to maximize impact.

The cornerstone of an effective IPM program is frequent and thorough scouting which provides real time information on the numbers and types of cannabis pests and diseases present in the cultivation environment. This requires knowled geable cultivation staff that have been trained in the identification of cannabis pests and diseases. Scouting data is then combined with a robust understanding of both crop and pest biology, along with how both are influenced by the cultivation environment, to identify and implement the most effective means of control. These control measures typically fall within one of the following categories:

Structural

Control elements present in the construction or maintenance of the cultivation facility.

Examples: air filtration, facility design elements for pest exclusion, and quarantine areas.

Environmental

Control category referring to the ability to manipulate the cultivation environment to promote crop health and negatively impact pest/disease development.

Examples: cooling and dehumidification capabilities, environmental monitoring, and air circulation.

Cultural

All cultivation practices that influence pest management outcomes.

Examples: plant spacing/pruning, facility sanitation, and employee workflow.

Biological

The use of living organisms to prevent and control pest infestations.

Examples: predatory mites, insects, nematodes, and parasitoids.

Compliant and Responsible Pesticide Use

Pesticides can be an effective and sustainable tool when used responsibly, but are considered a last resort within the IPM framework.

Introduction

The goal of an IPM program is to prevent, reduce, or maintain pest populations at non- damaging levels by utilizing a combination of structural, environmental, cultural, and biological controls in conjunction with compliant and responsible pesticide applications when necessary.

An effective program, implemented and monitored by employees trained in IPM, can eliminate high levels of crop damage, mitigate risk, and control pests. Robust scouting and early identification of pest infestations is critical. This information is utilized to inform pest control strategies on an ongoing basis, forming a data driven feedback loop. The philosophy of integrated pest management puts a large focus on the prevention of pest outbreaks via proactive structural, environmental, cultural, and biological control measures.

These elements, combined with scouting, create a cultivation environment in which pests are excluded, suppressed, and easily identified if preventative measures fail. If active pest management intervention is needed IPM practitioners can adjust cultural practices, conduct biological control releases and/or apply organic pesticides when needed.

SCOUTING

An effective IPM program requires the use of Standard Operating Procedures (SOPs) to govern an ongoing scouting program, including daily/weekly inspection of all cultivation areas, identification of cannabis pests, and logging of the data generated. All data should be recorded in a pest and disease log to track pest presence and population levels.

Scouting SOPs commonly include scouting intervals for all cultivation areas, the use of sticky cards for flying pest monitoring/quantification, visual inspection of plant canopies, random leaf pulls from within canopy areas, and the integration of environmental monitoring data to identify areas in need of additional scrutiny.

RECOMMENDED BEST PRACTICES

Maintain organized records of all scouting activities and use these to inform pest management decisions.

Systematically scout all cultivation areas at least weekly.

Provide scouts with note keeping tools, a 30x loop for quick diagnostic checks, disposable gloves, and tools for taking and analyzing samples under higher magnification if necessary.

Scouts should be trained in the identification of common cannabis pests and diseases including the following:

- Insect Pests including
  - Thrips, Foliar Aphids, Root Aphids, Fungus Gnats, Whiteflies, Caterpillars
- Mite Pests including
  - Hemp Russet Mites, Spider Mites, Broad Mites
- Fungal Pathogens including
  - Powdery Mildew, Botrytis, Pythium, Fusarium

STRUCTURAL CONTROLS

Structural controls are facility design features that exclude pests and diseases from cultivation areas. These design features act as the first line of defense in an IPM program and should be customized according to the needs of the facility as it is being constructed.

RECOMMENDED BEST PRACTICES

Facility Layout

- Indoor and greenhouse facilities should be designed such that cultivation areas are isolated from facility entrances, offices/administrative areas, post- harvest work areas, and product storage areas.

- The facility layout should require workers and visitors to pass through a sealed entry area with access to locker rooms and decontamination areas prior to moving into any production areas
- The layout of cultivation areas should facilitate separate access to propagation, vegetative, flowering, and post-harvest work areas.

Air Filtration

- All air entering cultivation areas should be filtered using a minimum of MERV 13 filter rating or equivalent.

Quarantine Areas

- Cultivation facilities should be equipped with quarantine areas for receiving cultivation materials and new plant material.

Footbaths

- Footbaths containing activated peroxide, bleach, quaternary ammonium, or similar disinfectants should be placed at the entrances to all cultivation areas.

Irrigation drainage

- Irrigation systems should be designed to prevent the transfer of plant pathogens. For drain to waste watering systems this can be accomplished by collecting irrigation drainage without allowing it to come into contact with additional plants. For hydroponic systems, or media based systems that re-use water, sterilization technologies such as ozonation or chemical injection are crucial in preventing the spread of plant pathogens.

ENVIRONMENTAL CONTROLS

Environmental systems should be structured in such a way that they offer cultivators the ability to adjust environmental parameters according to pest/pathogen scouting outcomes and crop needs. The disease triangle (pictured below) helps to illustrate the importance of environmental modulation in plant pathogen prevention and control. For a plant disease to develop there must be a susceptible host, the causal pathogen, and a conducive environment. Whenever possible, the cultivation environment should be manipulated to disrupt pathogen development.
HOST

RECOMMENDED BEST PRACTICES

Robust cooling systems

- Cooling systems should be sized according to the projected heat load produced from lighting systems, should take all other potential heat sources into consideration, and should be designed in conjunction with dehumidification systems.

Humidity control

- While dehumidification is often the primary focus of humidity control it is also important to consider where humidification may also be necessary, especially when bringing new facilities online prior to full plant load.
- Dehumidification needs should be developed by predicting total transpiration water loss according to the amount of plant canopy in each cultivation area. Systems should be oversized by at least 15% to account for variance in crop size and to provide the ability to lower humidity outside of normal parameters if necessary.

Airflow

- Maintaining proper airflow in all cultivation areas is critical in promoting plant health and reducing moist, still micro- climates that can be conducive to pathogen development. The use of Horizontal Air Flow (HAF) style fans are superior to wall mounted units and provide a solid platform for a customized facility air mixing plan.

Environmental Monitoring

- Cultivation areas should be equipped with environmental monitoring equipment capable for capturing temperature, humidity, and lighting intensity data that can analyzed to help cultivators maintain proper environmental conditions and to identify facility micro-climates that may be more prone to potential pest/pathogen development.

CULTURAL CONTROLS

Cultural control is a catch all term for cultivation practices that influence IPM outcomes. These can take the form of preventative cultural controls woven into normal procedures, or reactive cultural controls only utilized if pests/pathogens develop.

RECOMMENDED BEST PRACTICES

- Implementing SOPs for the ongoing cleaning and sanitation of all cultivation areas. This step is critical for both an effective IPM program and for the prevention of microbial contamination of cannabis products.
- Adequate plant spacing and routine pruning of under canopy areas to facilitate air movement, to avoid pockets of low light intensity and dead air within the canopy, and to remove under-growth that is not receiving sufficient light to be productive.
- Use of facility specific employee uniforms and footwear that are changed into at the beginning of the workday and stay at the facility to avoid pest introduction.
- Structuring staff duties and workflow to reduce the chances of cross contamination between different cultivation areas and/or crop phases.
- Utilizing harvest strategies that minimize contact between harvested materials and younger crop phases to reduce cross contamination.
- Use of beneficial plant inoculants to promote media/soil health and help guard against pathogen development.
- Plant nutritional monitoring to promote crop health and prevent over-fertilization.
- Manual removal of plant pests/pathogens if infestations occur. This step should be conducted in conjunction with other control efforts (I.E. clearing out pest damage prior to pesticide applications reduces pest numbers and increases pesticide contact).
- Culling infested plants if pest/pathogen pressure is concentrated in hot-spot areas and cannotbe easily controlled can sometimes be useful in stopping the spread of infestations.

BIOLOGICAL CONTROLS

Biological control is the use of mite and insect predators and parasitoids to prevent or eliminate crop pests. Predators are organisms that hunt and consume pests, parasitoids are organisms that develop as pest parasites, but must kill their host in order to complete development to adulthood.

Most biocontrols relevant to cannabis IPM are limited in the types of prey they consume. For this reason, it is important to make releases according to scouting results and/or historical pest pressure. This ensures that the biocontrol agents selected are appropriate for the control of the target pest(s). The developmental cycles of biocontrols often lag behind those of the pests they control, for this reason they are more effective if applied when pest levels are low. It is important to consider the influence that environment and other pest control measures may have on biocontrol agents. If pesticides are being used their toxicity to potential biocontrol agents should be assessed before biocontrol release.

Commonly used biological controls in cannabis IPM and target pests *(this list is not exhaustive):*

Phytoseiulus persimilis
- Predatory mite used for spider mite control

Neoseiulus californicus
- Predatory mite used for prevention of several pest mites species including Spider mties and broad mites

Green Lacewing (Chrysoperla carnea)
- Predatory insect used for aphid control, larvae will also feed on other cannabis pests

Minute Pirate Bug (Orius insidiosus)
- Predatory insect used for thrips control, will also feed on other cannabis pests

Steinernema feltiae
- Entomopathogenic nematode used for fungus gnat control

Aphidius colemani & Aphidius ervi
- Parasitoid wasp species that target multiple aphid species

RECOMMENDED BEST PRACTICES

- Select biocontrols according to pest species and release biocontrols when pest populations are low.
- Follow vendor application instructions and release biocontrols as quickly as possible after receiving them.
- If biocontrols must be stored, do so according to the vendor's instructions (many species require cool storage).
- Ensure that other IPM and cultivation techniques are compatible with the biocontrols being used.
- Tailor biocontrol strategies according to crop age because some species and application methods are not compatible with mature cannabis flowers due to resin content.

RESPONSIBLE AND COMPLIANT PESTICIDE USE

Pesticides should be considered the last line of defense in the IPM practitioners toolbox. However, the use of pesticides can be critical in meeting pest management outcomes and they can be an effective part of an IPM program when used responsibly. Cannabis cultivators are limited in the types of pesticides that can be legally applied during cultivation because pesticides are regulated at the Federal level and cannabis is not Federally legal. This means that pesticide use decisions for Cannabis cultivation must be made at the State level.

In Colorado the Colorado Department of Agriculture (CDA) is responsible for enforcement of Colorado specific rules that govern which pesticides can be used in the production of Cannabis and Federal/State regulations pertaining to safe pesticide use in all agricultural industries. In addition to maintaining a list of pesticides that are allowed for use in Colorado cannabis production, the CDA also enforces the Federal Worker Protection Standard (WPS). WPS is a large set of regulations that was developed to protect worker safety in agricultural industries that utilize pesticides. WPS regulations apply to all EPA registered and include specific supplies and information needed in cultivation facilities, training for general workers and pesticide handlers, notifications and restrictions related to employee movements into areas that have been treated by pesticides, and the maintenance of records related to training and pesticide use.

It is also important to understand that certain municipalities and local jurisdictions may have rules and regulations that act alongside or in addition to State/Federal regulations. As an example, in the city of Denver, the Denver Fire Department (DFD) requires pesticide inventory permits and the Denver Department of Environmental Health is actively involved in monitoring for and carrying out enforcement actions related to pesticide residues in Cannabis.

RECOMMENDED BEST PRACTICES

- Utilize pesticides as a last resort and give preference to organic products if they must be used.
- Tailor pest management strategies to crop age and avoid the use of pesticides on developing cannabis flowers when possible.
- Always read pesticide labels and abide by all applicable regulations and safety guidelines.
- Apply pesticides according to label instructions in sufficient volumes and concentrations to be effective against target pests.
- In order to avoid crop damage:
  - Mix products according to label instructions and test for phytotoxicity before wide spread use.
  - Make sure plants are well watered before making pesticide applications.
  - Turn off any cultivation lighting prior to applications.
  - Avoid extremes in cultivation room temperature during applications.
- Utilize multiple modes of action and rotate pesticides with different modes of action to avoid the development of pest resistance.

HELPFUL LINKS

Colorado Department of Agriculture Cannabis Pesticide Use Information:
https://www.colorado.gov/pacific/agplants/pesticide use-cannabis-production-informationColorado

Department of Agriculture WPS Compliance Information:
https://www.colorado.gov/pacific/agplants/worker-protection-standards

Pesticide Informational Resources Collaborative:
http://pesticideresources.org//index.html

Marijuana Occupational Safety and Health Resources:
https://www.colorado.gov/pacific/cdphe/marijuana-occupational-safety-and-health

Colorado Hemp Insect Project:
https://hempinsects.agsci.colostate.edu/

CLIMATE CHANGE AND THE CANNABIS INDUSTRY

I. INTRODUCTION

This chapter focuses on two aspects of climate change facing the cannabis industry:

1. Adaptation: managing the risks and negative impacts of the effects of climate change on the industry's businesses; and

2. Mitigation: developing the operational techniques and technologies to reduce direct and indirect greenhouse gas (GHG) emissions, particularly carbon dioxide, that are known contributors to global warming and climate change

As a relatively young regulated industry, cannabis businesses not only face the challenges of all businesses to build resilience against the effects of climate change, it also has the opportunity to embed sustainable business practices and become an example to other industries on how to reduce GHG emissions.

The effects of climate change are already affecting businesses worldwide[1, 2, 3]. Cannabis cultivation is significantly impacted by climate change from increased intensity and frequency of weather extremes such as extended periods of unusually hot or cold temperatures, droughts and flooding. Denver recognized the need to develop plans to adapt and build resilience in response to climate change impacts. Denver convened a climate adaptation working group, reviewed research and work done by other cities and at the state level, engaged with stakeholders to develop such a plan.

The City and County developed a Climate Adaptation Plan[4] which identifies the most critical climate change impacts facing Denver:

1. Increase in temperature and urban heat island effects;

2. Higher frequency of extreme weather events; and

3. Reduced snowpack and earlier snowmelt.

The contribution to climate change from human activity is largely due to GHGs emissions associated with energy generation and transportation. Despite the recent government goals, shifts toward renewable energy sources, increasing awareness of many people, emissions of greenhouse gases (GHGs), and specifically carbon dioxide, have not been reduced since the 2015 Paris Agreement[5]. Even with dramatic reductions in certain business activities and transportation over the past 15 months due to the global COVID-19 pandemic, global GHG emissions for 2020 were not significantly reduced from 2019 levels. In fact, the average atmospheric benchmark measurement collected each May at the Hawaii observatory showed a continued increase in carbon dioxide concentration[6,7].

The overall strategy to solve the problem of increased atmospheric carbon dioxide is simple: reduce sources (i.e., GHG emissions) and increase "sinks" (mechanisms that remove carbon dioxide from the atmosphere and return carbon to the ground, such as forests or soil). Our natural world is magnificently designed to provide balance to this carbon cycling on its own. Human activity has overwhelmed this balance and we collectively need to do everything we can to reduce our sources and increase the sinks.

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[1] *"Final Report — Recommendations of the Task Force on Climate-Related Financial Disclosures", June 2017*
[2] *"Feeling the Heat: Companies are Under Pressure on Climate Change and Need to Do More", M. Coppola, T. Krick, and J. Blohmke, Deloitte Insights, December 12, 2019*
[3] *"The Heat Is On Businesses to Respond to Climate Change", J. Drizik, World Economic Forum, January 15, 2020.*
[4] *"City and County of Denver, Climate Adaptation Plan", prepared by Denver Environmental Health, www.denvergov.org/Government/Departments/Climate-Action-Sustainability-Resiliency/Initiatives/Climate-Action, June 2014*
[5] *Our World In Data: CO2 Emissions https://ourworldindata.org/co2-emissions*
[6] *"Carbon Dioxide in The Air Is At Highest Level Since Measurements Began", Thomson Reuters, June 7, 2021*
[7] *"Despite the Pandemic, Carbon Dioxide Level in Atmosphere Hits Record Level", The Washington Post, June 7, 2021*

In 2018, the City of Denver released its Climate Action Plan detailing its plan to reduce greenhouse gas emissions in line with the goals of the 2015 Paris Agreement — 80% emission reduction by 2050. As a result of that research and planning effort, the City's Plan focuses on the areas of greatest impact: energy use in large buildings; generation of electricity; and transportation[8].

Climate actions to deal with climate risks to businesses and communities consist of adaptation and resilience strategies: adapting operations and the way we live in the face of climate change to avoid and manage the potential impacts businesses and communities may experience; and building resilience, or the ability to withstand, recover and rebound from set-backs or disruptions that can occur from climate change effects.

This guide will address some of the impacts to and from the cannabis industry related to climate change and offer best management practices that can be considered to avoid and/ or mitigate these risks.

Indoor cannabis cultivation uses the largest amount of energy when compared to any other production method, and creates the largest associated carbon footprint. Greenhouse gas (GHG) emissions baselining provides companies with a snapshot of short-term energy use and long-term financial risk. Studies have consistently found that implementing comprehensive climate protection programs make companies more competitive for a wide variety of reasons, including significant financial savings, brand reputation, and increased employee and customer satisfaction. A recent report from Goldman Sachs found that companies that are leaders in environmental, social and good governance policies are outperforming the MSCI world index of stocks by 25% since 2005. Seventy-two percent of the companies on the list outperformed industry peers. Taking a more in-depth view of fuel use and electricity/resource consumption allows cannabis companies to identify opportunities to increase efficiencies and reduce costs while minimizing GHG emissions. This will also keep the company's policies, procedures and operations ahead of rapidly evolving, energy-related building codes and regulatory frameworks.

Denver has determined that maintaining progress toward the 2050 carbon reduction targets is critical to the longevity of the city. These factors show us that not only is it a good business decision to look at your carbon output and explore ways to create reductions, but it also contributes to the local community and reduces the environmental impact of the industry.

II. CLIMATE CHANGE RISKS TO THE CANNABIS INDUSTRY

The immediate visible and physical effects of climate change include increasing occurrence of extreme weather events such as extreme heat or cold, greater frequency and intensity of wildfires, and greater frequency and intensity of rainfall events, tropical storms and hurricanes, and flooding.

The cannabis industry is frequently characterized as being agricultural, but it also includes processing and manufacturing a variety of products, distribution and transportation, and retail. Agriculture, including even indoor cannabis cultivation, is directly impacted by these climate changes. Shifts in longer-term weather patterns and regional climate trends such as droughts, flooding and changing seasonal temperatures, and record-setting annual high temperatures resulting in the 10 hottest years on record having occurred since 2005[9] are all confirmation of these changes.

Outdoor Growing and Climate Risks

Outdoor cannabis has the same challenges faced by agriculture in general such as exposure to the elements, pests, and temperature swings, plus industry specific factors such as compliance, security, and quality control which are all drivers for the majority of Colorado's marijuana to be grown indoors.

Wildfires present climate change related risks that are unique to outdoor cannabis growing where ash deposition and reduced sunlight can affect the quality and yield under extreme conditions[10]. While ash from wildfires is known to impact the quality of wine by imparting smoky or ashy flavor as result of chemical reactions within the grapes, a bigger concern for cannabis is accumulation of chemical contamination.

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[8] "Denver — 80 x 50 Climate Action Plan", prepared by Denver Public Health and Environment, www.denvergov.org/Government/Departments/Climate-Action-Sustainability-Resiliency/Initiatives/Climate-Action, July 2018

[9] "Climate Change: Global Temperature" https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

[10] "How the West's Wildfires Impact Crops", High Country Times article by Virginia Gewin, 10/20/20.

The nature of the flower can cause the capture and entrainment of heavy metals as well as dioxins and residual hydrocarbons depending on what was burnt in the wildfire. Pressure treated lumber is a known source of chromium and arsenic, while other building materials (e.g., roofing, siding), household or business chemical storage can release organic toxic chemicals into the air and settle out with the ash.

Direct impacts from wildfires for growing operations in the potential path of a wildfire can include destruction or loss of the crop, or growers may need to make difficult decisions about harvesting a crop early or trying to wait out the fire. Even if the crop can be protected from direct loss, the flower may be contaminated and require destruction. For growing operations which are not directly threatened, the crop may be impacted from reduced sunlight due to heavy smoke.

Other potential climate change driven impacts can include droughts or periodic water shortages in areas that normally have sufficient rainfall, or just the opposite effect of extreme rain events and flash flooding beyond the capacity of historical drainage infrastructure. Extreme cold or heat and broadly shifting local climate can be a long-term risk to outdooring growing. For example, the brewing industry has reported on how climate change is already causing a shift northward since 1980 for barley growing, increasing length of growing seasons, and reduced protein in barley and drought tolerance of hops[11].

These concerns run state-wide with state lawmakers passing legislation in June 2021 to allow, among other things, outdoor cannabis and hemp growers greater latitude in developing contingency plans to protect crops from extreme weather already being experienced as a result of climate change[12]. For example, in 2020, marijuana and hemp growers reported heavy losses — in the millions of dollars — after a September snowstorm and freezing temperatures hit early and plants were still in the field. The new law would allow growers to create an emergency plan and get it approved by the Marijuana Enforcement Division to remain compliant.

Advocates for the law noted that it's only going to get more difficult for outdoor growers as Colorado experiences greater weather swings due to climate change. As climate change brings greater extremes in weather and less predictability, growers need the flexibility in a highly regulated industry to take steps to move or otherwise protect their crops.

Beyond Colorado, Cannabis cultivators in the Pacific Northwest are adopting new work restrictions to protect employees as a result of this summer's record-breaking heat[13]. New state restrictions, which took effect early in July 2021 in Washington and Oregon were rapidly adopted following extreme heat in the region that is to blame for at least one farmworker death in 115-degree heat. The new rules include expanded access to shade, cool water, and breaks during periods of heat.

Greenhouse and Indoor Growing and Climate Risks

Greenhouse and indoor growing minimize potential direct effects of wildfires from smoke and ash, although sunlight reduction can still become an issue for greenhouse growing. Other aspects of the cannabis industry from processing to dispensaries are at risk of regional impacts from climate change such as energy blackouts/rolling blackouts, restrictions or higher costs related to energy and water use, and the need to be prepared for extreme weather events. In addition, supply chains can be disrupted when suppliers or products from other regions experience severe climate change impacts.

Cannabis businesses, like all businesses, will ultimately face a financial impact. Electric and water utility costs will increase, other costs of doing business such as insurance will increase as insurers are actively and closely looking at how their coverage applies to climate change impacts, and eventually a potential carbon tax applied to fuel or materials that are petroleum-based.

[11] *"How Will Climate Change Affect Brewing?" — Steve Bertman, Professor of The Environment and Sustainability at Western Michigan University, presented at the 2020 Craft Brewing Convention.*

[12] *"Colorado Cannabis Cultivation Law to Tackle Adverse Weather, Cross-Pollination, Interstate Commerce" MJBizDaily, by Bart Schanerman, July 15, 2021*

[13] *"Northwest 'Heat Dome' Prompts New Rules for Outdoor Cannabis Growers" MJBizDaily, by Kristen Nichols, July 13, 2021.*

Climate Action efforts that cannabis businesses can pursue to support and align with the City's goals to reduce or prevent greenhouse gas emissions include: increase renewable energy use, upgrade or replace equipment to energy-efficient models, and improve the energy efficiency of buildings. In addition to other responsible business actions such as helping to educate consumers on sustainable decisions, making greater use of mass transit, and collaborating on city projects to enhance areas that accumulate and store carbon (such as tree plantings, parks and open spaces).

III. CANNABIS INDUSTRY POTENTIAL CONTRIBUTIONS TO CLIMATE CHANGE

Introduction

Indoor cannabis cultivation uses the largest amount of energy when compared to any other production method, and creates the largest associated carbon footprint. Two recent studies show the range of carbon footprints for indoor grown cannabis to be between 2,200 and 5,200 kg CO_2e for every kg of dried cannabis flower produced[17,19]. Specifically, Summers et al., (2021) estimate that cannabis grown in Denver has a carbon footprint of 4,000 kg CO_2e per kg of dried cannabis flower [14, 15]. Some preliminary reviews of cannabis cultivation have estimated reductions in greenhouse gas emissions of 42% with greenhouse cultivation and 96% with outdoor growing compared with indoor cultivation[16, 17].

Greenhouse gas (GHG) emissions baselining provides companies with a snapshot of short-term energy use and long-term financial risk. Studies have consistently found that implementing comprehensive climate protection programs makes companies more competitive for a wide variety of reasons, including significant financial savings, brand reputation, and increased employee and customer satisfaction. A recent report from Goldman Sachs[16] found that companies that are leaders in environmental, social and good governance policies are outperforming the MSCI world index of stocks by 25% since 2005.

Seventy-two percent of the companies on the list outperformed industry peers. Furthermore, through understanding it's GHG emissions, the cannabis industry can understand ways to avoid exacerbating the climate risks previously discussed that face the industry. Taking a more in-depth view of fuel use and electricity/ resource consumption allows cannabis companies to identify opportunities to increase efficiencies and reduce costs while minimizing GHG emissions. This will also keep the company's policies, procedures and operations ahead of rapidly evolving, energy-related building codes and regulatory frameworks.

A recent study at CSU concluded that at least 80% of GHG emissions from indoor cultivation practices are generated by indoor environmental control (HVAC), high-intensity grow lighting, and supplemental carbon dioxide for plant growth [15]. As commercial cannabis scales, so does the need for more data-derived technology solutions for HVAC, odor mitigation and environmental control systems. In an effort to reduce the amount of required electricity, cannabis producers are dialing in their technology to have the most efficient operation. Denver has determined that maintaining progress toward the 2050 carbon reduction targets is critical to the longevity of the city.

These factors show us that not only is it a good business decision to look at your GHG emissions output and explore ways to create reductions, but it also contributes to the local community and reduces the environmental impact of the industry[18].

Air quality has a cyclical relationship with climate change. The EPA is currently undergoing research to develop the scientific knowledge and tools to enhance regulators' ability to consider climate change when determining air quality rules to reduce the impacts of a changing climate.

[14] *"The 2018 Cannabis Energy Report", New Frontier Data, 2018*

[15] *"Environmental Risks and Opportunities in Cannabis Cultivation", M. O'Hare, D. L. Sanchez & P. Alstone, BOTEC Analysis Corporation, 2013*

[16] *"GS Sustain." Goldman Sachs 2007. http://www.natcapsolutions.org/Presidio/Articles/*

[17] *"The Greenhouse Gas Emissions of Indoor Cannabis Production in the United States", H.M. Summers, E. Sproul, & J. C. Quinn, Nature Sustainability, 2021*

[18] *Alderton, Margo, "Recent report finds corporations that lead in corporate responsibility also lead in the market," Socially Responsible Investing 07-11 17:57, also at http://www.csrwire.com/companyprofile?id=4489*

[19] *Mills, E. The carbon footprint of indoor cannabis production. Energy Policy, 46, 58–67 (2012)*

What Is a Carbon Footprint?

A carbon footprint in the context of the cannabis industry can be defined as the total amount of GHGs emitted during the production of raw cannabis and cannabis-related products.
However, a holistic approach to carbon foot-printing should include:

- A detailed breakdown of GHG emission sources, factors and calculation methodologies
- Short- and long-term emission reduction goals Specific strategies for reduction and tracking reductions
- A management plan for updating and continued tracking of the GHG emissions and sources

Creating a carbon footprint informs incorporation of GHG emissions reduction strategies and provides deeper insight into company operations, revealing the potential for cost-saving efficiency investments. The heavy data analysis portion of a carbon footprint will be the GHG Inventory. This section is a detailed accounting of all GHGs emitted during the production process and operations of a cannabis company. These GHGs can include Methane, Nitrous Oxide, Butane, Propane, and many other gases, but will usually be expressed as Carbon Dioxide Equivalent or CO2e. For any quantity and type of greenhouse gas, CO2e signifies the amount of CO2 which would have the equivalent global warming impact. Specific operational and company data are needed to make an accurate accounting of GHG emissions. Emissions factors, or the amount of CO2e per unit of energy/input, are readily available for most activities in the cannabis growing industry.

A well-rounded carbon footprint should analyze the applicable data and set reasonable, achievable goals based on the specific cannabis company and its projected strategic plan. This will allow the operations of the company to grow alongside its sustainability goals, creating a more resilient and adaptable business.
Recently, the Securities and Exchange Commission has released language purporting that publicly listed companies will be required to disclose various scopes of emissions with the potential to require ESG plans in the future. This should make GHG emissions inventories a priority for any publicly listed cannabis company or any that wish to become publicly listed in the near future.

Types of Carbon Emissions

Organizing and collecting all the data necessary for a carbon footprint is a good exercise in itself for looking at company operations, but can seem overwhelming at first. It is easier to understand what kind of data is necessary for the GHG inventory by breaking it down into the three primary scopes, as defined by the GHG Protocol:

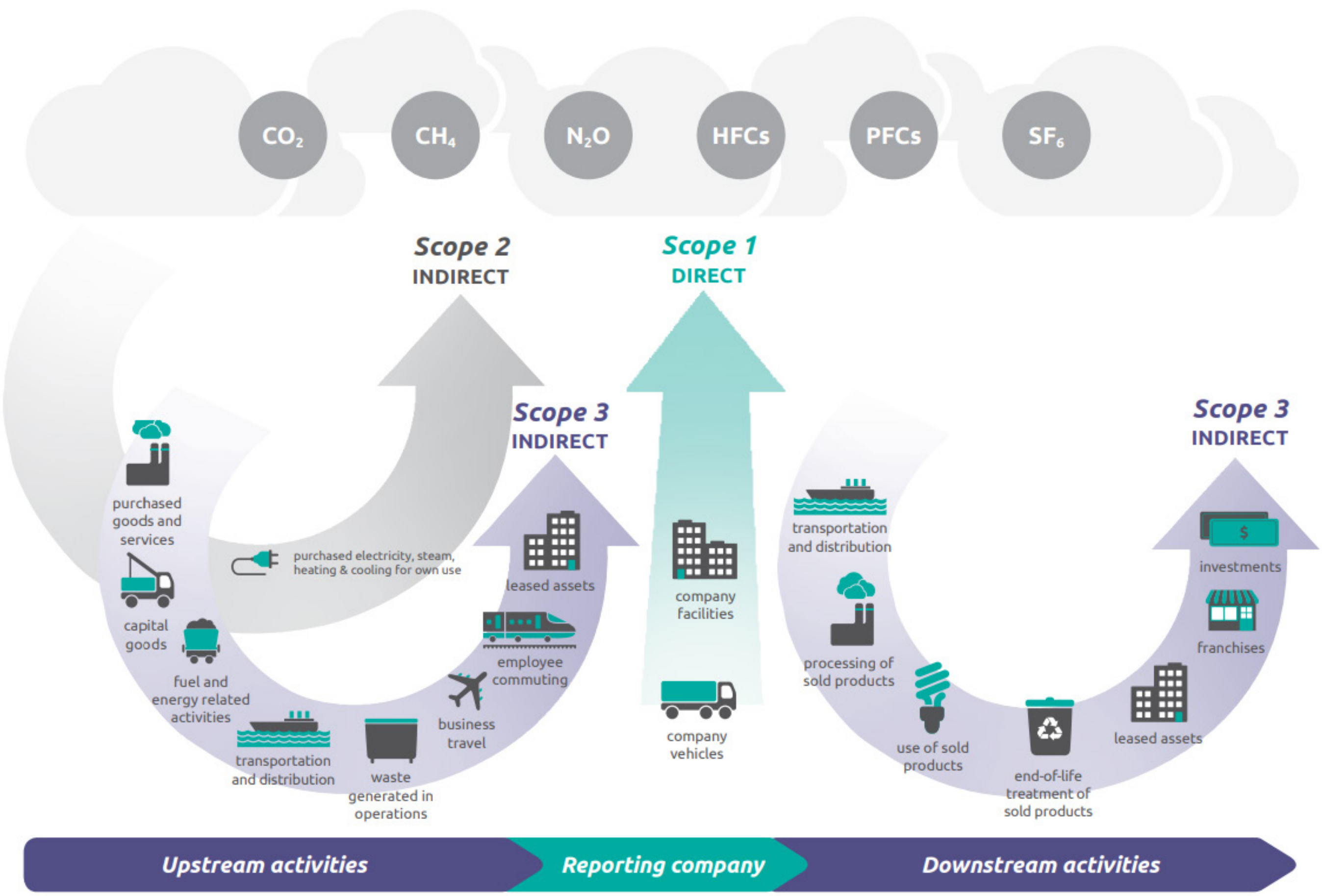
Scope 1 Emissions: An organization's direct GHG emissions produced on-site. Examples include diesel generators, transportation fuel for delivery/company vehicles, CO2 Enrichment being used in facility grow operations or any excess natural gas emissions attributed to concentrate production.

Scope 2 Emissions: An organization's off-site GHG emissions, or indirect emissions. This figure is most frequently attributed to electricity usage, unless a company is producing all of its energy through renewables on-site. For Denver, the primary sources of power generation are coal and natural gas, both of which have associated GHG emissions. Those GHG emissions are reflected in a reporting organization's electricity usage.

Scope 3 Emissions: All other indirect GHG emissions associated with the operation of a business. Examples include employee travel/commuting in their personal vehicles, grid transmission and distribution losses of electricity, waste products, water usage, packaging, product transport and delivery, and manufacturing of nutrients. Scope 3 examines operations and sourcing in-depth, making it a fantastic tool for analyzing a supply chain. Some analyses even go so far as to calculate associated processes and ingredients of production. For example, if a product uses plastic packaging, Scope 3 could include the entire life cycle of the product, such as GHG emissions from the raw oil extraction process, the refinement of the oil, the synthesis of plastic from the oil, the transport of materials between phases, and waste materials. On average petroleum plastic requires 1.6 times its weight in carbon emissions to be vproduced, therefore 1 ton (2,000 lbs) of petroleum plastic produces 5200 lbs of carbon emission per ton.

Most cannabis packaging due to rules and regulations weighs eight times more than the product inside. Example, on average a pre-roll tube weighs 7-8 grams, while the product inside only weighs 0.5-1 gram.

EMISSION SCOPE	DISPENSARIES	MIPS	GROWS
Scope 1	•Fuel usage for owned delivery service •Natural Gas Usage for Heating	•Natural gas/Butane/Propane/ CO_2 Usage & Ventilation (direct emissions) •Manufacturing Equipment Fuel	•Natural gas usage for heating or other operations •Soil & Fertilizers Water •CO_2 supplementation •Direct emissions
Scope 2	Purchased electric for lighting, HVAC, other operational needs		
Scope 3	•Vendors & Products •Retail Waste Packaging •Employee transit •New construction or build- out of existing bldg. •Waste disposal	•Third-party Delivery & Courier Services •Supply chain emissions •Construction or build-out •Packaging •Waste disposal •Employee transit	•Third-party Delivery & Courier Services •Construction or build-out •Packaging •Waste disposal •Employee transit



CALCULATION & TRACKING METHODS

Setting a Boundary

The preliminary action required for undertaking a carbon footprint analysis is setting a boundary around the study. A boundary defines the breadth and depth of the GHG inventory. It is up to the developer of the footprint to determine the appropriate boundary limits, but it is recommended that the process go back as far as it can for more transparency and accuracy in the final report.

A proper boundary analysis should include a detailed layout of the system and processes which will be analyzed. It is important to consider the full life cycle of the product or operation being calculated. This will include extensive research into ingredient sourcing, where and how ingredients were developed, what type of transport was utilized, and the energy consumption related to their production, etc. As carbon footprints have become more mainstream, many vendors have this information readily available. Furthermore, companies can implement or request GHG emissions tracking of their vendors to facilitate more detailed data collection.

The detail of the calculations should encompass all operations of the business, including processes or products that may seem irrelevant or whose value may not be immediately evident. For example, waste from plants or soil, water usage and courier usage are all relevant to the analysis. It is crucial to get a complete, comprehensive look at company operations to ensure the utmost accuracy in a GHG inventory. This stage of planning will set the boundary for the inventory and determine which data is necessary to collect in order to calculate an accurate carbon footprint.

Calculating a Carbon Footprint

It is recommended that if a cannabis organization wishes to undertake creating a carbon footprint and calculating a GHG inventory, they utilize comprehensive guides such as the WRI GHG Protocol: A Corporate Accounting and Reporting Standard or the EPA Center for Corporate Climate Leadership Greenhouse Gas Inventory Guidance. Otherwise it is recommended to look for help from outside professionals to assist in the detailed calculations necessary for a comprehensive inventory.

Facility Variations

Each facility and operation will have its own unique inputs in a carbon footprint calculation. It is important to closely review every area of an operation to identify the largest drivers of carbon emissions. The following chart outlines some of the unique GHG emission sources in different types of cannabis facilities:

Tracking Metrics Over Time

https://www.energystar.gov/buildings/benchmark/understand_metrics/how

https://www.energystar.gov/buildings/resources_topic/portfolio_manager_building_emissions_calculator

Scope 3 Specific: https://quantis-suite.com/Scope-3-Evaluator/

https://coolclimate.berkeley.edu/business-calculator

https://www.carbonfootprint.com/businesscarboncalculator.html

https://carbonfund.org/take-action/businesses/business-calculators/

It is important that a carbon footprint is continually updated to track and report progress over time. The data can be managed easily when appropriately developed in a data analysis program. An annually updated carbon footprint progress report demonstrates commitment to customers and shareholders.

Tracking GHG emissions data allows for proper allocation of resources based on which area is lagging behind or stalling. Once data has been regularly tracked for an extended period, it is possible to compare GHG metrics to other important industry metrics (sales, return on investment (ROI), repeat customer generation, etc.) and look for general trends and correlations.

BEST MANAGEMENT PRACTICES

Carbon Reduction Strategies for Climate Change Mitigation

Once the calculation of the carbon footprint is complete, strategies to reduce the carbon output of the facilities can be identified. It is important to understand that this is a long-term goal and will have many stages of planning, implementation and progress. The best way to make progress is by focusing on projects with a significant ROI and contributing to the operation's overall mission. A good initial approach is to increase operational efficiencies within the facility and operations of the company. Creating efficiencies wherever possible will reduce the largest impacts of a carbon footprint while simultaneously saving money and resources. That way, when larger potential projects are considered, the resources required to fulfill that project's needs will be much lighter. For example, it will be much easier to install on-site renewable energy if the facility's operating energy has already been quartered due to efficiency upgrades. Goal setting is essential for any organization wishing to reduce its carbon footprint.

It is imperative to set a baseline from which to develop GHG emissions-reduction goals. Organizations can either set one baseline year (e.g., X% reduction against their 2018 baseline year by 2025) or use the most recent year as their baseline year — a "rolling" approach (this approach is more challenging to show large amounts of reductions). Using a rolling approach will not allow the reporting organization to "count" the same reduction year after year toward their goals and become idle. Whichever approach is chosen, the concept and establishment of a baseline year is essential. Once a goal is achieved, it is essential to establish a new goal that challenges the organization to come up with new ideas and implement more aggressive reduction strategies.

The CSU analysis is consistent with other studies suggesting that practices to reduce GHG emissions should focus on HVAC operations and efficiency, high-intensity grow lights and carbon dioxide supplementation. All aspects of creating an artificial climate for cannabis growth are the major levers to optimize to minimize GHG emissions while maintaining yields and quality. For any grow operation focused on plant yield, air changes per hour (ACH) was identified as the next most sensitive factor in optimizing HVAC operation, lighting and carbon dioxide supplementation to reduce GHG emissions15.

ACH is also greatly determined by ambient air temperature and humidity which varies geographically, by time of year, daily or weekly in some regions and during daylight or night-time hours.

Based on information from the available studies at this time, the following best practices should be given the highest priority in optimizing cultivation operations with GHG emission reduction goals:

- Use of LED lighting
- Use of high-efficiency HVAC systems
- Local sourcing of carbon dioxide for supplementation
- Optimizing ACH with lighting, HVAC, carbon dioxide supplementation and real-time ambient temperature and humidity
- Upgrade to onsite renewable energy
- Reduce fertilizer usage in exchange for living soil or other more sustainable methodologies
- Compost your cannabis waste

Additional steps that can be taken to increase efficiency and zero-carbon upgrades are discussed more in-depth in other sections of this guide, and include:

- Increased insulation in facilities
- Heat recapture systems on operational machinery
- Electric or natural gas fleet vehicles
- Recycle everything possible
- Optimize delivery routes
- Sourcing carbon neutral ingredients
- Carbon neutral, recyclable, or compostable packaging
- Solventless extraction methods
- Environmentally friendly employee commute programs
- Participate in composting programs

Another option for reducing GHG emissions for cannabis facilities is looking at local options for GHG emissions mitigation and renewable energy credits, but this should be a final approach to reducing GHG epremissions output after reduction initiatives have been undertaken. Cannabis operations can contact their electricity supplier to learn about options for purchasing local renewable energy. Though these options are helpful in the short term, they have fewer long-term benefits than carbon-reduction strategies and projects.

Outlined below are examples of calculations for the various scopes.

SCOPE 1

Example: Calculate Scope 1 emissions for Company A consuming 140 gallons of gas per year for company owned vehicles used at the site of operations.
The EPA conversion rate for gallons of gas to grams of carbon dioxide equivalent: 8,887 grams of CO_2e/ gallon of gasoline.

Use this conversion rate and multiply by gallons of gasoline used that year: 140 gal X 8,887g CO_2e= 1,244,180 grams of CO_2e.

This number can also be represented as 1,244.18 kilograms of CO_2e or 1.24 metric tons of CO_2e.
It is up to the analyzer to determine the best metric to use.

SCOPE 2

Example: Calculate Scope 2 emissions for a grow operation using 2000 kWhs of grid-supplied electricity. The EPA conversion rate for kWh to CO_2e. is 744 grams per kWh.

Take the conversion rate and simply multiply it by the number of kWhs emitted annually.

2000 kWh X 744g CO2 = 1,488,000 grams of CO_2e.
.
Again this number can be represented as 1,488 kilograms of CO_2e or 1.49 metric tons of CO_2e.

NOTE: It is important here to note, that these number are derived from EPA standards that do not take into account regional sources or other GHGs associated with the various scopes emissions. It is very important to source regionally based emission factors as well as CO2 equivalences in order to get the most accurate reading for all emissions associated with an organization's operations. The EPA's Power Profiler is a good source for regionally specific electricity emissions factors.

SCOPE 3

A scope 3 calculation includes all other associated GHG emissions such as employees driving to work.

Example: Calculate Scope 3 transportation GHG emissions total for employees driving a total distance of 200 miles.
The EPA conversion rate for miles to CO2e is 408 grams of CO_2e per mile.
200 miles X 408g CO_2e = 81,600 grams of CO_2e or 81.6 kilograms of CO_2e.

CULTIVATION FACILITIES

As cannabis plants grow, they release a distinctive range of odors which are made up of different types of VOCs called terpenes, as well as sulfur-containing compounds called thiols.

Higher concentrations of VOC emissions and odor from cannabis are released during harvest and processing. Installing control technologies can reduce the amount of VOC emissions released from the cultivation process and control odors in compliance with the Denver city and county odor ordinance. Terpenes commonly emitted from cannabis cultivation include: pinene, limonene, myrcene, and terpinolene.

CARBON FILTRATION —

Best Option for Controlling Odors and Vocs

Carbon filtration is currently the best control technology for reducing odor and VOC emissions from cannabis cultivation and manufacturing facilities. Carbon filtration is effective and reliable when scaled, installed, maintained and replaced properly. Carbon filters work by using an absorption process where porous carbon surfaces chemically attract and trap VOCs along with other gas phase contaminants. As the filter ages, less carbon surface area is available to trap VOCs and odor emissions; at this point the filter will need to be replaced. Depending on the filter load, most carbon filters will last 6-12 months in a commercial cultivation environment and should be replaced according to the manufacturer's recommendations. One method for reducing VOC and odor breakthrough is to run a Butane Life Test (ASTM D5742-95) on a carbon filter at your facility. This test evaluates remaining carbon media life to effectively capture VOCs and odor, which dictates the replacement schedule to avoid breakthrough.

Carbon filters can operate as stand-alone units that clean and recirculate the air, or can be integrated into the HVAC system. Typically, carbon filters are at their peak performance when positioned at the highest point in your grow space where heat accumulates. High humidity levels hinder filter performance, so this control technology is better suited for facilities with environmental controls. An effective filtration system for volume and air-flow requirements.

Maintaining an optimal environment can require multiple filters. The exact number of units required can be calculated by first measuring your facilities' emission load. Carbon filters can be used in combination with other odor control technologies.

Benefits:

Improve indoor air quality by capturing airborne gas phase contaminants and odors. Control the odor impacts of the facility: A properly installed and maintained carbon filtration system is highly effective at controlling odors. This satisfies the requirements of the odor ordinance in Denver and improves community relations as well as business reputation.

Control VOC emissions: a carbon filtration system will control odors and can remove VOC emissions. This improves public health, community relations and the environmental impacts of the facility.

Recommended Best Practices:

- Design and invest in a carbon filtration system. that meets the specific needs of your facility. It is recommended that you work with an HVAC consultant and odor mitigation experts with cannabis industry experience.
- Get information from the manufacturer about the effectiveness of the filter at removing high concentrations of VOCs in a high humidity environment and choose a filter with a high efficiency rate.
- Do not exceed the maximum rated cubic feet-per-minute rating for air circulation through the filter. If you exceed this max flow rate, the passing air will not have enough "contact time" with the carbon, and the filter will not be effective at removing VOCs and odor-causing compounds.
- Regularly inspect your filter and replace the filter if it is releasing a smell near the filter effluent, or has reached its lifespan according to the manufacturer's specifications.
- Set up a maintenance schedule based on your facility's emission load to replace your carbon media, as filter manufacturers will not know the scale and rate of emissions.
- Time your filter-replacement schedule so that filters are replaced in early May, the beginning of the ozone season. This ensures that the filter is at peak performance for VOC removal during the high ozone season, resulting in the greatest public health benefits.
- 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 about every 6-8 months for proper air flow depending on the scale of operation and concentration of emissions.

BIOFILTERS AND CHEMICAL ODOR TECHNOLOGY

Biofilters are an emerging odor technology that could prove to be more cost effective and less resource intensive than carbon filtration once it is refined in the future. These filters use an organic medium, such as wood chips, that are inoculated with bacteria and consume odorous molecules. Research is currently being conducted on biofilters that contain bacteria that will consume terpenes and will not harm the cannabis plants. Biofiltration is successful at treating biodegradable VOCs, but it requires a large footprint and careful operation control.

Odor absorbing neutralizers: use the power of adsorption to mist or vaporize compounds into the airstream eliminating cannabis odors on contact. When sourcing a neutralizer, make sure to ask about the VOC and odor reduction effectiveness as it can vary (20%-90%) by product and contact time.

Masking and counteractive agents: use chemical odor control technologies that are misted at the cultivation facility's exhaust. The use of these agents is subject to Colorado's air quality regulations. Higher VOCs are associated with this technology, which lead to more severe impacts of air quality and are not recommended in urban areas.

Ozone generators: are mostly used for sanitization purposes and have also been used in industrial settings to control strong odors. These generators are harmful to humans and can damage or destroy crops because they are a direct emission source of ozone pollution; therefore, ozone generators are not recommended as a best practice for odor control.

Recommended Best Practices:

- Regularly inspect and perform maintenance checks on your HVAC, ducting and odor mitigation systems. If you are operating an indoor cu ultivation facility, keep windows and doors closed to the cultivation space and inspect the infrastructure for potential leaks.
- For greenhouses, "sealing" the grow space and circulating inside air for one week's time is a common practice that allows the VOC concentration to build up within the greenhouse. When it is time to "purge" the greenhouse by bringing in fresh air, do this at a time when the potential for ozone formation is lowest (e.g., evenings, windy days, and cloudy days). Avoid purging air during times that have the highest risk of ozone formation (e.g., mornings, sunny and hot days, and stagnant weather). During the time the greenhouse vents are closed or sealed, using molecular filtration or carbon scrubbers to mitigate VOCs and odor compounds will reduce the amount that could potentially reach outside air during the time when the ridge vents are open. Consider having a secondary barrier, such as ridge vent vapor systems running for odor control during the "purge" or opening up of the ridge vents to outside air.
- Make sure that the temperature and relative humidity are under control within tolerance levels of the cultivation room. High temperature and humidity will perpetuate any odor issues the facility is producing; this is especially true during the flowering phase of cultivation. Proper air circulation is critical for maintaining temperature and humidity control. Be sure to replace pre-filters and carbon as needed to ensure effectiveness of your odor control system under these high temperature and relative humidity conditions.
- Have a documented system in place for recording and responding to odor complaints in compliance with Denver's Odor Ordinance. If feasible, using cloud-based smart technology for odor control can help provide reporting data during the time of the complaint to prove compliance.
- Purchase a "scentometer" or Nasal Ranger to be able to quantify odors and record "defensible data" from self-testing. This can be used to determine if your operation is meeting local odor regulations.
- The harvesting phase results in a higher emission of VOCs than other cultivation phases. Time the harvesting phase to minimize its ozone impact, with respect to time of day, time of year and periods with high forecasted ozone. Minimize emissions during the morning and early afternoon, and during the summer.
- 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.
- Communicate and coordinate with other cannabis cultivators to learn what solutions are the most practical and effective.

MIP FACILITIES AND EXTRACTION PROCESSES

MIP facilities manufacture marijuana concentrates and infused products such as edibles, ointments, and tinctures. These methods can be divided into two main categories: solvent and solventless extractions. Solvent extraction methods apply a chemical to remove terpenes and cannabinoids from the plant, which results in a variety of different products.

Solventless extraction methods involve the use of physical methods to create concentrates.

The processing of plants where solvents are used to extract cannabis concentrates is considered a manufacturing process that is subject to state air quality regulations. The applicability of the air quality regulations will depend on the annual amount of VOC emissions quantified in tons emitted per year. It is the responsibility of the business to calculate an estimate of their VOC emissions from solvent extraction.

For specific guidance on air quality requirements for MIP facilities and how to calculate emissions, visit:

https://cdphe.colorado.gov/prevention-and-wellness/marijuana/greening-the-cannabis-industry

Regulatory Applicability

CCR 212-1 M 605 D4 requires a professional- grade, closed- loop extraction system capable of recovering the solvent, with the exception of ethanol and isopropanol solvent-based systems (CCR 212-1 M 605 E). The disposal of VOCs by evaporation or spillage is prohibited under 5 CCR 1001- 9 Regulation 7 V.A. CCR 212-2 R 605 A2 delineates the solvents that are permitted for use. The rule states: "A Retail Marijuana Products Manufacturing Facility may also produce Solvent- Based Retail Marijuana Concentrate using only the following solvents: butane, propane, CO_2 , ethanol, isopropanol, acetone, heptane and pentane. The use of any other solvent is expressly prohibited unless and until it is approved by the Division."

All permitted solvents besides CO2 are VOC-based and result in direct VOC emissions when evaporated. The law is the same for medical marijuana concentrate production and is provided in CCR 212-1 M 605 A2. This list of solvents was formulated with the health and safety of workers in mind, and using any other solvent is a violation of the law and could also lead to negative air quality impacts. CCR 212-1 M 605 D5 requires that all solvents used are food grade or at least 99% pure.

Recommended Best Practices:

- 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; ensure that the solvent is always recovered and kept in a closed-loop extraction system or designated container Maintain an inventory of all solvent liquids and ensure that the facility operating procedure allocates responsibility to keep an updated list.
- 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.
- Be sure your odor control technology is designed to capture your facility's emission load and make sure to replace carbon media at the determined frequency from either a Butane Life Test or another standardized carbon testing method.

CONCLUSION

Limiting activities that emit VOCs and making sure that odor control systems are optimally operating during high ozone periods can substantially improve the air quality impacts of cannabis facilities. It is recommended that an employee committee is designated to develop and implement a BMP plan specific to the facility needs.

Establishing and communicating BMPs through adequate training can help ensure that this becomes an integrated part of the routine operation in cannabis facilities. Colorado's cannabis industry can adopt BMPs that improve their air quality impacts, bolster their reputations as stewards of the environment, and control their odor, as well as air quality.

BUILDINGS & STRUCTURES

EXECUTIVE SUMMARY

Indoor Cannabis cultivation is a facility-based process. In the Denver area, indoor cultivations vary in size, from small-scale facilities to those larger than 25,000 sf., and come in an array of configurations including conventional operations that rely entirely on artificial light, as well as greenhouses, and hybrid structures. To date, this Guide has looked primarily at the building systems of indoor cannabis cultivation–from energy, to water, waste, pest management, air quality, grow media and other process inputs such as bulk CO2–and how to implement industry best practices to improve the efficiency of those systems.

Although systems selection and design play a critical role in determining the overall energy efficiency of a cultivation, decisions about building systems should be part of an integrated approach that includes the entire physical structure. In fact, upfront decisions that answer fundamental questions about a building including whether to build in the first place, and–if building a structure is warranted–what, where, and how to build, are crucial to delivering an efficient, resilient structure that can contribute positively to the overall performance of your cultivation and to your bottom line.

Globally, buildings account for 40% of greenhouse gas emissions.[1] Of that 40%, approximately 11% can be attributed to embodied carbon–the upstream or upfront" carbon in the foundation and structure, envelope/skin, interior finishes, as well as in materials employed during the use phase, i.e. for maintenance and repair.[2] The remaining 29% can be attributed to the operation of the structure and to materials reuse, recovery, recycling and disposal at the end of the building's use life.

While it's clear that optimizing system design, operations, sourcing renewable energy and other strategies are necessary and can go a long way to reducing the carbon footprint of buildings in their operational phase, they are likely insufficient to achieve ambitious net zero carbon goals. In and of itself, building system optimization is incomplete from the standpoint of sustainability, which r equires a holistic consideration of the full lifecycle of a building.

In this section, we will discuss foundational concepts in green building, including life cycle thinking and circular economy, and draw on relevant research in building systems design for controlled environment agriculture to recommend a holistic approach to building design, construction, operations, and materials management through the entire lifecycle of the buildings and structures that comprise your cannabis cultivation business. Along the way, we will address key challenges to the industry and how your building can help solve critical business objectives to support compliance, reduce energy cost, decrease plant cost, and increase plant yield with an optimally designed and operated building. Our recommendations will include tools and resources to inform your planning and implementation of a sustainable facility strategy and cover:

- Optimizing the structure
- Optimizing systems
- Optimizing operations
- How to get started
- When to get help and what to look for in consultants

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[1] *Accelerating Building Decarbonization with LEED, USGBC, 2021. Accessible at:* https://www.usgbc.org/sites/default/files/2021-10/H06_Accelerating%20Building%20Decarbonization%20with%20LEED.pdf

[2] *Building System Carbon Framework, WBCSD 2020 Accessible at:* https://www.wbcsd.org/Programs/Cities-and-Mobility/Sustainable-Cities/Transforming-the-Built-Environment/Decarbonization/Resources/The-Building-System-Carbon-Framework

OVERVIEW

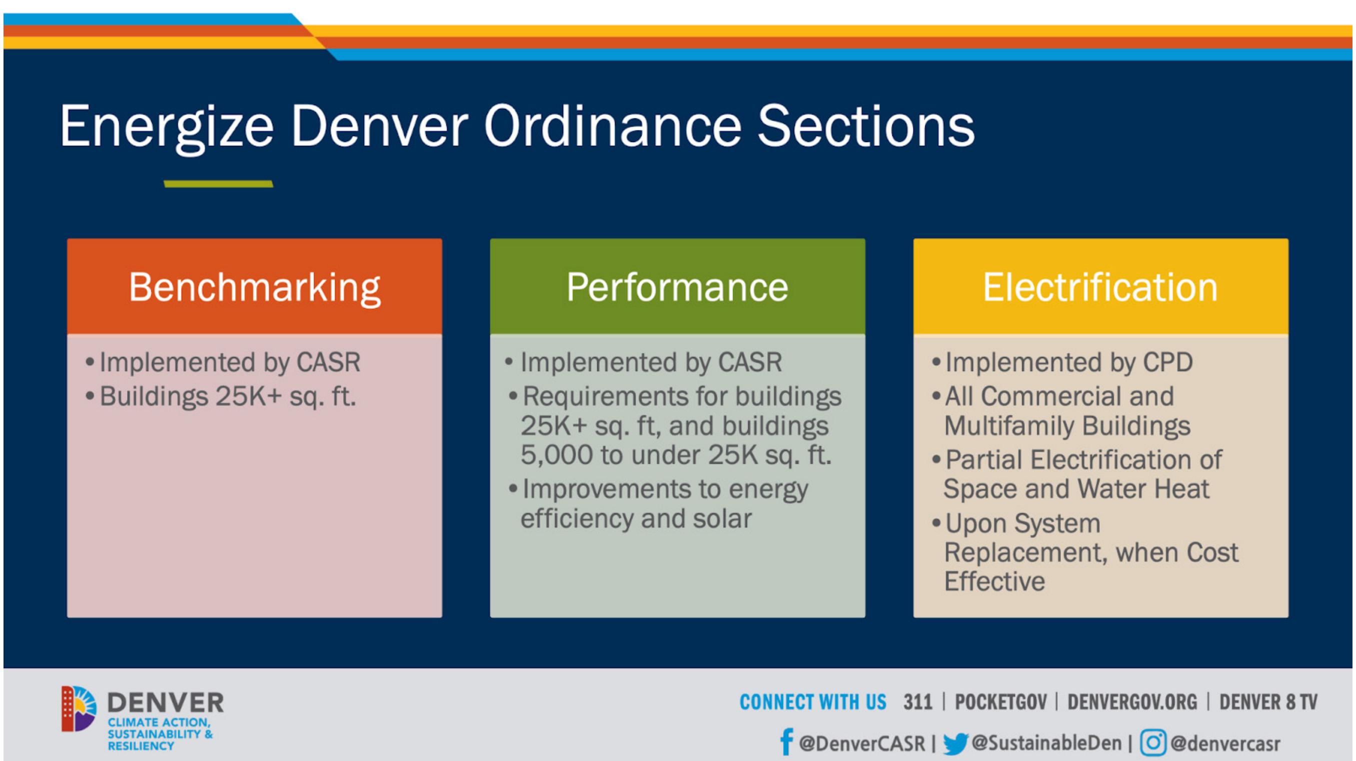
Practical and conceptual approaches to sustainable facilities planning, design, construction, and management

A holistic approach to your facility including its structure, systems, and operations can benefit from a basic understanding of green building and circular economy principles. Green building rating systems such as LEED (Leadership in Energy & Environmental Design), green building codes, and sustainable design frameworks can be helpful to break down the complexity of building decisions into manageable portions without losing sight of the big picture. For reference, Denver's Green Buildings Ordinance (summary sheet) requires developers and property owners to select from a range of efficiency, renewable energy, and structural design strategies to support sustainability. The ordinance covers new buildings, additions, and roofs for existing buildings (greenhouses are currently exempt):

- New buildings 25,000 square feet or larger
- Roof permits for existing buildings 25,000 square feet or larger
- Building additions 25,000 square feet or larger

The Energize Denver Ordinance, is another major component of the city's sustainability initiatives in the built environment. It establishes benchmarking, performance (including energy efficiency and solar), and electrification requirements for commercial and multifamily buildings, which are collectively responsible for 49% of the city's greenhouse gas emissions. The city is currently working with industry stakeholders to finalize compliance options for manufacturing, agriculture, and industrial (MAI) facilities including cannabis facilities and will require applicable facilities to begin benchmarking in 2023. For more information, see the MAI section of the Energize Denver Hub website.

Among other strategies, the Green Building Ordinance promotes increased adoption of green building programs including LEED. Specifically, LEED BD+C (building design and construction for new buildings and major retrofits) and LEED EB+OM (existing building operation & maintenance) may offer a roadmap for larger cannabis businesses, to incorporate sustainability into the design and operation of their facilities. It is important to note that aside from roofs, the ordinance lacks requirements for load bearing (e.g., foundation/ structure), envelope (e.g., walls, windows) building components and omits end-of-life management aspects of building materials.



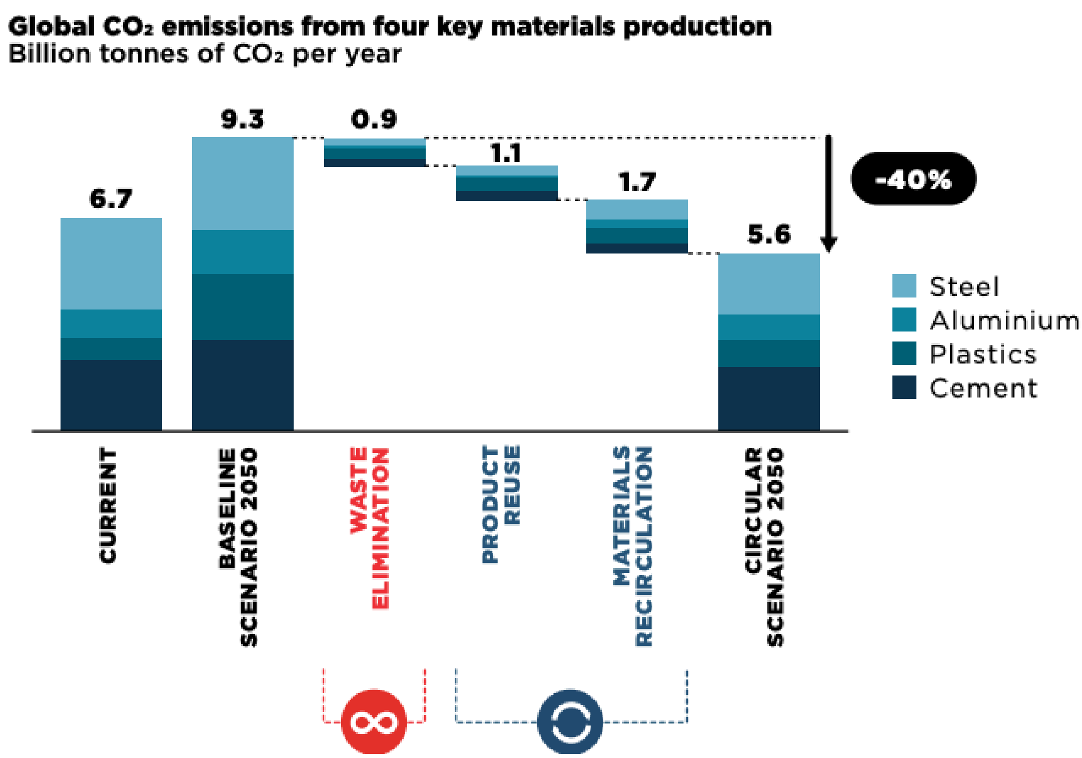
On a related topic, the city's Sustainable Resource Management plan, released earlier this year, supports the adoption of a Universal Zero Waste Reduction Ordinance by 2024 that would establish diversion requirements for construction and demolition waste. [3] Denver's commercial and construction sectors generate than 80% of Denver's total waste stream and divert (from landfill) a mere 36%. This represents a significant opportunity to increase waste diversion in Denver and will hopefully promote building deconstruction, reuse, and recycling options in the cannabis sector as well.

Circular Economy

Fundamentally, and particularly because the built environment is so material intensive, the concept of Circular Economy can help to orient a sustainable building approach. Circular Economy's three guiding principles are straightforward and easy to keep in mind:

1. Design out waste & toxics
2. Extend use life of materials
3. Regenerate natural systems

Put into practice, these principles can have a profound impact on the efficiency, resilience, and sustainability of structures and how they are used. The Ellen MacArthur Foundation projects that a circular economy scenario for the built environment could reduce annual global GHG emissions from key building materials by 40% or 3.7 billion MTCO2e by 2050. (CE applied to built environment: Completing the picture, 2019, pg. 31).[4]



[3] *Update to Denver's 2010 Solid Waste Master Plan: Sustainable Resource Management Plan. Accessible at:* https://www.denvergov.org/files/assets/public/climate-action/documents/resource-management/swmp-2022-update.pdf

[4] *Ellen MacArthur Foundation. Completing the picture: How the circular economy tackles climate change (2019). Accessible at:* www.ellenmacarthurfoundation.org/publications

Life Cycle Carbon

Another way to conceptualize sustainable building is to consider life cycle carbon. Life cycle carbon emissions may be used to help quantify a building's environmental impacts and guide decision making to optimize sustainability for cultivation and other facilities in the cannabis sector.

- **Embodied carbon:** carbon associated with all stages of a building's life cycle excluding the operation phase
- **Operational carbon:** carbon associated with operating the building
- **Life cycle carbon:** carbon emissions associated with all stages of a building's life cycle

Total life-cycle carbon = EC + OC

Phase	Life Cycle Carbon
Resource Extraction	Embodied Carbon
Manufacturing	Embodied Carbon
Transportation	Embodied Carbon
Construction/Installation	Embodied Carbon
Operation/Equipment Replacement/Maintenance	Operational Carbon
Demolition/End of Life	Embodied Carbon

(Credit: Overview of life cycle impacts of buildings. US Department of Energy, 2020)[5]

[5] *Overview of life cycle impacts of buildings. David Nemtzow, Building Technologies Office Director, US Department of Energy, 2020* https://www.energy.gov/sites/prod/files/2021/01/f82/bto-lifecycle-webinars-1-101620.pdf

Regarding life cycle carbon, a key point to keep in mind is the trend toward embodied carbon gaining relative importance to operational carbon over time. As we continue to decarbonize our energy grid and implement energy efficiency measures (and source renewable energy) at the building level, reducing carbon in our structures and managing embodied carbon will become increasingly necessary.

Due to the carbon intensity of buildings, and in light of projected growth in global construction, sustainable building strategies will play an outsize role in helping society respond to the climate crisis. The following decision matrix, adapted from the Department of Energy's 2021 presentation "Overview of life cycle impacts of buildings", is instructive. The strategic options listed are supported by green building "rules of thumb" and tools including Life Cycle Assessments (LCAs), Environmental Product Declarations (EPDs), and procurement programs such as the Embodied Carbon in Construction Calculator (EC3) and Buy Clean.

Decisions that heavily influence life cycle carbon of buildings

Optimize Project	Optimize System	Optimize Procurement
New vs retrofit	Alternate materials	Transparency
Reduce footprint	Building design, orientation, siting	EC limits/incentives (e.g. through LEED)
Design for disassembly	Life cycle thinking	Low carbon specs
⇧ Rules of Thumb/LCAs	⇧ Life Cycle Assessment	⇧ EPDs, EC3, Buy Clean

(Credit: Overview of life cycle impacts of buildings. US Department of Energy, 2020) [2]

To catalog life cycle carbon through the building stages from material production, through construction, use, end of life and beyond use (e.g., reclaiming building materials in new construction), the World Business Council for Sustainable Development's Building System Carbon Framework assessment tool can be useful.[6]

Although this is based on the European standard (EN15978:2011) it is relevant to facility construction here in the United States as either a generalized or detailed assessment of a building's life cycle carbon emissions and can be used for both planning and reporting purposes.

Carbon sources can be recorded through all building stages from raw material extraction and manufacturing to construction/refurbishment, use, end of life and beyond. To improve accuracy, the framework depends on product-specific data (e.g., EPDs for building materials), building life-cycle assessments, and building modeling tools. Both building LCAs and EPDs are worthy of mention due to their increasing use in green building rating systems such as LEED and in green building codes. For more on EPDs see the Supporting Sections of the Guide.

The Life Cycle Cost of Buildings and Structures

Now that we understand the need to design and build more sustainably and operate buildings more efficiently, and that a range of strategies are relevant to improving the sustainability of cannabis facilities here in Denver, it's time to consider cost. In so far as green building goes beyond the "minimum standard" imposed by building codes and established construction practices, added complexity, time, and cost are to be expected for a sustainable facility project. However, a long-term perspective that not only considers upfront costs, payback, and other project financing metrics, can reveal the financial benefits of a green building approach for your cultivation.

[6] *Bringing embodied carbon upfront. Accessible at: https://buildingtransparency-live-87c7ea3ad4714-809eeaa.divio-media.com/filer_public/14/f1/14f1a27b-906d-4224-8291-a3dd1fcfae68/wc_am-bringingembodiedcarbonupfrontpdf.pdf*

BUILDING LAYERS	BUILDING STAGES						BEYOND LIFE
	PRODUCT	CONSTRUCTION	USE		END OF LIFE	EMISSIONS	
	A1-A3	A4-A5	B1-B5	B6-B7	C	$kgCO_2/m^2$	D
Structure Foundation, load-bearing							
Skin Windows, roof, insulations							
Space Plan Interior finishes							
Services Mechanical, electrical, plumbing							
Stuff *(optional)* Furniture & appliances							
Building carbon emissions							
Carbon compensation Removals and offset							

● Embodied carbon ● Operational carbon ● Partial and total sums

In conjunction with a life cycle analysis of carbon, life cycle costing may help reduce costs associated with facility investments and expenses for construction, operation & maintenance, and building end-of-life (retrofitting/deconstruction/ demolition). A recent study in Energy & Buildings employed a systematic life cycle cost (LCC) analysis approach to optimize the design of indoor farming facilities around energy efficiency measures (EEM) and renewable energy systems while providing optimal yield and quality.[7] The authors developed an energy model for a CEA facility in Denver's RiNo district, Uchi's rooftop aeroponic garden facility, which produces lettuces and leafy greens. However, the model can be adapted for any CAE facility producing any crop type.

Results of the analysis indicate that several EEMs can be implemented, including a high-efficiency furnace, temperature set back, shading devices, daylighting controls, and evaporative cooling, to cost-effectively reduce annual energy consumption by 50% and reduce the LCC by 26%, or $895,923, against the baseline of $1,208,775.

Though this study does not consider embodied energy or carbon, LCC methodology can and should be applied to the structure of the building as well, considering the integrated interdependent nature of all building components including both the structure and its systems.

BEST PRACTICES

Optimizing the Structure

According to the Southwest Energy Efficiency Project's 2017 report on energy efficiency best practices for cannabis cultivation, the ideal time to incorporate energy efficiency is during the "new construction phase" when the design, acquisition, and installation of equipment necessary to convert an empty building into a new cultivation facility occurs.[8] To achieve optimal building performance throughout the life cycle of a grow operation, building systems and structural design considerations should go hand-in-hand with building selection, design,and construction of the facility. An integrated approach that begins with optimizing the structure may improve efficiency, reduce life cycle costs, and avoid a need for expensive retrofits/system upgrades in the future.

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[7] *Nicholas Engler, Moncef Krarti, Optimal designs for net zero energy-controlled environment agriculture facilities, Energy and Buildings. Volume 272, 2022. Accessible at: https://www.sciencedirect.com/science/article/abs/pii/S0378778822005357?via%3Dihub*

[8] *Kolwey, Neil, 2017. Southwest Energy Efficiency Project. A Budding Opportunity: Energy efficiency best practices for cannabis grow operations.*

In the Denver area, most cannabis grows are fully indoor facilities converted from warehouses and other pre-existing building stock. Due to Colorado's abundant sunshine and relatively mild climate, greenhouses may offer the greatest potential energy savings over indoor grows–between 60% to 75% of the energy required per pound of flower–but currently only represent a small share of all indoor cultivations in Denver.8 It's likely that up-front construction costs, permitting, perceived security risks, and other factors have contributed to a slow adoption of greenhouses in Denver's cannabis sector. Considering the efficiency gains, primarily from the reduced need for artificial light, greenhouses may become an increasingly attractive option to reduce operational costs while still retaining other benefits of indoor cultivation.

For an in-depth look at the potential benefits to greenhouses, including guidance on decision-making for greenhouse design, including the building envelope, systems (lighting, climate control, etc.), and how energy conservation measures can be incorporated into a cannabis greenhouse, please see the Supporting Sections of this document. One of Colorado's premier dispensaries, Lightshade, discusses its flagship greenhouse, which features a state-of-the art irrigation and re-circulation system that was integrated into the design of its greenhouse.

Optimizing Systems & Operations

Energy consumption is the leading driver of greenhouse gas emissions for Denver's cannabis industry and provides the best opportunities for growers to improve efficiencies and reduce operating costs. As previously mentioned, the ideal time to incorporate energy efficiency and renewable energy measures into a cultivation is during the design phase. For established facilities, there are several steps that can be taken to improve energy performance:

- **Controls:** Deploy control systems to reduce energy consumption and peak demand.
- **Shading (for greenhouses and hybrid facilities):** Incorporate shading devices for glazed surfaces to reduce air conditioning thermal loads.
- **Lighting:** Install LED fixtures.
- **HVAC and Dehumidification:** Install high performance heating cooling and dehumidification systems: evaporative coolers are ideal for Denver's climate
- **Renewable energy sourcing:** Although not likely a cost-saving measure, sourcing renewable energy, particularly solar PV (e.g. Jacks Solar Garden), can extend the overall energy savings potential for all indoor, hybrid, and greenhouse facility types.

Regardless of the approach to design for the structure and building systems of your cultivation, verifying that your facility is operated properly and efficiently is key. A comprehensive measurement and verification system is essential to ensure that your facility achieves its full design potential, both for your business and for the planet. The Energy section of this Guide covers everything from what metrics to track, to how to gather data from utilities, conduct audits, and engage specialists to expertly inform your operational procedures. Though highly recommended to all indoor cultivation facilities, a Building and/or Energy Management System may be financially out of reach, particularly for smaller operations. Tracking key energy, water, waste, and other operational metrics is where any cultivation should start and will provide the basis for a holistic and robust measurement and verification system.

To complement the detailed focus areas on building systems in this Guide, the following table offers a quick reference for the range of building envelope, systems, and controls that can be implemented to deliver significant efficiency improvements for the three facility types that are common here in Denver. While the intent is to be as complete as possible, additional options exist and should be considered as part of a holistic approach to building design, construction/retrofitting, and operation and maintenance.

A Comparison of Potential Energy Savings Across Facility Types

Energy Efficiency Measure	Indoor Cultivation	Hybrid*	Greenhouse
Controls: Economizer	✅	✅	✅
Controls: Temperature Set-back at night	✅	✅	✅
Controls: Lighting	✅	✅	✅
Envelope: Shading	N/A	✅	✅
Envelope: Glazing	N/A	✅	✅
Envelope: Insulation	(Applicable but not modeled)	(Applicable but not modeled)	✅
Systems: LED Lighting	✅	✅	✅
Systems: High-efficiency Heater	✅	✅	✅
Systems: High-efficiency Fans	✅	✅	✅
Systems: Evaporative Cooler	✅	✅	✅
Estimated Overall Efficiency Savings:	32%	50.1%	60% - 75%

*Based on a hybrid (non-cannabis) CAE facility in Denver consisting of a 5898.62 sf cultivation space, 398 sf office, 200 sf cold storage, and 1292 sf of unconditioned spaces, consuming 1,256,395 kWh/Year.[9]

Resources:

- What Can You Do Now to Prioritize Embodied Carbon in Specifications?
- Denver Green Building Ordinance
- Complying with the Green Buildings Ordinance
- Energize Denver: Manufacturing, Agricultural, and Industrial (MAI) Buildings
- Current and Future Perspectives for Controlled Environment Agriculture (CEA) in the 21st Century
- GSA Sustainable Facilities Tool website

[9] *Nicholas Engler, Moncef Krarti, Optimal designs for net zero energy-controlled environment agriculture facilities, Energy and Buildings, Volume 272, 2022. Accessible at:* https://www.sciencedirect.com/science/article/abs/pii/S0378778822005357?via%3Dihub

APPENDICES

SAMPLE WATER QUALITY REPORT

COLORADO STATE UNIVERSITY
Soil, Water & Plant Testing Laboratory
Room A320, NESB
Fort Collins, CO 80523-1120
Phone: 970-491-5061 / Fax: 970-491-2930

Date Received: 11/3/16
Date Reported: 11/8/16

Billing:

IRRIGATION WATER ANALYSIS

SOURCE: Arapahoe City

LAB # W519 I

"Metals" and "Individual Element" Analysis

	mg/L	Recommended Limit mg/L
Aluminum	0.13	5.0
Ammonium	*	N/A
Arsenic	*	0.2
Barium	0.03	1.0
Boron	<0.01	5.0
Cadmium	<0.005	0.05
Chromium	<0.01	1.0
Copper	0.02	0.5
Fluoride	*	2.0
Iron	<0.01	N/A
Lead	0.01	0.1
Manganese	<0.01	N/A
Mercury	*	0.01
Molybdenum	0.02	N/A
Nickel	<0.01	N/A
Phosphorus	<0.01	N/A
Selenium	*	0.05
Zinc	0.06	24.0

* Not requested

"Routine Package"

	Results	Results
Conductivity	398	µmhos/cm
pH	7.5	
pHc	8.0	
	mg/L	**meq/L**
Calcium	29.2	1.46
Magnesium	7.24	0.60
Sodium	19.8	0.86
Potassium	1.87	0.05
Carbonate	<0.1	<0.1
Bicarbonate	103	<0.01
Chloride	7.20	0.20
Sulfate	50.5	1.05
Nitrate	0.9	0.9
Nitrate-Nitrogen	0.2	0.2
Boron	<0.01	
Pounds of Sulfate per acre foot	44.9	
Pounds of Nitrate per acre foot	0.5	

SAR 0.8 Salinity Hazard Low Sodium Hazard Low

COMMENTS: This is good quality water for irrigation.

COLORADO STATE UNIVERSITY
Soil, Water & Plant Testing Laboratory
Room A320, NESB
Fort Collins, CO 80523-1120
Phone: 970-491-5061 / Fax: 970-491-2930

Billing:

SOURCE: Arapahoe City

SAMPLE ENERGY AUDIT FORM

Name:	

Grow Type:	
Cultivation Sq. Ft.	
Buidling Type	
Building Age	

Basic Overview	
Annual Energy Used (kWh)	
Annual Water Used	
Production (Dried Wt.)	

Month	Energy (kWh)	Water (gallons)	Production (Dried Wt.)
January			
Feburary			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

Growing System

Grow Medium Description:

Plant Phase	Capacity (# of Plants)	Cycle Duration	Cycles Per Year	Irrigation Type	Irrigation Schedule/Amount	Lighting Type	Make	Model	# of lights	Lighting Hours

Equipment	Make	Model	Quantity	Est. Run time (hrs/day)	Location/Phase Used
HVAC					
Ocsillating Fans					
Fertigation					
Dehumidifiers					

TERMS AND DEFINITIONS

2020 Sustainability Goals	The 2020 Sustainability Goals focus on 12 resource areas and set goals for the City and County of Denver, and community. The resource areas are Air Quality, Climate, Energy, Food, Health, Housing, Land Use, Materials, Mobility, Water Quantity, Water Quality and Workforce.
AHAM	Association of Home Appliance Manufacturers: AHAM provides leadership, advocacy, and a forum for public policy, standards and business decisions to consumers and appliance manufacturers.
anion	A negatively charged ion.
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
BMS	Building Management System: A system that controls the environment of a facility and which, when monitored, may alert to alert facility managers about broken or malfunctioning equipment.
Ca++	Calcium cation
cation	A positively charged ion.
CASR	Climate Action, Sustainability, and Resiliency: The CASR works with city, state and community partners to conduct education, community engagement, and enforcement to ensure healthy people, healthy pets and a sustainable environment.
CDA	Colorado Department of Agriculture: The mission of the CDA is to strengthen and advance Colorado agriculture; promote a safe and high-quality food supply; protect consumers; and foster responsible stewardship of the environment and natural resources.
CDPHE	Colorado Department of Public Health and Environment: State department providing services in the areas of health, environment, marijuana, vital records, public records, laboratory services, health equity, and emergency preparedness and response.
CESQG	Conditionally Exempt Small Quantity Generator: An EPA category for waste generators, based upon quantities of hazardous and acutely hazardous waste generated and accumulated.
CHP	Combined Heat and Power: CHP systems, also called cogeneration systems, generate power and heat in a single system.
CMH	Ceramic Metal Halide: lamps provide energy-efficient wide-spectrum lighting.
CO 2	Carbon Dioxide: is a naturally and artificially produced compound. It is naturally produced by decompositions, respiration, and other natural sources and used by plants for photosynthesis (along with water and sunlight). It is artificially produced from burning fossil fuels, deforestations and manufacturing processes.
CSWG	Cannabis Sustainability Workinggroup, also called “the Workgroup”: The CSWG was developed by CASR to determine best practices and to develop this manual and other education resources for the industry.
DG	Distributed Generation: DG is an approach to energy production that generates power at the end-user location.
Denver’s Climate Action Plan 2015	Denver’s Climate Action Plan 2015 is a document developed that sets forth Denver’s goals, priorities, and strategies to meet the 2020 Sustainability Goals and to reduce greenhouse gas emissions 80 percent from its 2005 baseline by 2050.
EAS	Engineering Assistance Study: An EAS is conducted to identify and evaluate energy savings opportunities.
EC	Electrical Conductivity: EC is the potential for material to conduct electricity (i.e. the potential for an electrical current to move through water.)
ECA	Electrochemically Activated Water: ECA is water mixed with food-grade salt fed through a reactor that electrically charges the salt water to produce disinfect or detergent solutions.
EER	Energy Efficiency Ratio: The EER is the ratio of cooling capacity to power input.

EMS	Energy Management System: A system that monitors the environment of a facility and which may be used to alert to alert facility managers about broken or malfunctioning equipment.
Energize Denver	A benchmark ordinance requiring owners/operators of large commercial and multifamily building to annually assess
EPA	U.S. Environmental Protection Agency
FCU	Fan Coil Unit: An FCU is a device consisting of a heating and/or cooling heat exchanger or coil and fan. It is part of an HVAC unit.
Feasibility Study	Also called a qualification study, a specialist performs the feasibility study using 6 to 12 months of utility bills to build a high-level model that provides a "ballpark" economic, environmental and operational impact assessment.
g/kW	grams per kilowatts
g/W	grams per Watts
g/sq ft or g/SF	grams per square feet
HCO3-	Bicarbonate anion
HPS	and report the buildings' energy performance using the free ENERGYSTAR Portfolio Manager tool.
HVAC	Heating, Ventilation and Air Conditioning: The system used to heat and cool buildings.
InfoWise	An Xcel Energy service providing interval data that is used to create a web-based energy dashboard.
ion	An electrically charged atom or groups of atoms.
IPLV	Integrated Part Load Value: IPLV describes the performance of a chiller capable of capacity modulation.
kW/cycle	Kilowatts per cycle
LED	Light-Emitting Diode: An LED is a two-lead semiconductor light-source.
LEP	Light-Emitting Plasma: LEP is high-intensity full-spectrum light source.
LFG	Landfill Gas: LFG is created by the microorganisms in a landfill.
LQG	Large-Quantity Generator: An EPA category for waste generators based upon quantities of hazardous and acutely hazardous waste generated and accumulated.
MED	Marijuana Enforcement Department, Department of Revenue: The MED's mission is to promote public safety and reduce public harm by regulating the Colorado commercial marijuana industry through consistent administration of laws and regulations and strategic integration of process management, functional expertise and innovative problem-solving.
Mg++	Magnesium cation
MH	Metal Halide: An MH lamp is a high-intensity gas discharge lamp.
mL	milliliter
mol/m2/day	mole per square meter per day
mol/m2/S	mole per square meter per Siemens
mol/µmol	mole per micromole
µmol/mol	micromole per mole
µmol/SF	micromole per square foot
µmol/m-2 s-1	micromole per square meter and second (PPFD unit)
Na+	Sodium cation
MSW	Municipal Solid Waste: MSW is non-hazardous waste, such as household trash.
NFT	Nutrient Film Technique: NFT is a hydroponic technique whereby the bare roots of a plant are watered using a controlled, shallow, nutrient-dense stream.

nm	nanometer
PAR Spectrum	Photosynthetically Active Radiation: PAR designates lighting spectral range.
PPFD	Photosynthetic Photon Flux Density: PPFD is the number of photons in the photosynthetically active range per square meter per second.
PV	Photovoltaic: Conversion of light into electricity.
Qualification Study	See Feasibility Study
Reheat	A term used to describe heating a space to allow a cooling system to run 24 hours a day to produce dehumidification without reducing temperatures in the space.
RH	Relative Humidity: RH is the ratio of actual vapor density in the air to saturated vapor density of the air.
ROI	Return on Investment: ROI is calculated as gains-costs/costs. Though typically used in costs analyses, it can be used to calculate investment benefits of any type.
SEER	Seasonal Energy Efficiency Rating: A measure of the efficiency of an air cooling system.
SQG	Small-Quantity Generator: An EPA category for waste generators based upon quantities of hazardous and acutely hazardous waste generated and accumulated.
VRF	Variable Refrigerant Flow: VRF is an HVAC technology that is used to reduce loss of efficiency.
XCEL	Xcel Energy is a utility company serving several Midwestern and Western States, including Colorado.