



CANNABIS
ENVIRONMENTAL
BEST MANAGEMENT
PRACTICES GUIDE

OCTOBER 2021

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FROM THE EXECUTIVE DIRECTOR



Denver's Office of Climate Action, Sustainability and Resiliency would like to congratulate the Cannabis Sustainability Work Group (CSWG) on the 2021 update to the Cannabis Environmental Best Management Practices Guide. The content for this guide has been developed over five years with the input from industry professionals, the community, environmental experts and state and local governmental agencies with the aim to help cultivators increase efficiency and reduce their climate and environmental impacts.

This Work Group was born from the desire to proactively embed an ethos of sustainability within the cannabis industry upon legalization in Colorado. Recognizing that the cultivation of

cannabis has the capacity to consume considerable amounts of energy and natural resources, the group has worked tirelessly to create tools to educate industry professionals and foster a network of environmental leaders within this ever-expanding industry.

Denver is now home to over 500 active cultivation licenses. Thanks to this group and guide, many are taking strides to increase efficiency while reducing their consumption and environmental impacts. The CSWG also hosts regular workshops and an annual Cannabis Sustainability Symposium.

The partnership between cannabis professionals and local and state governments serves as a model for successful community collaboration to make meaningful progress toward common sustainability goals. Their work helps to advance programs and policy, remove barriers where appropriate and foster the broad adoption of sustainable business practices, ultimately helping the City achieve its climate goals.

We would like to express our sincere gratitude for the Cannabis Sustainability Work Group and for their commitment to fostering sustainability practices within the cannabis industry in Denver, in Colorado and beyond. We hope that you find this guide useful and inspiring and continue to engage with the CSWG through their workshops, tools and symposium.

Sincerely,

Grace Rink

Executive Director, Office of Climate Action, Sustainability and Resiliency

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, and the facilitation of dialogue between the cannabis industry, the community and technical experts.

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 2020 release is the fourth 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.

SUSTAINABILITY DRIVERS

- Economic Competitiveness
- Community Relations
- Environmental Impact

SIGNIFICANT ASPECTS

- Land Use
- Materials Use
- Indoor Air Quality
- GHG Emissions
- Water Consumption
- Odor Control
- Effluent Discharge
- Regulatory Compliance
- Energy Consumption
- Solid Waste Generation
- Public Wellbeing
- Product Quality
- Ambient Air Quality
- Worker Safety
- Long-term Stewardship of Natural Resources
- Consumer Safety



DENVER 2020 SUSTAINABILITY GOALS

RELATED IMPACTS

- Climate
- Employee Well-Being
- Community Relations
- Operational and Compliance Budgets
- Water Quality
- Ecosystem
- Environmental Justice
- Regional Stakeholder Alignment

ENERGY

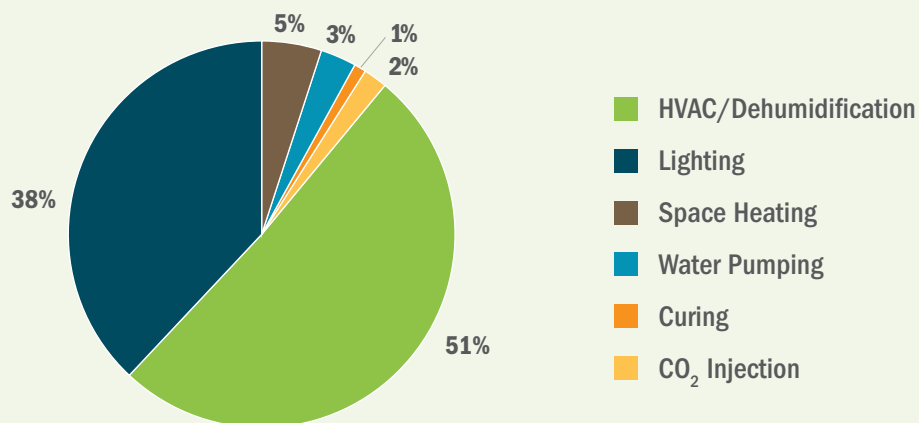
EXECUTIVE SUMMARY

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 1²: 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

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

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

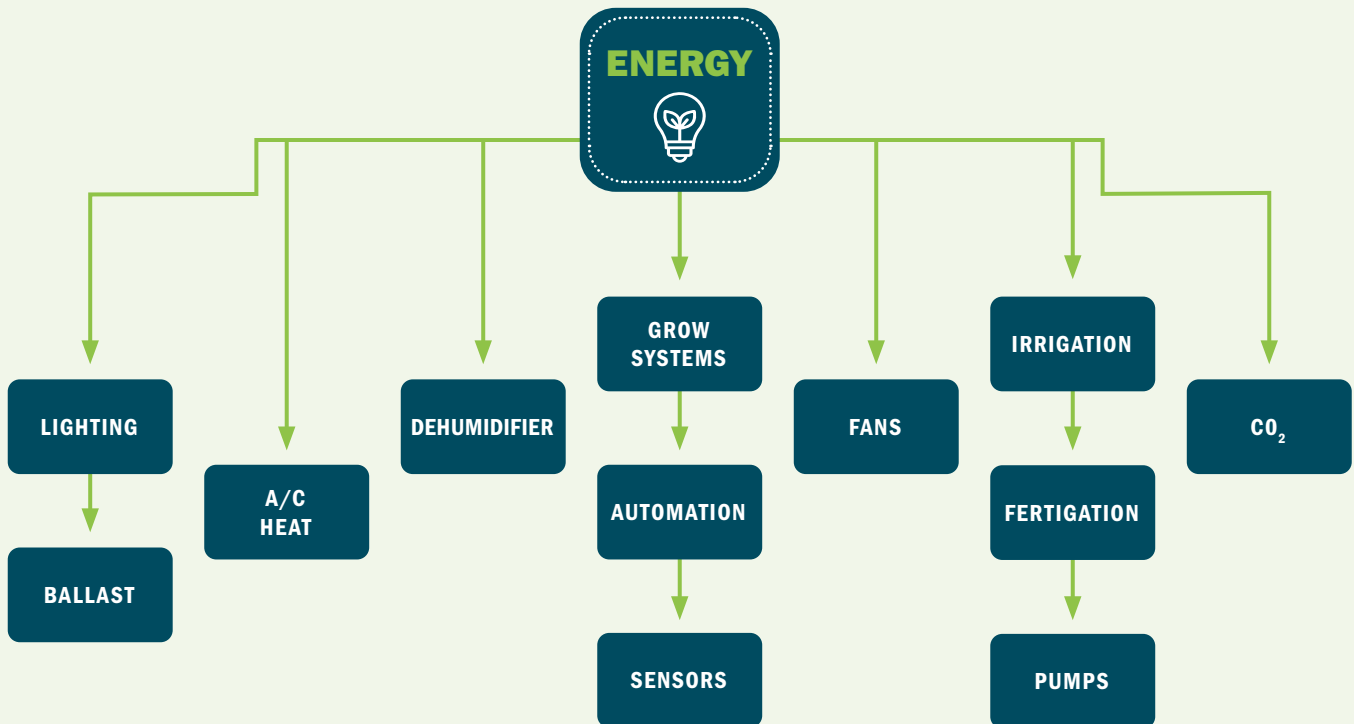
ENERGY EFFICIENCY & MANAGEMENT

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).

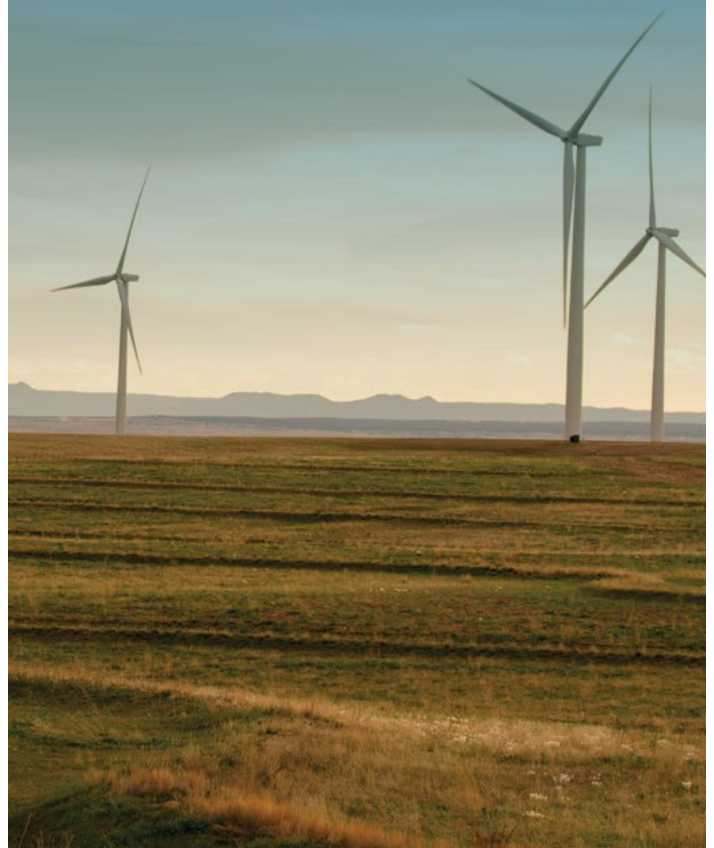
In contrast, Denver's electricity consumption has continued to increase over the past several years due to a variety of factors, including overall community growth. Electricity use from cannabis cultivation and infused products manufacturing grew from about 1% to about 4% of Denver's total electricity 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.	$\mu\text{mol}/\text{m}^2/\text{s}$	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.	$\text{mol}/\text{m}^2/\text{day}$	Formula: $\mu\text{mol}/\text{m}^2/\text{s}$ (or PPFD) x 3600s x photoperiod (hr/day) / 1,000,000	Denver Outdoor Avg. Winter 15-30 $\text{mol}/\text{m}^2/\text{day}$ Summer 25-45 $\text{mol}/\text{m}^2/\text{day}$
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 (kWh), 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 www.xcelenergy.com and navigate to the Programs and Rebates page; click on the Business icon; then select the New Construction and Whole Building category to learn more about energy benchmarking.

UTILITY INTERVAL DATA

- Facilities with smart meters can request 15-minute interval data from the energy provider.
- Facilities can also opt to pay for Xcel's monthly utility bills.
- InfoWise service, which uses interval data to create a web-based energy dashboard that provides various insights and metrics. This service costs \$150 per month, with a \$900 equipment charge if a smart meter is not already in place.

- 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.

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 2 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.

Resources:

- Xcel Energy – Business Programs & Rebates
- Sample Energy Audit Form
- Blooming Benchmark

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.

SUSTAINABILITY ASPECTS AND IMPACTS: ENERGY

- ENERGY CONSUMPTION
- GHG EMISSIONS
- CLIMATE
- REGIONAL STAKEHOLDER ALIGNMENT
- COMMUNITY RELATIONS

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.

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.

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.

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 CO₂ 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 ($\mu\text{mol/s}\cdot\text{m}^2$) 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 PPF, 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 PPF.

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}.

Table 3: Lighting Technologies for Cannabis Production

LIGHT TECHNOLOGY	GENERAL USE/ GROWTH STAGE	SPECTRUM	RATED LIFE IN HOURS	INTENSITY* IN PPF	EFFICACY IN μMOLES/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 PPF measured at the top of the canopy. Once an operator has determined the target PPF, 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 PPF 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 PPF of the designed area. PPF 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 PPF. 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 PPF, but must take into consideration how much natural light/sunlight will be obtained. Light fixture count will undoubtedly decrease in most geographies

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.*

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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. Marcellis, 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.*

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

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 amount of 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.

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

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



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 Secretary of State. 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.

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

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.

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 larger facilities; and will require the use of a separate, standalone dehumidification system.

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.

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 are an extremely competitive option. 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.

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 standalone 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 CO₂ 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-off 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).

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

² ASHRAE *Advanced Energy Design Guides*:

<https://www.ashrae.org/technical-resources/aedgs/aedg-free-download>

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.

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 CO exhaust, improve biosecurity and reduce odors emanating from the facility.
- Cultivators should keep rooms warmer at night to manage latent load.
- 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.

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](#)

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 placed into 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.

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.

There are two primary approaches to supply side energy optimization that cultivators should consider as part of a broader energy management strategy:

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 Optimization:

The second approach is entering into an 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.

Table 4: Xcel Energy – Power Supply Mix for Colorado Customers⁶

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 & 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.

⁶ Xcel Energy – Energy that Works for Colorado

⁷ IPCC Renewable Energy Sources and Climate Change Mitigation

⁸ U.S. Energy Information Administration

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.

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).

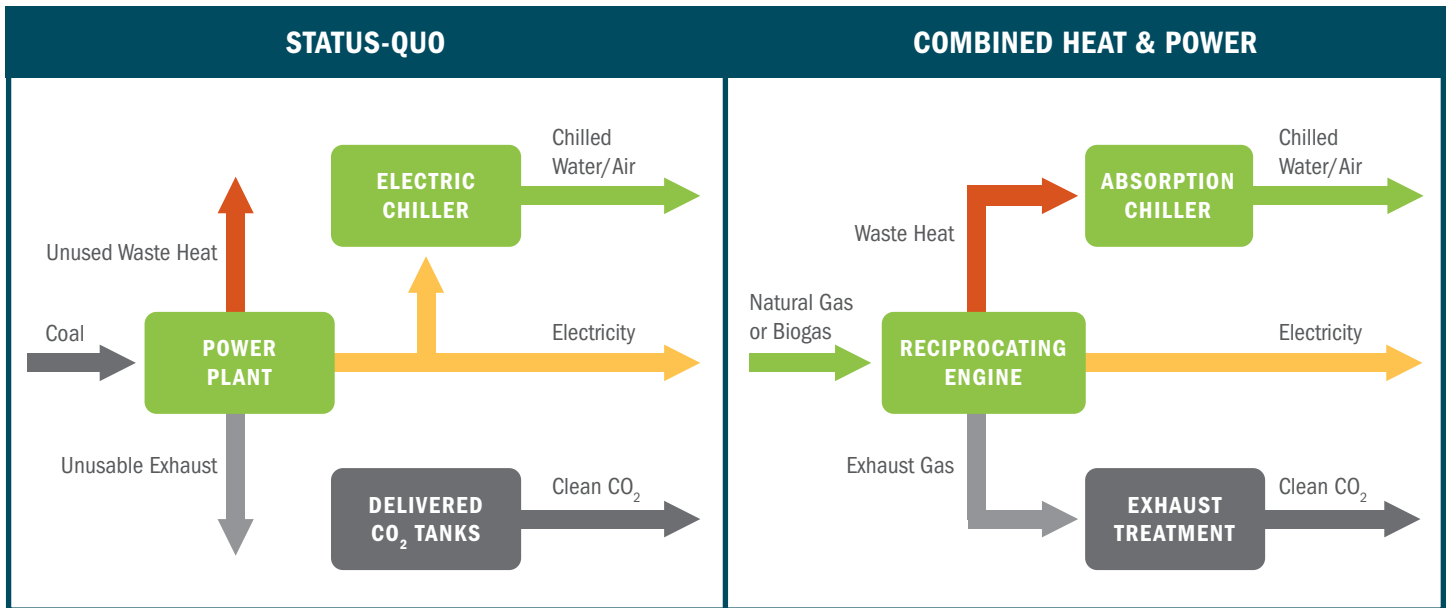
OFF-SITE ENERGY SUPPLY

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.

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.

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



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.

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.

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 PPF 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.
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 PPF 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 PPF 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 kW

12 hours per day (runtime) x 165 kW = 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 kW

12 hr. per day (runtime) x 97.5 kW = 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

This exercise shows the basic calculations and process for calculating a custom rebate and when coupled with the appropriate documentation should allow you to capture the highest rebate possible. Keep in mind many rebate programs cap rebates based on the simple payback or the total equipment cost. This means that even though your energy savings result in a certain rebate, the utility might cap the rebate at least depending on factors such as product cost, rebates acquired that year, and incremental cost.

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.

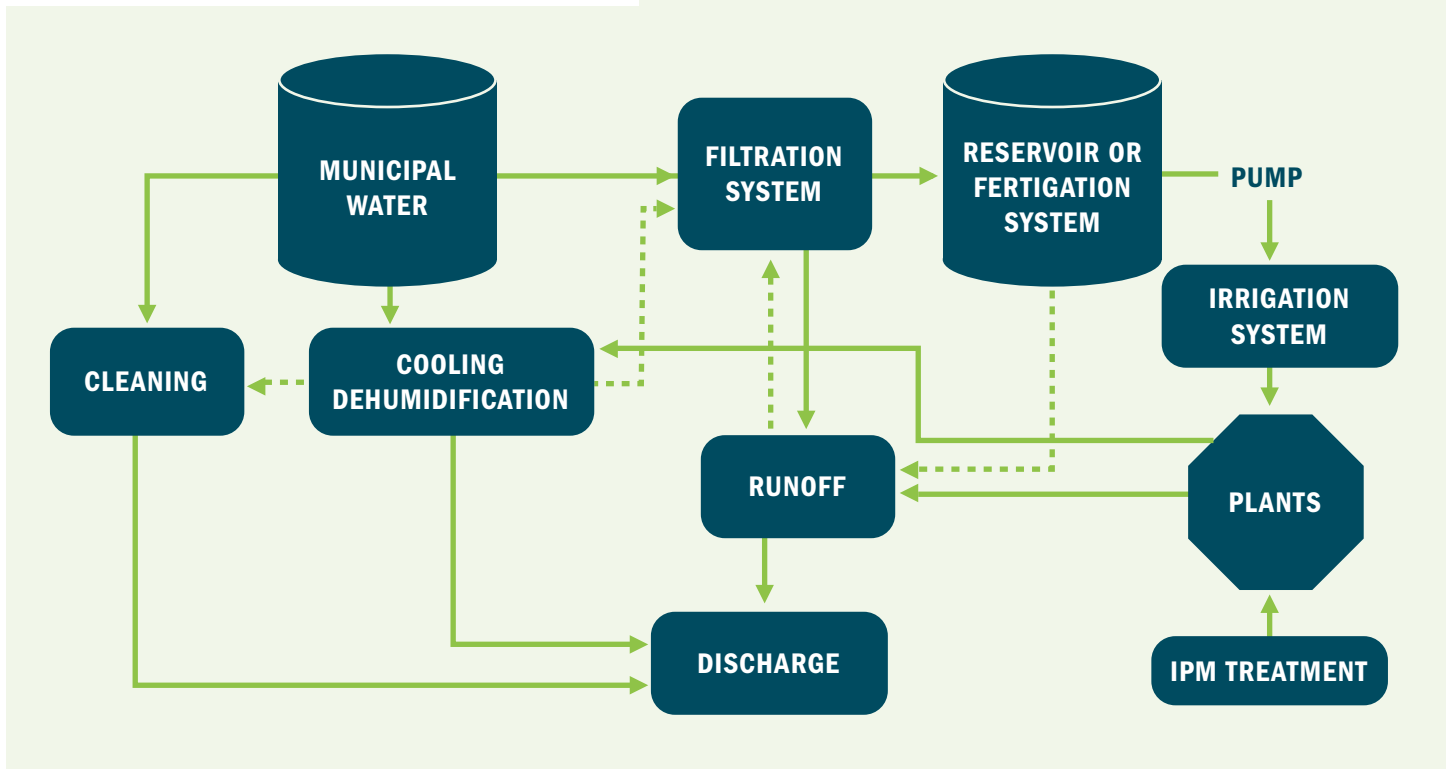
Community Relations

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.

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

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/>

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.

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 nitrified 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.

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.

Resources:

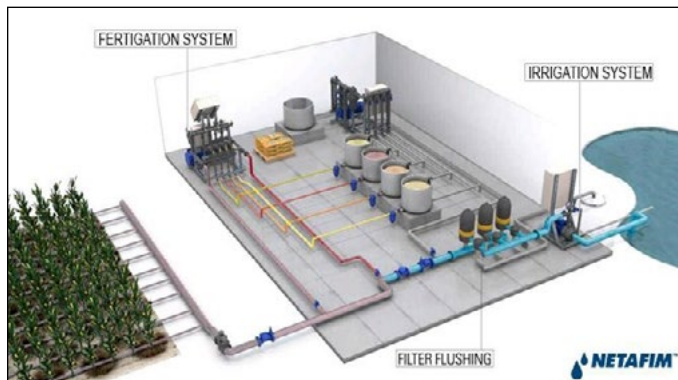
- Colorado State University – Soil and Water Testing Laboratory
- Denver Water Quality Reports
- Example of water testing report

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, renutrient 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-nutriented 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 nutrient 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 mixing by 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. Nutrient 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. High-quality

drip emitters are pressure compensated, so each plant gets the same amount of water regardless of position on the irrigation line. Many cultivators using drip irrigation systems water several times per day (pulse irrigation), delivering the total desired volume of water over a longer period. This allows the cultivator to carefully manage the amount of water runoff. To maximize water conservation, cultivators should measure moisture levels within the media as well as electrical conductivity to determine irrigation timing and quantity. 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 a 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

Table 6: Irrigation Methods for Indoor Cannabis Cultivation

IRRIGATION METHOD	EFFICIENCY	BENEFITS	DRAWBACKS
Hand Watering	Low	<ul style="list-style-type: none"> • Eyes on all plants during watering • Gives grower “hands on” feel • No high-tech equipment required 	<ul style="list-style-type: none"> • Inconsistency of volume per pot • Inconsistency between employees responsible for task • Labor-intensive
Drip	High	<ul style="list-style-type: none"> • Automated • Precise volume of water • Allows cultivator to water a large number of plants at once 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Automated • Less chance of under-watering plants • Easy and inexpensive to build 	<ul style="list-style-type: none"> • 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](#)

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.

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.

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.	<ul style="list-style-type: none"> • Natural • Contains nutrients • Easily amended 	<ul style="list-style-type: none"> • 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.	<ul style="list-style-type: none"> • Lightweight • Inert, so grower can control nutrients • Manufacturing process ensures material is clean • High steerability 	<ul style="list-style-type: none"> • 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.	<ul style="list-style-type: none"> • Natural • Easily amended • Medium steerability (depends on thickness of fibers) 	<ul style="list-style-type: none"> • 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 H2O: [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

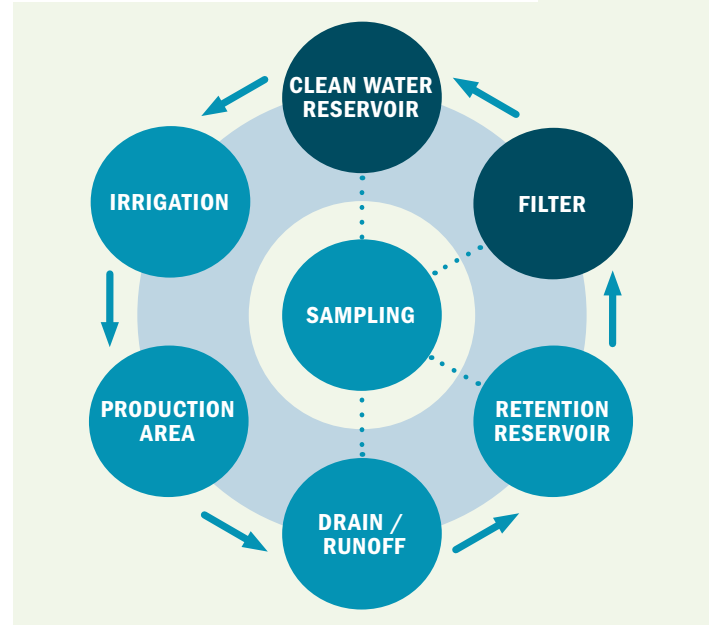
Cultivating cannabis in controlled indoor environments provides multiple opportunities for water efficiencies and water recycling. Virtually all excess water runoff and water vapor can be captured and delivered back to the beginning of the watering process.

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](#)
- [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:
Hortimax 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

Waste streams are capable of having big impacts on operations. Positive environmental impacts can be significant when sustainable waste practices are chosen. Also, economic competitiveness is an advantage of less waste. Community relations are also strengthened when operators prove to be responsible environmental partners. Unfortunately, landfilling is currently the main form of waste disposal in the cannabis industry. Some recycling and composting do take place, but at a much smaller percentage of total waste.

There are three waste categories that cultivators must deal with: organic, recyclable, and universal and hazardous waste. How these waste streams are disposed of is dictated by regulatory frameworks. 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 reducing unusable/unrecognizable. Dispensaries can now collect consumer packaging for recycling and reuse (with sanitization and inspection steps).

With low rates of waste diversion, more organic waste could be composted instead of shipped to landfills; especially with the new regulation changes that now allow for direct composting of low-THC organic waste from cultivations. Cultivations should side-stream stalks, stem, fan leaves and rootballs for direct composting. Composting can take place on the licensed operator's property or at a certified compost or waste operator's facility. A Living Soil System for cultivation can reduce waste generation by eliminating the need to throw "soil" or grow media away after each harvest. Bokashi is an

anaerobic type of composting that can be done on site with a relatively small footprint. Bokashi can be thought of as a fermentation process that "pickles" the organic material inside the composting container.

Since packaging can be a large source of waste, operators should focus on minimizing materials used for packaging as well as sourcing reusable or recycled materials when possible. Reusable packaging requires a sanitization and inspection step but is the most sustainable option. It is important that recyclable waste be dealt with properly. Recycling bins and composting bins should be placed near trash receptacles throughout facilities to make organizing waste an easy process.

It is important for operators to minimize the amount of universal and hazardous waste they produce. When generating universal and hazardous waste, 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.

In conclusion, all operators should have a waste management plan to address each type of waste. Avoid over-purchasing and consider sustainable vendor options when available. Reduce, reuse, recycle and then track, track, track, to understand where improvements can be made.



OVERVIEW

The cannabis industry generates waste and can benefit from the adoption of sustainable waste management practices. Currently in Denver, landfilling is the main form of waste disposal, with recycling and composting used to a lesser extent. Therefore, cultivation facilities should aim to reduce, reuse and recycle 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. The industry can further reduce the waste generated and landfilled by designing packaging that adheres to local guidelines for reuse, recycling, and composting, minimizes material inputs through recycled content, and or by implementing package collection take-back programs.

The sustainability impacts of waste management and diversion 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:

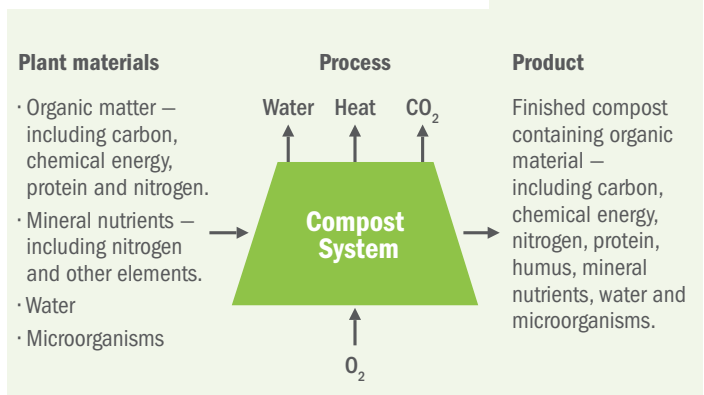
Waste reduction and diversion results in lower volumes of municipal solid waste (MSW) and subsequently lower embedded energy, landfill gas (LFG) emissions and landfill leachate.

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.

ORGANIC WASTE MANAGEMENT

Organic wastes represent a significant component of the cannabis production waste stream. Unusable plant material, paper, creating valuable agricultural inputs while maintaining compliance, and food waste are all compostable in commercial compost facilities. Low-THC plant components (stalks, stems, fan leaves and rootballs) can be directly composted without mixing or rendering activities. Alternatively, plant and food waste can be processed on- or off-site using Bokashi fermentation or anaerobic digestion. In either scenario, separating these materials from the general waste stream can present some logistical and compliance challenges. Careful implementation of best practices for organic waste management can reduce the environmental impact of a facility by creating valuable agricultural inputs while maintaining compliance.

Figure 12: Composting process diagram



PROCESS DESCRIPTION

Composting

Plant waste and other compostable wastes – including growing media, paper and food waste – can be diverted from the landfill through disposal with a licensed hauler to a commercial composting facility. Per MED rules, cannabis plant debris must be rendered “unusable and unrecognizable” before disposal. However, low-THC plant components (stalks, stems, fan leaves, and rootballs) can now be directly composted without mixing or rendering. The most sustainable way to accomplish this is by grinding high-THC containing plant debris with paper or cardboard waste, growing media or soil. Once this has been done, plant debris can be composted by a licensed commercial composter. There is an additional exemption to this 50/50 mixing rule that allows

stalks and stems to be diverted from the waste stream if used specifically for industrial fiber recovery.

Bokashi Fermentation

Plant waste can be treated on-site using the Bokashi method, an acidic anaerobic fermentation process. To take advantage of Bokashi fermentation, the marijuana waste must be made “unusable and unrecognizable” on the licensed marijuana cultivator’s property by grinding the waste and letting it fall into a 55-gallon drum or other similar container that is capable of becoming airtight when closed, adding additional organic material to achieve a 50% marijuana-waste mix, and adding Bokashi or other compost activator and water. It is important that the proportions of Bokashi compost activator to organic material and the resulting pH of the mixture be correct. Otherwise, the material will fail to ferment and will rot.

Having been made “unusable and unrecognizable”, the waste should be allowed to rest at the licensed facility, or be transported to an off-site facility.

Microorganisms contained in the Bokashi compost activator will quickly “pickle” the marijuana and begin breaking down the organic matter. After a two-week anaerobic (oxygen-free) fermentation period, the resulting liquid (probiotic tea) may be used as nutrient-rich fertilizer. The solid organic matter may be used as a soil amendment.

Bokashi fermentation can be done throughout the year and requires a very small footprint. It is easily scalable, produces neither heat nor gases, and eliminates nuisance factors linked to composting sites, such as odors and vermin. The fermenting container will not attract flies because it is kept sealed.

Bokashi fermentation remains a largely unknown technology with numerous nuances. It is also new to regulators such as Colorado Marijuana Enforcement Division (MED), Colorado Department of Public Health and Environment, and the Colorado Department of Agriculture (CDA), and carries additional regulatory requirements not expanded upon within this procedure.

Cultivation facilities that are interested in adopting this new technology, and its technical and regulatory nuances, are advised to seek professional assistance.

BEST PRACTICES

Organic waste recycling through Bokashi fermentation on-site or through off-site composting are the two most sustainable options for managing organic waste. Cultivations should side-stream low-THC plants components (stalks, stems, fan leaves, and rootballs) for direct composting without mixing.

Paper or cardboard that cannot be recycled due to contamination should be discarded with the high-THC compostable materials. 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 waste 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 composting practices. Providing a short 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:

- [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.

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).

Any generation of regulated hazardous wastes must be disclosed to CDPHE. Cultivators must obtain an EPA identification number before waste can be accepted for disposal by a 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](#)

CASE STUDY

LIVING SOIL AT DISTRICT 8

You can't produce high-quality cannabis without first starting with high-quality soil. District 8 is a provider of wholesale cannabis and hemp-wrapped blunts, and produces it all using a no-till, living soil method. Building a strong ecosystem within the soil allows them to grow their cannabis utilizing nutrients from natural systems that have already been shown to be effective through the Earth's ecological processes. Natural methods and beneficial organisms such as insects, fungi, and bacteria increase the health of the soil and nutrient content every harvest.

With ever-increasing soil health, District 8 is able to completely eliminate their soil waste and address one of the main industrial waste issues facing this industry. Living soil also benefits their plants and process by creating greater water infiltration and retention, greatly reducing their water usage and wastewater production. This method eliminates the need for artificial chemical fertilizers and uses only biologically proven processes. When they do need supplemental nutrients, they even go so far as to utilize ingredients from other industries' byproducts and their very own compost.

This means they use 0 lbs of fertilizer a year and waste 0 lbs of plant and soil annually. This closed-loop system that District 8 has created allows them to create less waste, use less water, lower their soil costs, and produce a more natural cannabis that is not only safe but high-quality.

BEST PRACTICES

- The best way to reduce the expense and risk associated with managing hazardous wastes is to reduce the amount of hazardous materials entering the facility. Opportunities for cultivators include:

- 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 application.
- 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 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

PACKAGING

Packaging cannabis products for sale to consumers represents a significant downstream waste source. Reducing the amount of nonrecyclable product packaging reduces overall impact and can be attractive to customers. The most sustainable option is to implement reusable packaging with an incentivised take-back program at the dispensary.

PROCESS DESCRIPTION

Cannabis products are sold in a variety of packaging, encompassing a number of different materials, sizes, shapes and functionalities. Below is an overview of some common types of packaging, as well as attributes and uses.

Vials: Typically made from virgin polypropylene (#5) plastic and widely used for packaging flower. Vials are accepted in most municipal recycling programs; some manufacturers include recycled materials in the containers. These containers

are resilient enough to withstand cleaning/sterilization and reuse therefore take-back programs are encouraged at retail outlets. Versions with childproof caps are available, eliminating the need for an additional exit package.

Mylar Bags: Used to package a variety of products, usually concentrate and food products. Mylar, or polyethylene terephthalate (PET) plastic film, is typically not accepted in mixed recycling programs. Resealable versions are preferable because they enable longer use by the customer.

Concentrate Containers: Small, typically screw-top containers can be made from a variety of materials, including polystyrene, acrylic, silicone, glass, or mixed materials such as polystyrene with a silicone insert. While some of these materials are technically recyclable, recycling facilities sort out very small items, and the small size of these containers generally means they will end up in the landfill even if placed in a recycling bin. Therefore reusable take back programs are the most sustainable option.

Pre-Roll Tubes: Narrow plastic tubes, typically made from the same materials as polypropylene vials, are used to sell single joints. Similar to concentrate containers, small dimensions make pre-roll tubes difficult to recycle.

Exit Bags: Child-resistant bags used as outer packaging when products sold are in non-child-resistant packaging. Often made with mixed materials, such as foil with polyethylene coating, these are typically not recyclable. Reusable versions are available and take-back programs are encouraged.

BEST PRACTICES

Cultivators should:

- Choose packaging that is lightweight, as lightweight materials require less fuel to ship, reducing the associated emissions.
- Reusable packaging coupled with dispensary take-back programs is the most sustainable option. When possible, select packaging that is made from recycled content and is recyclable and/or compostable, such as recycled PET plastics, recycled high-density polyethylene (HDPE) or cardboard.
- Implement a packaging return program at the point of sale. New regulations in 2021 allow for retail locations to have take-back programs for both reuse and recycling of packaging materials and spent vape cartridges. Some customers may not have recycling service at home, so returning to the store may be the only recycling option. Also, smaller plastic pieces and containers, 5- or 10-mL concentrate containers, are so

compact and lightweight that they often miss getting sorted out in the recycling process, ending up in the landfill. Take-back programs are a better alternative.

- Similarly, discuss with packaging suppliers or manufacturers the possibility of a take-back program. Manufacturers may be able to accept used packaging and reuse it or re-form it into new packaging, helping lead to a closed-loop for product packaging.
- Utilize child-resistant packaging to eliminate the need for an additional exit package. If exit packaging is necessary, operations should offer a reusable type and encourage customers to return them to the store.

ADDITIONAL CONSIDERATIONS

Packaging materials and designs are quickly evolving, in many cases with enhanced sustainability attributes. As consumers and business customers demand more sustainable options, the industry responds with more reusable, recyclable, compostable and innovative material options that support circular design principles to: design out waste/pollution, extend the use life, and regenerate natural systems. One future opportunity would be to make cannabis packaging closed-loop, whereby cannabis plant waste is used as a feedstock, for Bioplastics, or Polyhydroxyalkanoates (PHA).

Table 7: Sources of Environmentally Preferable Packaging

SOURCES OF ENVIRONMENTALLY PREFERABLE PACKAGING				
COMPANY	WEBSITE	RECYCLED CONTENT	RECYCLABLE	COMPOSTABLE
Higher Standard Packaging	www.higherstandardpackaging.com	Yes	Yes	No
STO Responsible	www.storesponsible.com/	Yes	Yes	No
Elevate Packaging	elevatepackaging.com	Yes	Yes	Yes
Sun Grown Packaging	www.sungrownpackaging.com	Yes	Yes	Yes
Sana Packaging	www.sanapackaging.com	Yes	Yes	No
Dama Distributing	www.damadistributing.com	Yes	Yes	Yes

Figure 13: Diversion Totals for Denver 2017



RECYCLING

Denver's recycling rate of 22 percent falls well below the 34% national average.¹¹ Currently, recycling in Denver is not mandatory, helping lead to low rates of waste diversion. However, businesses can benefit from properly sourcing, separating and diverting recyclable materials. Single-stream collection and hauling is the practice of choice of local recyclers, making it simple for the customer to participate. Combined with the sophistication of area Materials Recovery Facilities (MRFs), the single-stream process can lead to high rates and high quality of material recapture. Recycling reduces environmental impact of waste generated in cannabis operations.

PROCESS DESCRIPTION

Recycling opportunities in the cannabis industry are similar to those in other warehouse-based industries. The exceptions to this are the packaging and universal waste recycling mentioned in previous sections. Packaging from inbound materials, waste generated during operations and employee waste are the main sources of recyclable materials. Recyclable materials should be separated from other waste streams and picked up by a recycling service provider to achieve environmental benefits.

Resources:

- [Marijuana Enforcement Division Permanent Retail Marijuana Rules](#)
- [Sustainable Packaging Coalition – Definition of Sustainable Packaging Framework for Sustainable Food Packaging Design](#)
- [Ellen MacArthur Foundation: Plastics and the Circular Economy](#)
- [Ellen MacArthur Foundation: Circular Design](#)

BEST PRACTICES

Cultivators should:

- Make sure recyclables are clean, dry, and separated from solid waste items such as plastic bags, waxed paper, broken glass and packaging that looks like cardboard but is actually plastic (meal packaging, receipts, coffee cups, etc.).
- Co-locate recycling bins with all trash receptacles and include signage for all bins, ideally using photos of acceptable items for each bin.
- Use signage provided by the waste hauler, or create custom signage for specific items. Hang signage on bins or above bins to help employees when sorting materials.
- Take advantage of new regulations in 2021 that now allow for retail locations to have take-back programs for collecting, reusing, and recycling both packaging materials and spent vape cartridges.
- Examples of Recycle, Compost, General Signage are available through local waste hauler websites.

CONSIDERATIONS

Recycling technology and service providers in the Denver area are improving and growing. Many items that were not accepted for recycling in the past, such as cartons and polystyrene foam, are now accepted by some or all local recycling haulers but under strict protocols. Two-way communication between haulers and businesses is necessary to ensure that business managers stay up to date on the correct recycling processes.

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 knowledgeable 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

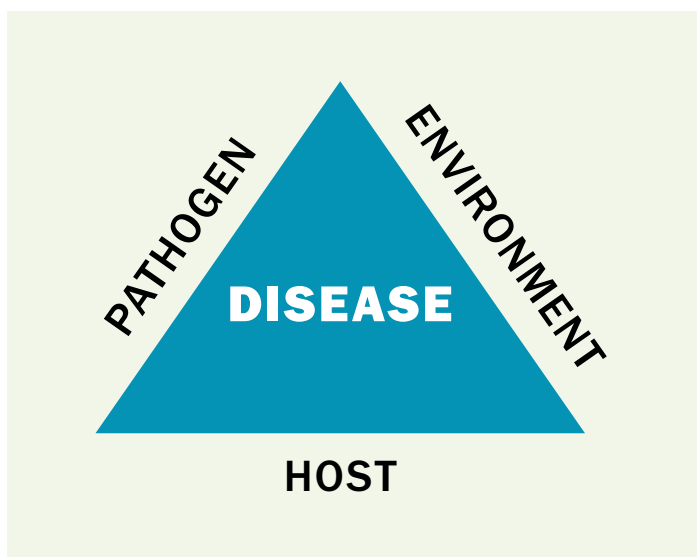
Structural controls are facility design features that exclude pests and diseases from cultivation areas. These design features act as the first line of defense in an IPM program and should be customized according to the needs of the facility as it is being constructed.

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.
- **Infrastructure to facilitate proper decontamination of facility equipment and work areas.**

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.



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 cannot be 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 mites 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/>

AIR QUALITY

Cannabis plants naturally emit terpenes, which are biogenic volatile organic compounds (BVOCs), as they grow. Marijuana Infused Product (MIP) facilities also emit VOCs from solvent evaporation during extraction processes. VOCs react with oxides of nitrogen in the presence of sunlight to create ground-level ozone, a pollutant that is dangerous to human health and the environment. Controlling emissions of VOCs from cultivation and MIP facilities helps improve air quality and reduce odors, which is especially important in urban areas and from May to September, when ground-level ozone levels often exceed health standards.

This guide provides recommended best management practices to improve air quality impacts and reduce odor and VOC emissions from cannabis industry operations.

CARBON FILTRATION

Installing control technologies can reduce the amount of VOC emissions released from cultivation and MIP processes while simultaneously controlling odors. Carbon filtration is currently the best control technology for reducing VOC emissions from cannabis cultivation and MIP facilities. Best management practices for carbon filtration include:

- Design and invest in a carbon filtration system appropriate to your facility and don't exceed the maximum rated cubic feet-per-minute rating for air circulation through the filter.
- Choose a filter with a high terpene and odor removal efficiency that is engineered to the calculated baseline emission load at your facility.
- Inspect and conduct regular maintenance of HVAC systems and carbon filters to avoid break-through.
- Make sure that all operations are conducted within sealed infrastructure, and check regularly to ensure there are no leaks.
- Have a documented system in place to respond to odor complaints.
- Develop training for staff members to ensure best practices are being implemented as a part of the the routine facility operating procedure.

In Denver, an odor ordinance requires that cultivation facilities control the odor impacts of their growing operations. Denver Revised Municipal Code, Chapter 4 – Air Pollution Control, Section 4-10.

SOLVENT EXTRACTION

Only certain solvents are permitted for use in Colorado MIP facilities: butane, propane, CO₂, ethanol, isopropanol, acetone, heptane and pentane. All but CO₂ release VOCs when they evaporate. The disposal of solvents by evaporation or spillage is prohibited. Best management practices for solvent extraction include:

- Regularly inspect all solvent storage devices and extraction system to prevent leaks.
- Be careful to prevent leaks during the transfer of solvents between containers and systems at all stages of the production processes.
- Ensure that solvent is always kept in a closed-loop extraction system or sealed container.
- Maintain an inventory of all solvents and their use over time.

Air quality regulations may apply to MIP facilities, depending on the annual amount of solvent lost to evaporation: <https://cdphe.colorado.gov/prevention-and-wellness/marijuana/greening-the-cannabis-industry>

BENEFITS OF VOC/ODOR CONTROL

- Reduces community odor complaints and improves neighborhood relations.
- Enhances your brand image with environmental stewardship.
- Helps to shift the cannabis industry at large toward sustainable and environmentally conscious business practices.

INTRODUCTION

The cannabis industry directly impacts air quality in two predominant operations:

1. Plant growth cultivation
2. Marijuana Infused Product (MIP) facilities

At cultivation facilities, the natural growth of cannabis plants and other processes emit terpenes, which are Biogenic Volatile Organic Compounds (BVOCs) known for their strong odors. At MIP facilities, the evaporation of solvents and other processes in the production cycle results in Volatile Organic

Compound (VOC) emissions. VOCs alone do not typically pose a direct threat to human health or the environment.

However, they do contribute to ground-level ozone by chemically reacting with other types of pollution, specifically, nitrogen oxides (NOx) in the presence of sunlight. Ozone is an air pollutant that is harmful to human health and negatively impacts the environment; therefore, it is important that the cannabis industry mitigate VOC emissions in their processes. This chapter provides recommended best management practices to improve air quality impacts and reduce VOC emissions from cannabis industry operations.

In Colorado's Front Range, cultivation and MIP facilities are generally in dense urban areas near heavily trafficked highways and other industrial sources of NOx pollution. Because VOCs require the presence of NOx and sunlight to form harmful ozone, VOCs from these facilities have a greater impact on ozone formation than facilities in rural areas. This makes mitigating VOC emissions from the cannabis industry especially important in these regions.

Fortunately, most odor control practices at cultivation and MIP facilities also substantially reduce VOC emissions. The correct operation and maintenance of odor control systems at cultivation and MIP facilities is a best management practice for reducing air quality impacts from the cannabis industry.

CLIMATE CHANGE

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 facing 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 Plan⁴ 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 Agreement⁵. 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}.

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

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.

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 transportation⁸.

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 2005⁹ 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 conditions¹⁰. While ash from wildfires is known

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.

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. 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 outdoor 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 hops¹¹.

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 change¹². 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 heat¹³. 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 fuels or materials that are petroleum-based.

Best Practices – Climate Change Adaptation and Resilience

The City of Denver's Climate Action, Sustainability and Resiliency (<https://www.denvergov.org/Government/Departments/Climate-Action-Sustainability-Resiliency>) provides a thorough repository of the City's plans, initiatives, assistance, resources and other information related to climate change adaptation and mitigation best practices. We recommend that cannabis businesses become familiar with Denver's Climate Protection Fund, created in 2020.

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. 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^{14, 15}.

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 Sachs¹⁶ 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. A recent study at CSU concluded that at least 80% of GHG emissions at the indoor cultivation operations included in the

study are generated by indoor environmental control (HVAC), high-intensity grow lighting, and supplemental carbon dioxide for plant growth¹⁷. 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 carbon output and explore ways to create reductions, but it also contributes to the local community and reduces the environmental impact of the industry¹⁸.

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.

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 carbon 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

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>

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.

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:

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 carbon 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 carbon emissions. Those carbon emissions are reflected in a reporting organization’s electricity usage. This is the largest area of impact for the cannabis industry in Denver due to the exclusive use of indoor grow operations.

Scope 3 Emissions: All other indirect carbon 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 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 carbon emissions from the raw oil extraction process, the refinement of the oil, the synthesis of plastic from the oil and the transport of materials between phases.

According to an analysis conducted by Evan Mills in 2012, for each kilogram of cannabis produced, roughly 4,600 kg of CO₂e is emitted. More data and research are needed to confirm this analysis, as many experts have brought up potential issues and new efficiency practices in the determination of this number.

EMISSION SCOPE	DISPENSARIES	MIPS	GROWS
Scope 1	<ul style="list-style-type: none"> · Natural gas heating · Fuel usage for owned delivery service · Waste disposal 	<ul style="list-style-type: none"> · Natural gas/Butane/Propane/CO₂ Usage & Ventilation (direct emissions) · Manufacturing Waste · Manufacturing Equipment Fuel · Packaging 	<ul style="list-style-type: none"> · Natural gas use · Fuel use · Soil & Fertilizers Water · CO₂ supplementation · Direct emissions · Packaging
Scope 2	Purchased electric for lighting, HVAC, other operational needs		
Scope 3	<ul style="list-style-type: none"> · Vendors & Products · Retail Waste Packaging · Customer Transit · New construction or build-out of existing bldg. · Contracted solid waste management. 	<ul style="list-style-type: none"> · Third-party Delivery & Courier Services · Supply chain emissions · Construction or build-out 	<ul style="list-style-type: none"> · Third-party Delivery & Courier Services · Construction or build-out

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 tracking has become more mainstream, many vendors have this information readily available. Furthermore, companies can implement or request carbon 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. Outlined below are examples of calculations for the various scopes.

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 carbon emission sources in different types of cannabis facilities:

Tracking Metrics Over Time

<https://www.energystar.gov/buildings/benchmark/understand-metrics/how>

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 carbon 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 carbon 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 carbon-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 emissions. 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

Another option for reducing carbon for cannabis facilities is looking at local options for carbon mitigation and renewable energy credits, but this should be a final approach to reducing carbon 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.

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: 8,887 grams of CO₂/gallon of gasoline.

Use this conversion rate and multiply by gallons of gasoline used that year: 140 gal X 8,887g CO₂ = 1,244,180 grams of carbon.

This number can also be represented as 1,244.18 kilograms of CO₂ or 1.24 metric tons of CO₂. 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 CO₂ is 740 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 carbon.

Again this number can be represented as 1,488 kilograms of CO₂ or 1.49 metric tons of CO₂.

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.

SCOPE 3

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

Example: Calculate Scope 3 transportation emissions total for employees driving a total distance of 200 miles.

The EPA conversion rate for miles to CO₂e is 408 grams of CO₂e per mile.

200 miles X 408g CO₂e = 81,600 grams of CO₂e or 81.6 kilograms of CO₂e.

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 cultivation 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, CO₂, 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 emissions.

The Colorado Small Business Assistance Program
can also help you calculate your annual air emissions for free by calling 303-692-3175.

SUPPORTING SECTIONS

An Environmental Product Declaration (EPD), or Type III environmental declaration as defined by ISO 14025, is a standardized, third-party verified life-cycle assessment (LCA) used to communicate the environmental performance of a product. It can be thought of as a standardized LCA that results in a comprehensive but simplified environmental report card. According to the ISO 14025 standard, EPDs are primarily intended for but not limited to business-to-business communication. An EPD can support expedited evaluations of the life cycle impacts of a product and facilitate meaningful comparisons of products that serve the same function. In this way, an EPD can be a decision-support tool to execute sustainable procurement policies.

EPDs are developed according to product-category specific technical guidelines called Product Category Rules (PCR). The PCR specifies how the supporting LCA must be conducted and other requirements including the environmental impact categories that will be modeled product types and their respective subcategories. EPDs are well established in Europe and used across a broad range of product categories from chemicals, to building products, food and beverages, furniture, machinery, and more.

While lagging Europe, EPD adoption in North America and Asia continues to expand, albeit with a primary focus on construction and building materials. Green building certifications in the United States such as LEED and WELL offer credits for projects that source EPD-certified building materials. Program operators including NSF International, SGS Global Services, UL Environment, ASTM International, Sustainable Minds, and others provide essential EPD-related services to complete, certify, and publish EPDs in accordance with ISO standards.

In the near-term, the relevance of EPDs to the cannabis sector may be limited to procurement for new facility construction and/or retrofits that seek green building certification through LEED or WELL. However, the application of EPDs in Europe to food and beverages (including beer), chemicals, and other product categories provide a precedent to develop PCRs for the cannabis sector. EPDs could be developed both for facility and process inputs as well as for the various products of cannabis cultivation.

It should be mentioned that the costs associated with developing EPDs and PCRs are not insignificant. In a 2017 survey published in Science Direct (Tasaki et. al. 2017), the

authors concluded that the total cost to create a PCR and EPD ranges from \$13,000 to \$41,000 USD, requiring 22 to 44 person-days of effort. The value of an EPD may or may not provide a sufficient ROI for cultivators to invest in EPD development. But, with increasing scrutiny on the industry's environmental and social impacts, EPDs could provide a promising direction for the cannabis sector to standardize sustainability assessment, communication, and marketing for its products.

Resources:

- **Adriana Del Borghi, L. Moreschi, M. Gallo, 3:** *Life cycle assessment in the food industry.* Editor(s): Charis Galanakis, *The Interaction of Food Industry and Environment.* Academic Press, 2020, Pages 63-118. <https://www.sciencedirect.com/science/article/pii/B9780128164495000035>
- **Tasaki, Tomohiro & Shobatake, Koichi & Nakajima, Kenichi & Dalhammar, Carl. (2017).** *International Survey of the Costs of Assessment for Environmental Product Declarations.* Procedia CIRP. 61. 727-731. 10.1016/j.procir.2016.11.158. <https://www.researchgate.net/publication/316334185> *International Survey of the Costs of Assessment for Environmental Product Declarations/citation/download*

CANNABIS CERTIFICATIONS

There are currently a wide range of certification programs available to the cannabis industry. These environmental certification programs range in scope from organic to sustainable to regeneratively focused. When selecting a certification, pick a program with a set of standards that aligns with your company goals and that fits your current budget. Most certification schemes require an annual inspection or audit that assesses compliance to the certification standards. Certification standards should be publicly available and developed through a stakeholder engagement process to ensure transparency and credibility toward driving positive social, environmental, and economic impacts.

Certifications usually begin with submitting an application that includes a self-assessment of your company's practices in relation to the certification standards. Once the assessment is reviewed by the certification body, an

inspection will be scheduled. An inspection will consist of a facility tour and documentation audit. The materials reviewed during the documentation audit will vary by certification but usually include company policies, farm and/or manufacturing plans, standard operating procedures, employee handbooks, material/ingredient use records, invoices for materials and sales, along with any other documents relevant to the cultivation or manufacturing of a product. After the inspection, the inspector will submit an inspection report to the certification body, which will review the report and determine compliance to the standard. Based on the results, the certification body will award certification or provide a corrective action report on areas that need improvement.

Most certification programs require similar documentation and follow a similar procedure so starting the process with one certification body will get you on the right track even if you choose a different certification program in the future. It is worth noting that a Quality Management System or Environmental Management System is very helpful with all certification programs. The below list of certifications is provided for informational purposes only and this guide is not meant to recommend one certification over the other. It is also not meant to list every available certification program. A business should do its due diligence when choosing the best certification program for its unique needs.

CERTIFICATION NAME	CERTIFYING ORGANIZATION	DESCRIPTION	CONTACT	AREA OF FOCUS
Simply ECO Certified	The Cannabis Conservancy	Sustainability certification focused on a holistic, ecosystem approach to consciously cultivated cannabis that goes beyond organic.	jacob@cannabisconservancy.com	Sustainability
Carbon Conscious	The Cannabis Conservancy	Certification for cultivators who demonstrate a commitment to reducing their carbon emissions with strategic energy management.	jacob@cannabisconservancy.com	Energy and Carbon
Sun+Earth Certified	Sun+Earth Certified	Certification for regenerative cannabis that is grown under the sun, in the soil of mother earth, without chemicals by fairly-paid farmers.	andrew@sunandearth.org	Regenerative Agriculture
Certified Kind	Certified Kind	Certification program that holds farmers and processors accountable to the highest organic standards.	andrew@certifiedkind.com	Organic Cultivation
DEM PURE	Dragonfly Earth Medicine	Regenerative certification focusing on polyculture and closed loop systems.	88@dragonflyearthmedicine.com	Regenerative Agriculture
EnviroCann	EnviroCann	Organic to sustainable certification for cultivation, manufacturing, retail.	envirocann.com/	Sustainability
TRUE Certificatio	Green Business Certification Inc.	Certification program that enables facilities to define, pursue and achieve their zero waste goals.	true.gbci.org/	Sustainable
Green Building: LEED	U.S. Green Building Council	Certification focusing on green building design, construction, operations, and performance.	usgbc.org/leed	Sustainable building/facility design, operation and maintenance
Certiably Green Denver	City of Denver	Free sustainability certification offered by the City of Denver.	certifiablygreendenver@denvergov.org	Sustainability
Environmental Leadership Program	CDPHE	https://cdphe.colorado.gov/sustainability-programs/environmental-leadership-program	Rayna.oliker@state.co.us	multi-faceted
Organically Grown Cannabis	Cannabis Certification Council	Organic certification following National Organic Program guidelines.	cannabiscertificationcouncil.org/contact-us	Organic Cultivation
Clean Green	Clean Green	Organic certification following National Organic Program guidelines.	cleangreencertified.com/	Organic Cultivation
Naturally Grown Cannabis	Organic Cannabis Growers Society	Organic certification similar to the National Organic Program standards.	ogcannabisgrowers.com	Organic Cultivation

Additional Certifications:

- Cannabis Conservancy
<https://cannabisconservancy.com/>
- Resource Innovation Institute
<https://resourceinnovation.org/>
- Climate Resources Group
<http://www.climateresourcesgroup.com/>
- Sustainabis
<https://www.sustainabis.life/>
- Cannabis for Conservation, <https://www.cannabisforconservation.org/> is working on a Wildlife Conscious Certification Pilot Program.

GREENHOUSE CULTIVATION

INTRODUCTION

Greenhouses are quickly becoming the preferred structure for cannabis cultivation, with almost half (45%) of current cultivators nationwide using them in some capacity.³ As utility costs rise and already tight profit margins continue to shrink, more operations are viewing greenhouses as an economical solution.



By utilizing natural sunlight as the primary lighting source rather than lighting fixtures, greenhouses are typically more energy efficient and have been shown to reduce production costs by 30 percent when compared to indoor grow facilities, depending on the regional climate. Greenhouses now account for one quarter of all production space, with a little under half (43%) of current growers considering expanding into greenhouses. In Colorado, the trend toward greenhouse as well as outdoor growing can be seen in the 154% increase in cultivated plants in Pueblo during 2017.

A greenhouse is any structure for the cultivation of crops with a transparent (glazed) roof that allows natural light to penetrate the growing space. Glazing can vary from low-cost polyethylene film, to semi-rigid polycarbonate or tempered glass panels. The sidewalls can be constructed out of various materials, ranging from simple fabric/sheeting to insulated metal siding. Greenhouse structures run the gamut in size and complexity, from hoop houses to state-of-the-art sealed buildings.

All greenhouses are essentially structures that protect crops from the elements while utilizing the energy of the sun.

The structure of commercial greenhouses can be freestanding or gutter-connected. Freestanding greenhouses can have a variety of roof shapes, with hoop, gothic, or gable being the most predominant. A gutter-connected greenhouse uses a series of trusses connected at the gutter level to customize the width of the structure. These roofs are predominantly hoop- or gable-shaped. Greenhouses can be made to any length, but length is usually determined by available glazing sizes. Greenhouses tend to use modular-frame construction with spacing of 4'-5' for hoop houses and 10'-12' for gutter-connected designs.

For cannabis cultivation, a Light Deprivation System, also called a blackout system, is required to create the photoperiodism needed to induce flowering. These systems can be manual or automatic and utilize a range of fabrics. Breathable fabrics are preferred because they prevent condensation from forming and dropping onto the plants, creating an ideal environment for disease.

CONSIDERATIONS

GREENHOUSE DECISION-MAKING

When deciding to grow in a greenhouse, cultivators need to consider a multitude of factors. Start with a review of state and local cultivation regulations and zoning codes to ensure greenhouse cultivation is approved in your area, and pay specific attention to security requirements. Contacting the proper licensing and zoning offices is always a good idea, as many nonrural municipalities and zoning departments are unfamiliar with commercial greenhouse structures.

Greenhouses require adequate land to allow for roads, parking, and buffer zones, in addition to the structures themselves. Greenhouse operations typically require a minimum of two acres. When siting a greenhouse, look for a flat topography to ensure proper drainage, and orient

³Special Report: [2021 State of the Cannabis Cultivation Industry Report](#)

the structure to maximize unobstructed southern views to provide drainage and adequate sunlight and solar gain. The local geography and climate will further determine a suitable type and style of greenhouse. The temperature range and solar angle of incidence will determine the appropriate type of glazing with regards to transparency, dispersion, and insulation rates. The growing period, whether year-round or seasonal, will also determine the style of greenhouse.

DESIGN

At a minimum, greenhouses provide protection from wind and rain and help to minimize pest pressures while sealed. Environmentally controlled greenhouses provide the opportunity to control all aspects of the grow environment, similar to an indoor facility. A well-designed greenhouse that incorporates the many equipment systems with accurate environmental controls and good space utilization is the key to a successful cannabis production facility. Installing peninsular or moveable benches can achieve 80-90 percent space utilization, resulting in a more efficient lighting system and higher yields.

LIGHTING

The main benefit of using a greenhouse is that the primary source of lighting is the sun, and grow lights are used only as an occasional supplement. Grow lights are used to extend the seasons when daylight is limited. This allows the plants to maintain a vegetative state for the proper durations, to boost daily light levels when necessary, and to ensure consistent light levels. Since artificial light is secondary, larger light fixture spacing is used when compared to indoor setups.

The lighting types most commonly used are LEDs and HPS. Automation is essential for energy efficiency, and controls should be set to a specific light level (PPFD) to ensure lights are on only when needed. A timing delay helps to account for temporary cloud cover. Lights should also be subdivided in a checkerboard pattern so that the minimum number of lights are used to achieve the appropriate light level.

In regard to controlling the sunlight that enters a greenhouse, the standard glazing material is light-diffusion fabric. This type of material spreads out the light particles and infrared radiation while blocking UVB to dampen the sun's intensity and generate more light. Shade cloths can also be used during the summer months to lessen the sun's intensity and lower solar heat gain. Some grows are experimenting with painted films to achieve these results. Double- or triple-glazed material will increase the insulation factor, reducing heat loss if needed.

CLIMATE CONTROL

Utilizing the sun as the primary source of light brings with it unique climate control challenges in the form of solar heat gain. Due to the "greenhouse effect," special attention needs to be paid to the HVAC system. The "greenhouse effect" is when solar radiation enters the greenhouse and heats up the thermal mass; the glazed panels then trap the infrared radiation inside.

In addition, greenhouses are traditionally leaky structures due to the space between the glazed panels and frame. Solutions to the HVAC dilemma diverge depending on the type of system employed – either open (passive) or closed (sealed).

Open greenhouses rely on more passive systems, such as vents and actuators, to provide climate control via air circulation and can be thought of as an extension of the outdoor environment. These systems depend on temperature and wind gradients to cool, resulting in low average air volume exchanges of around two to three times per hour. Some common structural elements are open-roof designs and guillotine, or roll-up sides which reduce the need for ventilation fans. In drier climates, a fan and pad system can be ideal.

When employing fans, a design with several stages of ventilation can be more energy efficient than one with just a single stage. Using light-colored groundcover and pots will limit heat absorption in the greenhouse. In regions with hot days and cold nights, thermal mass can be added to absorb and store heat during the day and then release it at night.

When heating is required, it should be located in the floor or under the benches to target the root zone, which will reduce the need to heat the entire greenhouse by 5-10F. For every 1F the air temperature can be set, fuel consumption is reduced by 3%. To avoid excessive drying of the growing media, it is best to limit root zone heat to 25 BTU/sq.ft.

Closed greenhouses, on the other hand, closely resemble indoor facilities and rely on equipment with advanced climate control systems to control heat and humidity. These systems seek to eliminate air exchanges in order to better control the indoor environment. Newer structures that utilize this system are often hybrid designs with vertical metal insulated walls and a glazed roof. The insulated walls better protect against temperate swings. An added benefit of a sealed environment is reduced contamination from outside sources, such as pests, disease, and hemp pollen. In more urban environments, odor can be controlled. In this system, each greenhouse or bay should have independent temperature and climate control to account for variations within a site. For

larger greenhouses, an energy-efficient cooling technology currently being used is cooling towers, which are similar to a wet wall but housed in a separate unit. For dehumidification, desiccant boxes are now being employed, as they need little energy to operate. They utilize a media such as silicone gel to absorb water vapor from the air. This process is known as Ground to Air Heat Transfer (GAHT).

Heat exchangers store excess heat in a medium such as water or soil. The system circulates hot air from the greenhouse through pipes buried underground, whereby the heat gets transferred to the soil. The air is then exhausted back into the greenhouse cooler and drier. Thus, the GAHT system creates a closed-loop airflow, which cools and dehumidifies the greenhouse.

ENERGY CONSERVATION TECHNIQUES

- Insulate perimeter (side and end walls), foundation, and distribution piping.
- Install windbreaks on the north side to reduce wind-induced heat loss.
- Install automatic closing doors. Weatherstrip doors, vents, fan openings. Lubricate all louvers.
- Repair broken or torn glazing.
- Install an infrared inhibitor on the inner lining of glazing for 15% savings.
- For older structures, add a single or double layer of plastic covering to reduce infiltration and heat loss by 50%.
- Aspirate thermostats for more uniform temperature control.
- Select fans that meet Air Movement and Control Association International (AMCA) standards and have a Ventilation Efficiency Ratio greater than 15.
- Use the largest diameter fans with the smallest motor that meets ventilation requirements.

ENVIRONMENTAL JUSTICE

Environmental justice is equal protection for all communities from environmental hazards and equal access for all communities to environmental, social, and economic assets that promote health and well-being, such as clean air, safe drinking water, green space, public transit, and economic opportunity.⁴

⁴ Howard Frumkin. *Environmental Health: From Global to Local*, 3rd Edition. (Jossey-Bass, 2016), 267.

⁵ Frumkin. *Environmental Health*, 267.

The cannabis industry can be a model for sustainability. It also can be a model for environmental justice. It's not often that a novel industry enters the marketplace, builds infrastructure and scales up; typically, industries have to be retrofitted for sustainability. The open cannabis policy environment enables advocates in all 50 states to address environmental and social justice issues within local laws.

Extrinsic factors at the individual and community levels – such as race, gender, and socioeconomic status – can amplify the adverse effects of environmental hazards and contribute to health disparities.⁵ Persons and public spaces impacted by the cannabis industry are considered vulnerable. Capitalizing on a particular vulnerability or vulnerable group is considered environmental racism. In some cases, cannabis cultivation spaces are located in low socioeconomic status neighborhoods, whereas cannabis cultivation licensees tend to be disproportionately white and male. Incarceration rates for cannabis crimes tend to disproportionately impact persons of color. The World Health Organization defines environment as “the conditions in which people are born, grow, live, work and age, and are shaped by the distribution of money, power and resources at global, national, and local levels.”

The industry as a whole should seek to produce “Fair Trade Cannabis,” which is grown sustainably and sold in a manner that causes the community to flourish and the industry to become an asset and partner.

CASE STUDY

CULTIVATION CO₂ SUPPLIED BY A SUSTAINABLE BREWERY

The State of Colorado's Kaitlin Urso facilitated a pilot program with Earthly Labs, Denver Beer Co., and The Clinic to establish the first commercial exchange of recovered carbon dioxide, a greenhouse gas, in the Spring of 2020. The pilot program captured and stored excess carbon dioxide produced during the beer fermentation process for later reuse by cannabis cultivators that require carbon dioxide to stimulate plant growth during cultivation.

The exchange fills a need for both industries while reducing carbon dioxide emissions in Colorado. Beginning in January 2020, carbon dioxide produced by the beer brewing process at Denver Beer Co. was captured using Earthly Labs' system and then transferred via holding tanks to The Clinic where it was released to stimulate marijuana plant growth. The brewery can capture over 100,000 lbs/year with this technology. The pilot program proved to be an all-around environmental and

economic success and now the exchange of CO₂ continues as part of normal business operations for both the brewery and cultivation.

The Brewery

The beer-brewing process – specifically, the fermentation stage – naturally produces carbon dioxide. While beer makers use carbon dioxide to carbonate beer and pressurize lines throughout their facility, the current practice for most brewers, especially smaller-scale craft brewers, is to vent carbon dioxide from fermentation to the atmosphere and purchase commercial carbon dioxide from an outside source for the majority of carbonation. Using technology, brewers can instead capture and store excess carbon dioxide for use both in-house and sell it to other businesses who need CO₂ for their operations such as cannabis growers.

The Grow

The legal marijuana industry is a large market for carbon dioxide consumption, as carbon dioxide enrichment is used to grow premium products in a condensed time span and increase yields. Carbon dioxide is a key component in the cannabis cultivation process as the plants utilize light energy to fix carbon into the basic building blocks of growth.

The Success

The pilot program demonstrated a cost-efficient way for breweries and marijuana businesses to slash their carbon dioxide emissions, as companies will no longer have to purchase carbon dioxide from other sources and have it shipped by truck across the state. Implementation of this technology will meaningfully reduce the transportation portion of their carbon footprint. Additionally both businesses will cut the cost of the CO₂ supply that they use. The CO₂ captured has become a new source of revenue for the brewery.

The Result

The cultivation saves about \$0.20 per lb of CO₂ purchased from the brewery versus from a traditional supplier. During the pilot the Cultivation purchased 500 lbs a week of CO₂ from the Brewery and will continue to purchase more as they use the CO₂ throughout the rest of their operation. By using the Brewery's Supplied CO₂, the cultivation saw a slight increase in plant production and quality when compared to their traditional CO₂ supply:

Yield: 2.32% increase from average yield

Potency: 3%-5% variance from average, within tolerable range

Terpenes: 3%-5% variance from average, within tolerable range

This project reduces the amount of Carbon dioxide released into Colorado's atmosphere. We believe that with this single partnership, we will be able to capture more than 50,000 lbs/year of carbon dioxide. The state is relying on innovative investments by small businesses and innovation partners to achieve their aggressive greenhouse gas reduction plans. This is one such example of small businesses making investment to reduce CO₂ emissions in the state of Colorado.

"This is a classic win-win-win scenario," said Kaitlin Urso, environmental protection specialist for the small business assistance program at the Colorado Air Pollution Control Division. "We're connecting companies that have excess carbon dioxide with companies that need it, and in the process we're reusing CO₂ that would otherwise be released directly into the environment."



After implementation, the recirculation system proved capable of returning about 50% of the water sent out during an irrigation event if the water was allowed to drain back into the holding pits within 1-3 hours after tray flooding events. The graphs from the Argus system below show tank volumes through the course of an irrigation and recapture event. The first tank volume is the level before irrigation, the low point is the tank level after flooding, the next plateau is the level after recirculation has finished cycling water back, the blue bar shows the tank being topped off from the main water holding tank, and the final plateau is the tank level after all irrigation operations have been completed. While the system is capable of returning about 50% of the water sent out in an ebb/flood event, actual water recapture has been lower (closer to 40%) due to the practice of leaving trays flooded for an extended period, especially in early growth phases, to increase overall media saturation.

PLANT PATHOGEN CONTROL

Irrigation water recirculation provides an ideal means of transport for plant pathogen inoculum and can lead to widespread disease incidence if adequate water sterilization solutions are not implemented. The greenhouse recirculation system was designed with an integrated ozonation system, but after beginning operations we found that the ozonation system was undersized for the volumes of water we needed to treat and that it was ineffective in the elimination of plant pathogen loads. This led to some significant root/vascular plant pathogen pressure in several of our production batches before we were able to implement an effective solution.

Through the use of 3rd party plant pathogen testing services we identified the causal organisms as *Fusarium* sp. and *Pythium* sp. Both of these organisms can be spread through irrigation drainage. In order to eliminate the spread of these pathogens our team settled on a system of injecting a combination of concentrated calcium hypochlorite and a horticultural surfactant into our main water holding tank, combining these inputs with the existing ozonation system.

This has proven effective in eliminating the spread of the pathogens and besides the batches initially infected, we have not had any additional production impacts from these organisms. In addition to having our scouting team monitor for any symptoms we have continued to conduct monthly pathogen load testing at various points within the irrigation system to verify elimination of pathogens.

Below are test results obtained while we were still combating *Pythium*/*Fusarium* in several of the production batches showing the elimination of the pathogen load after treatment

(feed sample taken at production bench, pit sample taken after irrigation cycle, tank sample taken after circulation back to tank and treatment/blending with fresh water).

Maintaining Balanced Plant Nutrition During Recirculation Operations

Another challenge has been ensuring that the operation of the recirculation system does not negatively impact the delivery of the correct nutritional balance to our crop. Due to the nature of the ebb/flood irrigation system typical feedings only return between 15-30% of the water delivered to the plants back into the holding tank.

Our testing of the return water has shown that while the nutritional composition does vary from what was delivered to the plants the variation is not enough to significantly skew the overall nutritional balance of our recipes after the return water is blended with freshly nitrified water from the main irrigation holding tank. Our team continues to monitor and verify these findings through daily testing of nutrient solution EC/PH and bi-weekly third party testing of nutrient solution elemental composition.

Overall Facility Water Usage Data

Below are graphs detailing the total monthly water usage and average daily water usage per production benching square foot at the greenhouse over the course of 2020 (each monthly average date listed is for the prior 30-day period). As you can see our water usage increased steadily over the Winter and into the Spring as production increased and then jumped significantly in early April, spiking during later May into mid June and then stabilizing at our current use rate. While the increase in water usage corresponds with the use of the recirculation system the usage increase has been driven by the use of our reverse osmosis (RO) system which was brought online at the same time. The use of the RO system was necessitated by plant stress that was occurring due to sodium chloride buildup driven by the use of the municipal water supply in conjunction with our sub- surface irrigation strategy. This issue was exacerbated by the implementation of the recirculation system and it became necessary to utilize the RO system. The RO system in use at the greenhouse is a high efficiency unit, but still produces about 4,000 gallons of waste for each 9,000 gallons of pure water produced. The generation of this wastewater has been the main driver behind our increase in water usage and has outweighed the water savings we have captured with the use of the recirculation system.

In an effort to further reduce water usage and to increase plant health outcomes the greenhouse cultivation team is

currently in the process of transitioning our ebb/flood system over to a drip irrigation system. This is a more complex undertaking than it would normally be due to our use of palletized benching and has required significant design effort. However, we are confident that doing so will not only increase plant health, but also allow us to reduce overall water usage on two different fronts. First drip irrigation is more efficient than ebb/flood because it allows for more complete

hydration of media with less water and it avoids water loss to the atmosphere. The second and more significant factor is that running drip irrigation will allow us to reduce our reliance on the RO system and significantly lower our production of wastewater via that system. We will continue to collect data on these projects and look forward to providing a case study update next year!

SEE ALSO: Appendix for graphs

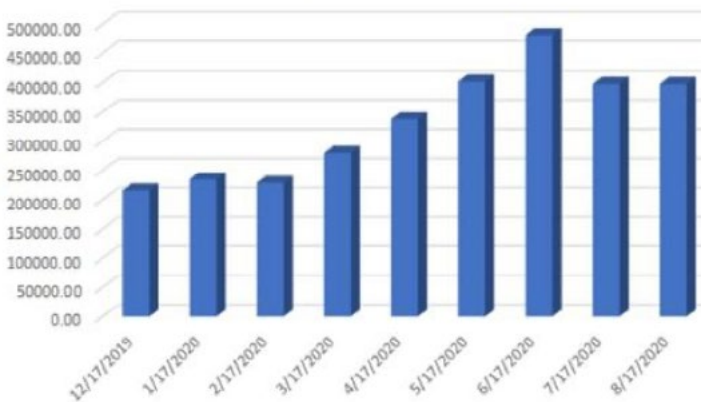
Results from Diagnostic Assays

Sample	Sample ID	Sample Type	Fusarium (CFU/ml)	Pythium (CFU/ml)
1	Zone 1 Tank	Water	0	0
2	Zone 1 Feed	Water	0	0
3	Zone 3 Tank	Water	0	0
4	Zone 3 Feed	Water	0	0
5	Zone 1 Pit	Water	0.005	0.015
6	Zone 2 Pit	Water	40	0.013
7	Zone 3 Pit	Water	60	0

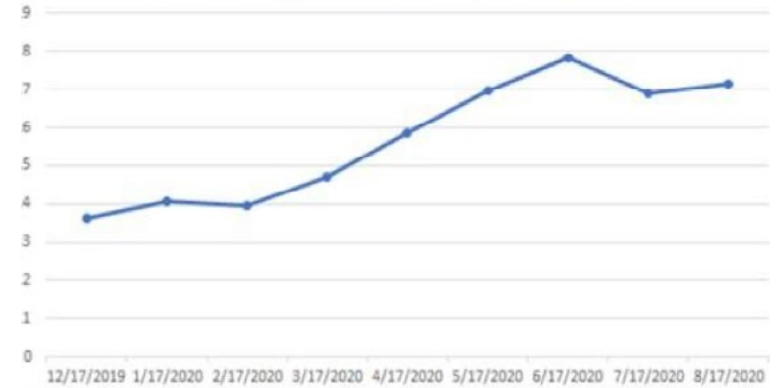
LIGHTSHADE CASE STUDY: IRRIGATION GRAPHS



Total Monthly Water Usage in Gallons



Facility Daily Water Usage Gal per Benching sqft



CASE STUDY

NATIVE ROOTS CANNABIS CO. COCO DONATION

Native Roots Cannabis Company is one of the largest marijuana companies in Colorado, with 20 retail locations and cultivation facilities around the state. With that footprint, it is vital that Native Roots embraces and leads the way in sustainable strategies. This includes efforts that span all three tiers of sustainability: economic, environmental and social. The recent pilot study regarding soil donations is a great example of a project that touches on all of those aspects.

One of the biggest outputs of indoor cannabis cultivation is the used grow medium, in addition to fibrous waste and marijuana products. Given that this is still a high value material after its initial use, finding an avenue for reuse seems intuitive. However, there are obviously challenges associated with various approaches. For example, there are opportunities for internal reuse of growth mediums, but this requires significant investments of equipment, space, labor and time. Those requirements can make internal repurposing difficult for many companies. Alternatively, external outlets could be used to supplement internal reuse strategies. Thus, in 2020 Native Roots began looking for external partners for reusing their grow medium, which in this case is coco choir.

The first step for this pilot program was outreach and collaboration. Identifying and connecting with organizations that would be interested in repurposing the coco choir required casting a wide net, but the primary organizations of focus were community gardens, local farmers and agricultural product suppliers. From that group, we identified one partner for a small scale pilot: SheGrows (a small Lavender & Cut Flower Farm on Colorado's Front Range).

During the initial outreach to potential partners, Native Roots was deliberate in providing as much useful information up front as possible. This included background on nutrient and pesticide usage, as well as soil contamination testing for pesticides and heavy metals. The intent was to ensure that all parties were satisfied with the safety and quality of the coco choir prior to any repurposing operations. Depending on the cultivation process, selection of partners may need to be more considered. For example, if the repurposed material is to be used for edible plants, contaminant testing would obviously be vital to ensure safety of end products. Conversely, if the grow medium will be utilized for non-edible products, such as cut flowers, the testing requirements may be less rigorous. It's important that these details be openly

discussed with potential partners to ensure everyone is in agreement with the safest and best practices.

The next step was to strategize around the logistics of hauling and processing the material. Again, space can be an important and limiting factor when it comes to storage prior to hauling. Depending on the available supply and demand on a given day, some amount of advanced notice is helpful. For example, if a partner requests 100 lbs of coco, it may take a day or two to stage sufficient amounts for hauling. This means that an appropriate temporary storage solution must be coordinated, assuming this is how the transfer will occur. For Native Roots, it made the most sense to stage coco for hauling, then schedule a pick up time for our community partners to come by the facility to collect the material.

Another key aspect of the coco repurposing is the actual process of making the material usable. For example, the coco after the point of harvest at Native Roots is in the form of densely packed pots/cubes. Thus, some processing is required in order to convert the coco back into a more loose and aerated condition. Based on the feedback from our community partners, the easiest way to accomplish this was to utilize a chipper or tiller. As you can see in the example pictures, this allowed for rather quick and easy processing. Native Roots requested that this processing be handled by our community partners at their location in order to minimize the space, time and labor impacts at the cultivation facility. The end product was of extremely high quality, demonstrating a great overall impact for sustainable practices.

While this was a limited pilot project, the results were quite promising for future partnerships that would allow for continued growth and increased efficiency. For Native Roots, the project allowed for the reuse of grow material, which had a positive environmental impact by reducing the amount of material sent to landfill. Additionally, by having community partners haul and use the coco, Native Roots was able to reduce waste hauling costs during the period of the pilot project. Finally, this project presented a fantastic opportunity for Native Roots to build new relationships with community partners with shared ideals around sustainability. These types of relationships are vital for the continued growth and normalization of the cannabis industry in Colorado and abroad. Any projects similar to the one summarized here have a lot of potential for substantive impacts, which can scale up and evolve based on the needs of both the cannabis industry and community partners.

CASE STUDY



SMOKEY'S CANNABIS CO. LIVING SOIL

Located in the small town of Garden City, CO, Smokey's Cannabis Company is making great strides to raise the bar on what it really means to cultivate

sustainable cannabis. Smokey's implements regenerative practices in cultivation that are often overlooked or abandoned due to logistical difficulties: reusing soil and reincorporating plant wastes. Smokey's team has developed a humane and environmentally friendly approach to indoor cultivation, incorporating closed-loop systems which reuse soil and plant waste without perpetuating pest and disease issues. Their stability and long-term success within such a competitive industry truly exhibits the economic viability of their production model.

Sustainable practices have allowed for substantial savings by reducing or negating the need for inputs like growing media, fertilizer, filtered water, and pesticides. Their growing media is never discarded, nor is it needed as a material to mix with plant wastes for compliance when leaving the facility, because plant wastes are not discarded. In a conservatively sized facility of about 3,000 ft², Smokey's diverts roughly over 6,500 lbs of plant wastes and over 160,000 lbs of growing media away from landfills every year.

By regenerating their soil harvest after harvest, cultivators focus on improving the soil microbiome by increasing its abundance and diversity of life. Microbes and plants develop numerous and complex symbiotic relationships. Compounds produced by/from microbiology not only provide mineral nutrition, but also boost the plants' abilities to create a greater diversity of phytochemicals such as cannabinoids and terpenes, which in turn increase resistance to biological and environmental pressures.

What this means in practical terms is that Smokey's cultivation techniques produce more complex flowers with less inputs.

Fresh plant wastes are recycled back into the soil either directly or after digestion via worms, reducing the need for supplemental nutrients. Instead of moving plant matter like leaves, stems, and root balls to the landfill, cultivators incorporate these materials directly back into the soil where

they are decomposed by a plethora of invertebrates and microbial species, building soil health and providing recycled nutrition for new plants. The reuse of organic plant wastes feeds and supports a healthy soil microbiome, which in turn helps build soil with better structure and water retention. Smokey's realizes a reduction in water usage of nearly 65,000 gallons per year (in comparison to their previous hydroponic-based production model).

Increased phytochemical production from microbial relationships also helps strengthen the plants' immune systems, which in turn lessens the need for pesticides (which are both costly and pose potential safety hazards). Smokey's uses beneficial insect predators for the bulk of their IPM strategy, only supplementing every few weeks with an organic spray – and never on developing flowers. Implementing a living soil system, they have reduced both frequency and volume of pesticide applications by at least 50%.

Microbes, arthropods, and worms all act to increase water use efficiency by developing networks and biofilms through the soil that increase aggregate structure and translocation of water & nutrients. A healthy soil microbiome also increases the rhizosphere's ability to buffer pH, meaning wasteful (yet common) methods of water filtration used to avoid pH imbalance and flush out excess nutrients (such as reverse osmosis filtration) are largely unnecessary. And because organic nutrients are being made available to plants on an as-needed basis by microbiology, the practice of "flushing" excess salts from the grow media with large amounts of water becomes extraneous altogether.

Through the creation of operating procedures that mimic certain principles of ecology, Smokey's cultivators have been using the same soil for over three years through more than 15 consecutive harvests, all the while continuing to improve plant health, quality, yield, and system resiliency. With their heels dug deeply into environmental and social sustainability, the Smokey's team knows what it takes to overcome the challenges that can arise with transitioning to organic production techniques. They have also been doing it long enough to see the immense benefits come to fruition.

APPENDICES

SAMPLE ENERGY AUDIT FORM

Name:

Grow Type:	<input type="text"/>
Cultivation Sq. Ft.	<input type="text"/>
Building Type	<input type="text"/>
Building Age	<input type="text"/>

Basic Overview	
Annual Energy Used (kWh)	<input type="text"/>
Annual Water Used	<input type="text"/>
Production (Dried Wt.)	<input type="text"/>

Month	Energy (kWh)	Water (gallons)	Production (Dried Wt.)
January			
February			
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					
Oscillating Fans					
Fertigation					
Dehumidifiers					

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

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:

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

Billing:

SOURCE: Arapahoe City

LAB # W519 1

SOURCE: Arapahoe City

IRRIGATION WATER ANALYSIS

"Routine Package"

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

	SAR	Salinity Hazard	Sodium Hazard
	0.8	Low	Low

COMMENTS: This is good quality water for irrigation.

"Metals" and "Individual Element" Analysis

	mg/L	Recommended Limit
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

ANNOTATED BIBLIOGRAPHY: SUPPORTING CANNABIS SUSTAINABILITY

Leslie McAhren, University of Colorado School of Public Health

energy/energy efficiency

water

waste – recycle organic waste, haz waste pest mgt

air quality

appendix a. carbon footprint

Methods

MeSH Terms (Medical Subject Headings) – environmental pollution; cannabis

I. Introduction

Carah, J. K., Howard, J. K., Thompson, S. E., Short Gianotti, A. G., Bauer, S. D., Carlson, S. M., ... Power, M. E. (2015). High Time for Conservation: Adding the Environment to the Debate on Marijuana Liberalization. *Bioscience*, 65(8), 822–829. doi:10.1093/biosci/biv083 Summary of Carah, 2015. Environmental harm caused by cannabis cultivation merits a direct policy response. neglecting discussion of the environmental impacts of cultivation when shaping future marijuana use and possession policies represents a missed opportunity to reduce, regulate, and mitigate environmental harm.

II. Energy

III. Water

Bauer, S., Olson, J., Cockrill, A., van Hattem, M., Miller, L., Tauzer, M., & Leppig, G. (2015). Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds. *PloS one*, 10(3), e0120016. doi:10.1371/journal.pone.0120016 Summary of Bauer, 2015. Environmental impacts associated with marijuana cultivation – reasons not to allow cultivation that is clandestine. This group used high-resolution aerial imagery to estimate the number of cannabis plants being cultivated in four watersheds in northwestern California, USA. This work was put together by the California Department of Fish and Wildlife, Eureka, California

IV. Waste

V. Integrated Pest Management (IPM)

Cuypers, E., Vanhove, W., Gotink, J., Bonneure, A., Van Damme, P., & Tytgat, J. (2017). The use of pesticides in Belgian illicit indoor cannabis plantations. *Forensic Science International.*, 277, 59-65. Summary of Cuypers, 2017. Main risks may come from pesticide residues on plants, cultivation infrastructure and materials; mycotoxins from fungal pathogens on harvested plants; and/or high levels of pesticide residue in cannabis plant parts for consumption.

Appendix A. Carbon Footprint

Mills, E. (2012). The carbon footprint of indoor Cannabis production. *Energy Policy*, 46, 58-67. doi:10.1016/j.enpol.2012.03.023

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: CMH lamps provide energy-efficient wide-spectrum lighting.
CO₂	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 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/m² 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.