CANNABIS ENVIRONMENTAL
BEST MANAGEMENT PRACTICES GUIDE

DENVER PUBLIC HEALTH & ENVIRONMENT

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EMILY BACKUS
Denver Department of Public Health & Environment

DUNCAN CAMPBELL
Scale Microgrid Solutions

ALICE CONOWITZ
Integral Consulting

LAURA DAVIS
Broomfield Public Health

CATHERINE DRUMHELLER
Oak Services

JEREMY C. GARLAND
Denver Department of Public Health & Environment

NICK HICE
Denver Relief Consulting

BRANDY KEEN
Surna

JEREMY LAUFFENBURGER
Denver Department of Public Health & Environment

JOSH MALMAN
The Clinic

D. JACOB MITCHELL
Sustainabis

JACOB POLICZER
The Cannabis Conservancy

AMBRA SUTHERLIN
Boulder County Public Health

KAITLIN URSO
Colorado Department of Public Health & Environment

THE RESOURCE INNOVATION INSTITUTE

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FROM THE EXECUTIVE DIRECTOR

Denver's Department of Public Health & Environment (DDPHE) is pleased to release the cannabis cultivation environmental sustainability guide. Developed by Denver's Sustainability Working Group, a collaborative effort that involves both DDPHE sustainability advisors and cannabis industry professionals, the guide aims to help cultivators reduce waste and conserve resources, turning this ever-expanding industry into a network of environmental leaders.

Specifically, the guide offers recommendations related to increasing energy efficiency while reducing waste and water use that have been tailored to the needs of cannabis cultivation operations. Each recommendation supports DDPHE's overall goal of helping Denver residents live better, longer. The health of our environment is inextricably linked to our physical health, and DDPHE works extensively with businesses across all industries, helping them to operate as sustainably as possible.

It is encouraging to see the interest and passion from cannabis cultivators throughout the industry, who have come together to craft this guide. Denver is now home to more than 591 active cultivation licenses operating out of 295 locations that has the capacity to consume a significant amount of natural resources. However, the opportunity also exists for each of these facilities to lead Denver toward lower resource consumption, bringing the community in line with Denver's 80x50 Climate Goal of reducing greenhouse gas emissions 80 percent below 2005 levels by 2050. This plan sets Denver at the forefront of efforts to address climate change by creating strategies to target the largest sources of emissions, commercial energy use chief among them.

By partnering with the cannabis cultivation industry, DDPHE sees endless opportunities to continue our commitment to partnerships and community collaboration, and to aggressively work to combat the threats and broad-reaching impacts of climate change.

As Mayor Michael B. Hancock stated in the City and County of Denver's 2015 Climate Action Plan, "climate action is the biggest opportunity of the 21st century to protect public health, grow our economy and secure a bright future for generations to come, and we have the technology to move to cleaner, more sustainable forms of energy. We must commit to being bold and inclusive about how we will meet this goal together."

Sincerely,

Bob McDonald
Executive Director
City & County of Denver
Department of Public Health & Environment

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. 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

The current version of the Guide addresses environmental best practices for energy, water and waste management in indoor cannabis cultivation facilities. There are also many other sustainability topics that pertain to the cannabis industry, including community engagement, employment practices, facility site selection, etc. As future editions of the guide are released, additional topics and facility types – such as greenhouses, outdoor cultivators, infused products manufacturers and retailers – may be addressed.

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.

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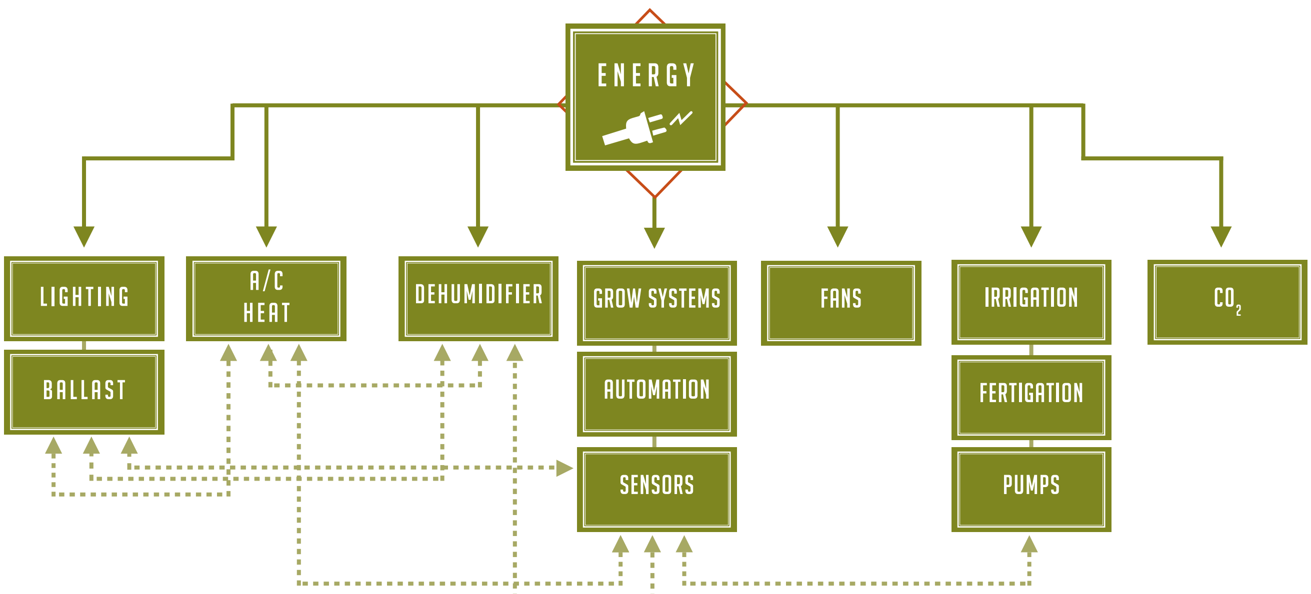
OVERVIEW

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 faster production and greater product variety, 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 contributes to negative public perception therefore active energy efficiency efforts can help cannabis businesses create positive improvements within communities.

Figure 1: Primary Electricity Use for Indoor Cannabis Cultivation



According to a 2014 study performed by the Northwest Power and Conservation Council, electricity is generally used to perform key functions in the average cultivation facility as shown below:[1]

Table 1: End Use Electricity Consumption

FUNCTION	PERCENTAGE OF TOTAL FACILITY ELECTRICITY CONSUMPTION
HVAC and Dehumidification	51%
Lighting	38%
Space Heating (assuming electric heat)	5%
Water Handling	3%
CO_2 Injection	2%
Drying/Curing	1%

[1] Northwest Power and Conservation Council Memorandum - Electrical Load Impacts of Indoor Commercial Cannabis Production

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

- **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.
- **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.[2]
- **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 by 36 percent annually, on average, between 2012 and 2016.

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.

[2] Utility Dive - Marijuana Grow Houses Trigger 7 Summer Outages for Pacific Power

REGULATORY DRIVERS

Colorado state regulations and local regulations in the Denver metro area significantly impact the methods of cannabis cultivation employed by growers and the per-gram energy use of cannabis grown. For example, Denver's zoning and other land use regulations require cannabis cultivation facilities to operate in industrial areas. Therefore, the cultivation facilities that result are primarily indoor warehouses that use 100 percent artificial light – the most energy-intensive option. Alternatively, in localities that allow cannabis cultivation facilities on agricultural, commercial, industrial and mixed-used land areas, growers can choose the properties and cultivation methods that offer the greatest returns. As prices drop and energy use becomes a larger percentage of revenue (and earnings), market forces incentivize growers to transition from indoor facilities to greenhouses and outdoor farms.

Requirements for cultivation facilities to open and operate within a specified period often push growers to focus on the fastest rather than the most sustainable methods of cultivation. These types of requirements typically occur in licensing systems that limit the number of businesses as to ensure that cultivators are not idly sitting on their limited license. However, these regulations can be problematic for businesses that want to construct high-tech greenhouses customized for cannabis cultivation. Companies often opt to cultivate cannabis within existing warehouses to get up and operating faster. This focus on speed rather than energy efficiency increases the environmental costs of cannabis cultivation.

The City & County of Denver has ambitious, community-wide energy and GHG emission reduction goals. Cannabis cultivation facilities, like all businesses, operate within the context of these goals, and energy efficiency at the individual building level is part of the solution. Denver's Climate Action Plan 2015 describes these goals and potential strategies.

Denver's climate goals include reducing GHG emissions by 80 percent below 2005 levels by 2050.

In December 2016, Denver City Council passed a new benchmarking ordinance, known as Energize Denver (www.denvergov.org/EnergizeDenver). The ordinance requires owners and/or operators of large commercial and multifamily buildings to annually assess and report the buildings' energy performance using the free ENERGY STAR Portfolio Manager tool. In 2017, buildings exceeding 50,000 square feet in size are required to report, and buildings exceeding 25,000 square feet in size will be required to report beginning in 2018. The data will be made publicly available on an online map published by Denver Department of Public Health & Environment. The cannabis industry is expected to utilize two exemptions to the reporting requirements:

- Buildings used primarily for industrial or agricultural purposes are exempt.
- Businesses are exempt from reporting when energy performance is a confidential business practice.

Benchmarking laws are becoming more common throughout the U.S., and such exemptions may not apply in other localities. Cannabis businesses that do not meet the square footage requirement, can participate voluntarily to understand and compare energy usage. Business owners can reference the Portfolio Manager section below for more guidance on how to get started.

MEASUREMENT & VERIFICATION

Measuring and verifying (M&V) building- and system-level energy use is typically the first step for organizations that are looking to reduce the energy footprint. While all facilities receive monthly electric and gas usage statements from utility providers, the data included on these statements represents a general overview and typically lacks the granularity needed to develop a comprehensive energy management strategy. The best practices outlined below represent options for facility managers looking to develop an effective M&V process.

Sustainability Aspects and Impacts

- Energy consumption
- GHG emissions
- Regional stakeholder alignment
- Operational and compliance budgets

Process Description

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.

Track Metrics

There is currently a paucity of relevant, high quality energy data in the cannabis industry. To improve the current state of industry data, cultivators should begin or continue to measure and share facilities' energy usage data both to make more strategic equipment and process decisions as well as to contribute to an understanding of the current state of the industry.

Recommended metrics to track include:

- Grams/Watt (lighting only) – Dry weight of flower and trim production measured against lighting power.
- Grams/kWh (total energy usage) – Overall production-to-energy efficiency ratio; dry weight of flower and trim production measured against total building energy use.
- Grams/sqft of cultivation space (efficiency) – Measures space utilization efficiency per cycle and/or per strain.
- Micromole/sqft – Lighting intensity measurement to identify when bulbs or fixtures must be replaced; also can compare multiple lighting types.
- Return on Investment (ROI) – ROI of each technology (based on replacement timing, maintenance/labor, yield under each technology) over a specified period. The ROI of specific equipment should be calculated by identifying the incremental costs and benefits over the costs and benefits of standard equipment.
- Energy consumption (units and costs) – Energy consumed per unit of product produced and energy costs as a percent of total operating costs.

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 1.6g/W Less than 1g/W - 8% 1g-1.49g/W - 16% 1.5g-1.99g/W - 8% 2g-2.49g/W - 10% 2.5+g/W - 3% Unknown to Operation 51%
Total Energy Efficiency	Identifies total production efficiency; helps identify trends in building.	grams/kWhs	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.	micromoles/ sqft	Measure at canopy. Measure for each type of lighting, for each stage of growth.	Currently unknown
Daily Light Integral	Measures the daily accumulation of photosynthetically active radiation (PAR) spectrum light reaching the plants.	mol/m^2/day	Formula: µMol/M^{2}S x 3600 s/ hr x photoperiod(hrs/day) ÷ 1,000,000 µMole/Mole = Mol/ M^2/Day	Denver Outdoor Avg. Winter 15-30 mol/m^2/ daySummer 25-45 mol/ m^2/day
Load Factor	Used to manage peak power demand; higher Load Factor reduces cost of energy.	kWhs / (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

OBTAINING BUILDING DATA FROM XCEL ENERGY

Energy usage data can include data pertaining 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. Certain parties may need to access more than 12 months of utility bills to fully cover the 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 which 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, 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.

PORTFOLIO MANAGER

As mentioned above, benchmarking energy use using Portfolio Manager is now required for commercial and multifamily buildings exceeding 25,000 square feet in Denver.

For a good example on 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.

Guidance on Collecting Data

- Three levels of data to consider:
  - Level 1 – Properly interpreting and recording monthly utility bills.
  - 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 only take a few minutes each month.

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 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, sub-metered 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 or malfunctioning equipment, saving facilities from 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.

Engage Specialists

- An energy specialist (such as a Certified Energy Manager) can perform any of the above tasks for a cultivator, particularly, if a grower should seek out an experienced contractor to install sub-meters. Interested cultivators should consider a local trade group or association such as Rocky Mountain Association of Energy Engineers.
- 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 grants/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.

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 sub-meters inside the building to collect power usage data, for example, those manufactured by e-mon, or Power TakeOff. Sub-meters 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.

Resources:

- Xcel Energy - Business Programs & Rebates
- Sample Energy Audit Form

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). While these two billing aspects are related, 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 consumption
- GHG emissions
- Operational and compliance budgets

Process Description

Load-factor Optimization

Energy-efficient technologies can improve both the total energy use and peak demand of a facility. Operating schedules, on the other hand, 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 and ventilation. 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

Xcel Energy does not 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 is 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. Lighting design also plays a significant role in the facility's overall sustainability profile. Employee health and safety should be considered in the design and delivery of indoor lighting as well.

Sustainability Aspects and Impacts

- Energy consumption
- GHG emissions
- Solid waste generation
- Employee well-being
- Climate
- Operational and compliance budgets

Process Description

Indoor cultivation facilities typically utilize a combination of High Pressure Sodium (HPS), Ceramic Metal Halide (CMH), Fluorescent and/or Light-Emitting Diode (LED) lamps. In addition to lamp type, lighting system design and time of lamp use are also critical to maximizing energy efficiency in cultivation facilities. 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 and ultraviolet light spectrums (sometimes useful, although widely debated) fall outside of PAR readings and thus do not register with standard light spectrum measuring equipment. The intensity of the lighting system or photosynthetic photon flux density (PPFD) is measured in micromoles per second per meter square (μmol/s-m2) and should be carefully monitored for optimal plant growth. PPFD can also be thought of as "PAR per square meter."

Equipment Overview

Cultivators have several choices when it comes to lighting technology. 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. Many of these lighting types have specific spectrums of PAR and are generally used for one stage of growth or another. Prescribing specific heights above canopy for lighting systems is not recommended, as PPFD, age of fixture, bench height and plant height will all dictate the location of the fixture. There should be a perpetual review of micromole levels for cannabis and the need to adjust fixtures with the aid of a good light meter to obtain the necessary PPFD.

Lighting fixtures emit energy in the form of light, as measured in PAR or photosynthetic photon flux (PPF), and reflectors direct the light towards 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 sub-optimal 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 PPFD	EFFICACY IN µMOLES/J
T5 Fluorescent	Plant propagation — mothers and clones	Full spectrum with ability to fine tune colors	20,000	150 - 300	TBD
Metal Halide	Vegetative growth	Full spectrum with blue and green peaks	6,000 - 15,000	500 - 800	TBD
Ceramic Metal Halide	Both stages of growth	Full spectrum, UV	20,000	800	1.46
High Pressure Sodium (single-ended)	Flower growth stage or both stages	Full spectrum with yellow and red peaks	5,000 - 20,000	700 - 900	1.16
High Pressure Sodium (double-ended)	Flower growth stage or both stages	Full spectrum with yellow and red peaks	5,000 - 20,000	700 - 900	1.70
Light Emitting Diode	All stages of growth	Full spectrum with ability to fine tune colors, UV	50,000	800 - 1200	1.70
Light Emitting Plasma	Vegetative growth or both stages	Full spectrum, UV	30,000	700 - 900	1.00

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

BEST PRACTICES

System Design

When designing for indoor cultivation, it is important to identify and understand target light levels for optimal growth. The correct measurement for obtaining best results is PPFD, or the number of photons of PAR that are hitting the top of the canopy. This measurement only gives the total amount of photons that the plants use in the process of photosynthesis. PPFD uniformity is critical to maximizing crop yield. The more useable photons consistently hitting the crop, the quicker the crop will grow. Many double-ended HPS fixtures have multiple reflector options. To decrease the amount of photons wasted on the side of the grow rooms, more directional reflectors are placed around the perimeter of the flower rooms. Broader reflectors are placed in the center of the room. The result is less wasted light on walls and more efficient production.

Once an operator has determined the target PPFD, the cultivator should work with an engineer or vendor to design the system around the target. If a manufacturer cannot assist in the design and technical review, the cultivator should consider seeking a more capable vendor, or be sure to have an appropriate consultant on the team. Master controllers should be used with quantum meters for 24-hour monitoring of light levels. It is also a best practice to make sure growers have access to handheld quantum meters for daily monitoring.

[3] Yorio, Neil. (2014) Towards Sustainable Lighting For Commercial Cannabis Production. Biological Innovation and Optimization Systems (BIOS)

[4] Nelson, Jacob A. and Bugbee, Bruce. (2014) Economic Analysis of Greenhouse Lighting: Lighting Emitting Diodes vs. High Intensity Discharge Fixtures. PLOS one.

Maximizing Production & 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. Artificial lights can only achieve approximately 24 inches of penetration on 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 branches on the bottom third of the plant. Lower branches can occasionally be left on the plant if they reach the top half of the canopy. Interior branches in the plant canopy can also be removed if they are smaller than one-eighth of an inch. This heavy pruning will create larger top colas with enhanced terpene profile and higher potency.

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. With greenhouse production, lights will only be needed occasionally for supplemental light. Weather stations wired to a quantum meter should be used to ensure lights are only activating when the meter dips below the minimum micromole target. These weather stations allow for the most efficient use of electricity.

When designing greenhouse cultivation facilities, many of the system designs with regard to lighting will be different when compared to indoor cultivation. Greenhouse lighting is still based on desired PPFD, but must take into consideration how much natural light/sunlight will be obtained. Light fixture count will undoubtedly decrease in most geographies compared with indoor operations, as the lights will only be used 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 help maximize plant density. Cultivators should install trellis netting in the first week of the flower stage before plants stretch. Installing low trellising early will help keep the plants stable and encourage heavier bud set. It is important to weave the plants up through the trellis daily for the first 30 days of the flowering cycle. The goal is to maximize production by making sure there is at least one branch/bud coming up through each four-inch square on the trellis netting. Monitoring the canopy via a step ladder can be helpful to make sure there are no gaps in the canopy.

Adjustable Light Fixtures

It can be beneficial to have adjustable ratchets on the light depending on the technology and layout. 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 percent. Different lighting technologies have different maintenance considerations.

High-Intensity Discharge Lighting

- **Aluminum Reflectors:** Calcium, dust and sulfur will damage reflectors and decrease efficiency. Cultivators should use caution in cleaning reflectors, as any wiping of the reflector will damage the finish. Cultivators should dip the reflector in a two percent vinegar solution and let it air dry, taking care to never wipe the reflector. This should be done once every six months or more often if heavy accumulation of dust is noticed. Tracking micromole levels at the canopy level will insure the proper amount of photons is hitting plants. Most manufacturers recommend replacing reflectors every 12 months along with the bulb, however tracking light levels and only replacing reflectors when they are underperforming is a more sustainable approach.
- **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 in 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 insure the proper amount of photons is hitting the plants. 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 used to consist 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 ballast, are heavier, less efficient, create more heat and are noisier than electronic ballasts. However, they may come with a longer warranty than electronic ballasts, 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:** Quality LED manufacturers will utilize a glass optic over the diodes. These optics should be cleaned every two months with a non-solvent cleaner and non-abrasive microfiber cloth.
- **Diodes:** Most diodes are rated for 50,000 hours. This means they could run, in theory, for more than a decade without replacement on a 12/12 schedule. 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 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 cost and disposal cost – as well as failure scenarios and associated costs – should be calculated and included in lighting decisions.

Resources:

- Gavita Lighting - Lumens are for Humans
- 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

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 savings 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

HVAC & DEHUMIDIFICATION

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 of heating, ventilation, air conditioning (HVAC) and dehumidification. 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 most 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 equation.

Sustainability Aspects and Impacts

- Indoor air quality
- Odor control
- Energy consumption
- GHG emissions
- Regulatory compliance
- Climate
- Community relations
- Employee well-being
- Operational and compliance budgets

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 and local ambient conditions. Due to the complexity of HVAC and dehumidification systems, it is strongly recommended that facility managers consult with a mechanical designer familiar with the cultivation space. 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® 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.

Cooling is not the addition of cold air, it is the removal of heat. The act of cooling is simply the absorption and relocation of British thermal units (BTUs) – the amount of thermal energy required to change the temperature of one pound of water one degree in one hour. The more energy efficient the heat exchange, the more energy efficient the cooling 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. It is important to understand the efficiency of the system as a whole for the intended purpose when evaluating any climate system.

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

COOLING METHODOLOGY

Evaporative Cooling

Evaporative cooling is a low-energy cooling method in which heat is absorbed from the space through the evaporation of water. When water evaporates, BTUs are absorbed and temperatures are reduced. This is an energy-efficient method of cooling for comfort applications and is especially attractive in dry climates, but also requires substantial amounts of water. This method is not recommended for cultivation spaces due to the introduction of humidity to the space.

Mini Splits

Small, ductless HVAC units allow for quick owner installation at 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, additional space and electrical connection points required. These systems lack direct dehumidification control and are designed for comfort cooling application, 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 and, thereby, does not allow the cultivator precise control of the indoor relative humidity (RH).

Standard 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 a facility. Each FCU has variable cooling capacity to meet load, promoting a higher level of indoor unit zoning and distributed cooling without 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. 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. Overall, VRF is a more energy-efficient option than traditional HVAC methods but is comparatively expensive to purchase and install. VRF also carries the potential risk of leakage from exposed refrigerant piping.

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 “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 sub-cooling 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 (i.e., 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 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 are the most affordable and easiest systems to integrate, but due to their plug and play nature they can be difficult to integrate with other climate control equipment.

Reheat

Reheat describes heating the space to allow the cooling system to run 24 hours a day to produce dehumidification without reducing temperatures. Reheat allows for more energy-efficient dehumidification via larger compressors. Energy is required to produce heat, which in some cases can offset the consumption savings. Reheat can also benefit the efficiency of standalone dehumidifiers by raising the temperature in the space. Increasing temperature has the added effect of decreasing relative humidity (RH) through expansion of air. Reheat can be produced by the following methods:

- **Electric reheat:** Electric heat strips are utilized to produce heat. Electric heat is not particularly energy efficient (consumption is comparable to or higher than standalone dehumidifiers in overall consumption), and the energy use should be compared carefully to standalone dehumidifiers to determine which solution is more efficient in a specific facility.
- **Hot gas reheat:** Heat removed from the space through the refrigerant system is rerouted to a reheat coil to be used to heat to neutral temps before being returned to the space. This method is near-zero energy reheat, but is limited in capacity and is generally not recommended in low ambient conditions due to difficulty managing refrigerant pressures. Additional standalone dehumidification or reheat from other sources will be required in conjunction with this source.
- **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 FCUs through a gas-fired boiler system. Superior energy efficiency can be achieved by modulating flow rates of hot and chilled water, allowing the system to consume exactly what it needs.
- **Heat recovery:** When water-cooled condensers are in use and rooms are running on opposite light cycles (i.e., some rooms are lit while others are dark), heat removed from the lit room can be absorbed from the condenser and returned to a dark room through the hot water loop described above. This improves the efficiency of the condensing unit and allows for nearly free reheat.

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 create more problems in cultivation environments than they solve with regard to CO_2 enrichment, biosecurity and odor control, and are generally not recommended (See "Ventilation and CO_2" section for additional detail).

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 for efficiency.

Destratification fans are important to energy-efficient climate management 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.

Airflow and airspeed need to be studied more closely in controlled cannabis environments so the industry can create a baseline standard for airspeed.

VENTILATION AND CO_2

In many CO_2-enriched environments, ventilation or air-side economization may waste significant amounts of CO_2 (which can conflict with the energy code and efficiency efforts overall). Cultivators should carefully weigh efficiency gains associated with ventilation against CO_2 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, CO_2 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 CO_2 is a better substitute practice.

DESIGN STANDARDS

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) publishes commonly accepted HVAC standards for architects and engineers. As a starting point, facility owners may benefit from familiarizing themselves with ASHRAE 90.1, Energy Standard for Buildings. ASHRAE has also published an Advanced Energy Design Guide Series 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. 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 are a highly efficient HVAC option.
- For larger facilities, variable refrigerant flow and chilled water systems offer higher efficiency and redundancy.
- If using standalone 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.
- Hot water and heat recovery are the two most efficient choices for reheat dehumidification.
- Desiccant dehumidification is highly efficient but costly.
- Cultivators should seal spaces to reduce CO_2 exhaust, improve biosecurity and reduce odors emanating from the facility.
- Cultivators should keep rooms warmer at night to manage latent load.

Cultivators should provide shade for rooftop units to reduce operating temperature and extend life.

Resources:

ASHRAE, Air Conditioning, Refrigeration and Heating Institute, See sample Preventative Maintenance schedule in appendix.

ENERGY SUPPLY

OVERVIEW

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

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

XCEL ENERGY – 2017 POWER SUPPLY MIX FOR COLORADO CUSTOMERS[6]		
	TOTAL GENERATION MIX (%)	MEDIAN LIFECYCLE CO_2 EMISSIONS (GRAMS/KWH)[7]
Coal	44%	1001
Natural Gas	28%	469
Wind	23%	12
Solar	3%	46
Hydroelectric	2%	4
Other*	0%	-
*Includes biomass, oil and nuclear generation		

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 on-site 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 losses. Roughly 5 percent of grid-generated electricity is lost in the transmission and distribution process.[8] Onsite renewables such as PV may only offset 10 percent to 15 percent 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, off-site optimization likely represents the simplest alternative for cultivators looking to reduce the environmental impact of their facilities.

As with the demand reduction strategies presented in the previous section, there is not a one-size-fits-all solution to supply-side energy management. While the following best practices are intended to provide a starting point for discussion, facility managers are strongly encouraged to consult with a licensed professional prior to acting.

[6] Xcel Energy - Energy that Works for Colorado

[7] IPCC Renewable Energy Sources and Climate Change Mitigation

[8] U.S. Energy Information Administration

REGULATORY DRIVERS

Denver does not have regulations that place special conditions on energy use for cannabis businesses. However, other local jurisdictions have passed requirements for renewable energy use and/or offset purchases, and it is expected that this type of regulation will become more popular as municipalities in California and across the U.S. develop regulations for the cannabis industry.

Boulder County Marijuana Licensing requires commercial marijuana growers to either offset electricity use with renewable energy or pay a 2.16-cent charge per kWh. Proceeds from this required fee will be funneled to the Boulder County Energy Impact Offset Fund. This fund is used to educate and encourage best cannabis cultivation practices regarding energy use, and to fund other carbon offset projects such as the development of more renewable energy.

ON-SITE POWER GENERATION

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.

Sustainability Aspects and Impacts

- GHG emissions
- Land use
- Climate
- Regional stakeholder alignment
- Employee well-being
- Operational and compliance budgets

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.

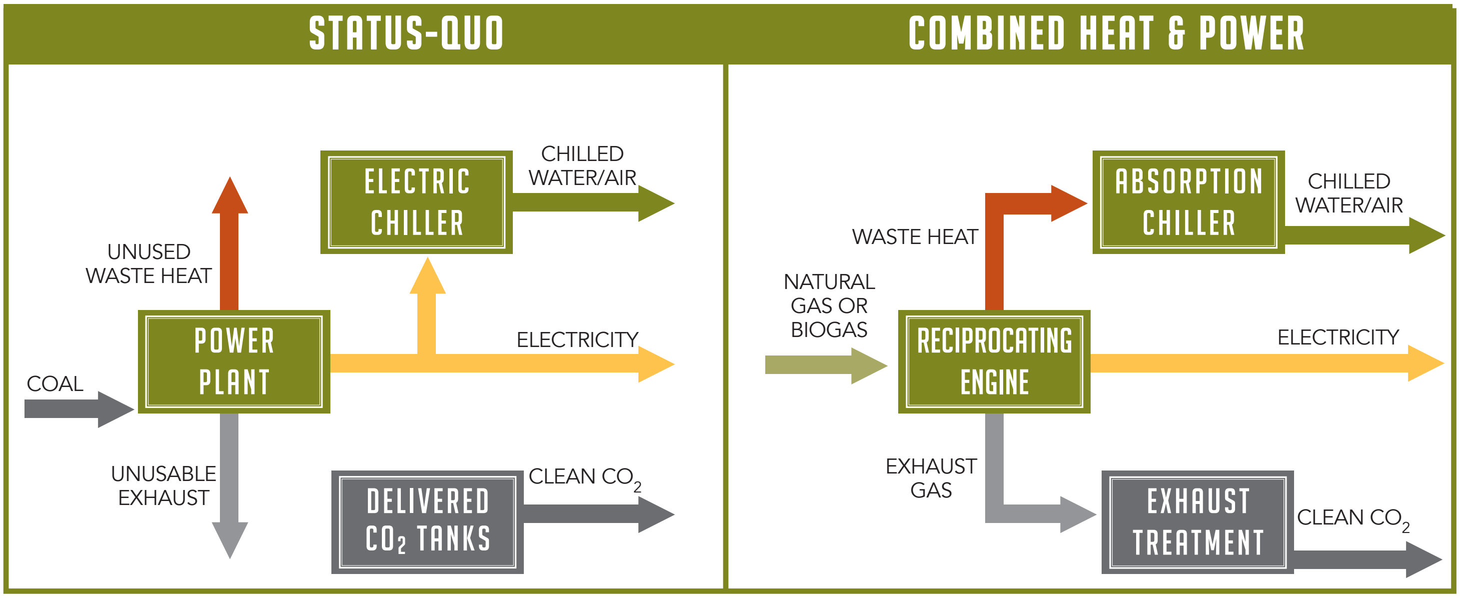
If the desktop feasibility study indicates an attractive value proposition, the next step is performing a Level 1 Feasibility analysis. The EPA provides a sample Level 1 Feasibility Analysis for facility managers to review in the event a project proceeds, a Level 2 Feasibility Analysis is subsequently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

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 CO_2 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.



Resources:

- 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

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.

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 offsite. 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.

Sustainability Aspects and Impacts

- GHG emissions
- Land use
- Climate
- Regional stakeholder alignment
- Operational and compliance budgets

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.

Resources:

- Xcel Energy – Community Solar Program
- Colorado Energy Office Community Solar Information

WATER USAGE & QUALITY

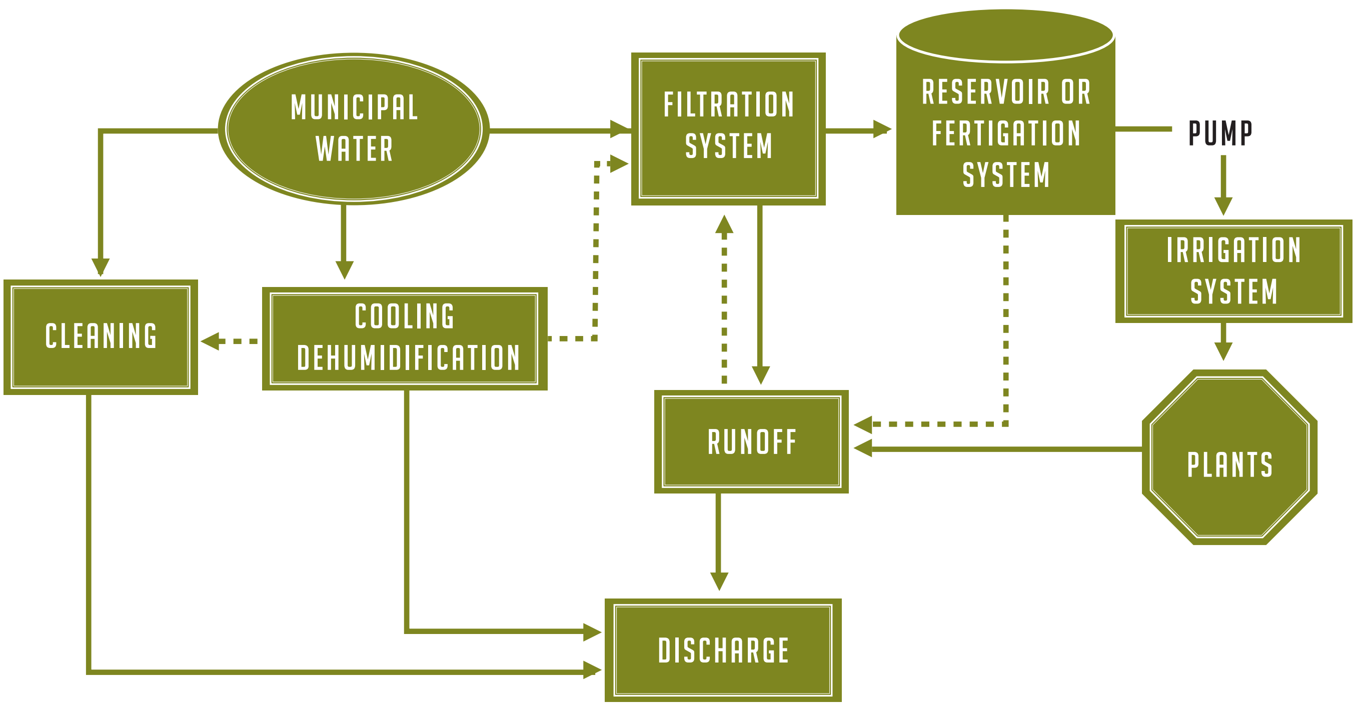
WATER OVERVIEW

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.

Figure 3: Water Flow for Cannabis Cultivation Facilities



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 – while anticipating regulatory changes.
- **Environmental Impact –** Water and energy are inextricably linked, as there is a significant amount of energy embedded in the water supply due to factors intrinsic to the water and energy infrastructure. Water and wastewater utilities account for approximately 5 percent of overall U.S. electricity use, resulting in significant GHG emissions.[9] In addition, regional water resource concerns – such as loss of agriculture in rural areas and biodiversity and watershed impacts of piping water outside of its native watershed – are of increasing concern. As such, introducing efficiencies in water use and quality can result in quantifiable reductions in GHG emissions and 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.

REGULATORY DRIVERS

Cannabis facilities in Denver receive water and wastewater service through Denver Water and Metro Wastewater, respectively. Fees from both services are based on incoming water usage and are generally combined into one monthly bill issued by Denver Water. For 2017, the combined rates for water and wastewa ter are $6.88 per 1,000 gallons. Higher summer water use may result in higher-tier charges. Metro Wastewater currently does not require any pre-treatment of effluent for cannabis 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/

Recapturing and reusing water within a facility's watering process is allowed and can be very beneficial for water efficiency. Conversely, facility water reused for alternate purposes is considered Graywater and is only allowed in specific instances, such as for using as wash water for outdoor irrigation on non-consumable plants. Review City of Denver Graywater Regulations prior to any possible greywater application.

Rainwater capture for indoor water use is not allowed, nor is it permitted to dump any liquids (or materials) down storm drains. Nothing is allowed in storm drains except rainwater and snowmelt. Storm drains empty directly into local waterways.

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.

Sustainability Aspects and Impacts

- Water conservation
- Water quality
- Regional stakeholder alignment
- Operational and compliance budgets

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-) 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. Generally, incoming water will not meet the strict specifications for optimal plant growth, therefore, some level of purification is needed. Water to be applied to plants should be purified and nutrified on demand or purified and held in storage tanks until nutrients can be added prior to application to the crop. Water can be purified using several different methods including carbon filtration, reverse osmosis and UV sterilization.

Best Practices

When considering environmental inputs, water treatment using carbon filtration has emerged as the most efficient method to reduce contaminants – such as chlorine, chloromine, sodium and bicarbonate levels – in a facility's incoming water. Carbon filters are very effective at achieving the desired nutrient load for cannabis plants when filtering is performed according to manufacturer's specifications. Additionally, filtering leads to very low levels of waste. Only water used to periodically clean filters is disposed of, whereas sterilizing water through reverse osmosis generates substantial water losses in the brine byproduct.

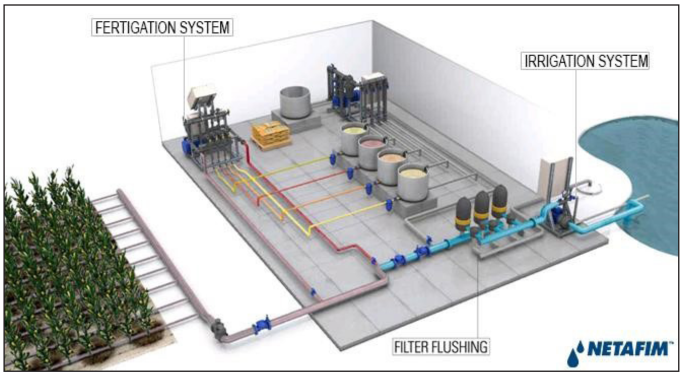
Resources:

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

IRRIGATION METHODS & AUTOMATION

Accurate irrigation is essential to the growth of healthy plants and the overall performance of a cultivation facility. Inefficient water use not only wastes this precious resource, but can cause facility damage by encouraging fungal growth, 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.

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



Sustainability Aspects and Impacts

- Water consumption
- Water quality
- Pest control

Process Description

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.

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 re-used. Typically, the recycled water will be treated to kill any waterborne plant pathogens (i.e., Pythium, Phytopthora, 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, re-nutrify and re-use the water. Flood tables are often used with rock wool mediums and the runoff is captured in a tank directly below the tray to be sanitized and re-nutrified in place.

Aeroponics

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

Wick Systems

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

NFT Systems

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

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

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:

Table 6: Irrigation Methods for Indoor Cannabis Cultivation

IRRIGATION METHOD	EFFICIENCY	BENEFITS	DRAWBACKS
Hand Watering	Low	• Eyes on all plants during watering • Gives grower "hands on" feel	• Inconsistency of volume per pot • Inconsistency between employees responsible for task
Drip	High	• Automated • Precise volume of water • Allows cultivator to water a large number of plants at once	• Potential clogging of dripper • Manual inserting/removal of dripper when moving plants • High cost to install and maintain
Flood Tables	High	• Automated • Less chance of under-watering plants • Easy and inexpensive to build	• Large amounts of water used at once • Increased humidity if reservoirs do not have lids • Manual labor to clean and refill reservoirs

Automation

Automated watering systems are highly recommended to help control accuracy and efficiency and to increase data collection as well as 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 insures real-time data is collected daily. Several major manufacturers currently offer environmental and fertigation packages that tie into one software program, allowing for a streamlined data collection process and easy, intuitive data mining. Production is all about repeatability, and data collection helps insure 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 percent runoff per watering event is an efficient and achievable target. 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.

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. 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 run-off may hinge on these numbers. If the plants are able to absorb all water provided, frequent flushing may not be necessary.

Resources:

Hydroponic and aeroponic system resources:

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

Drip irrigation resources:

- Irrigation Tutorials - The Basic Parts of a Drip System
- Irrigation Tutorials - Drip Irrigation Design Guidelines

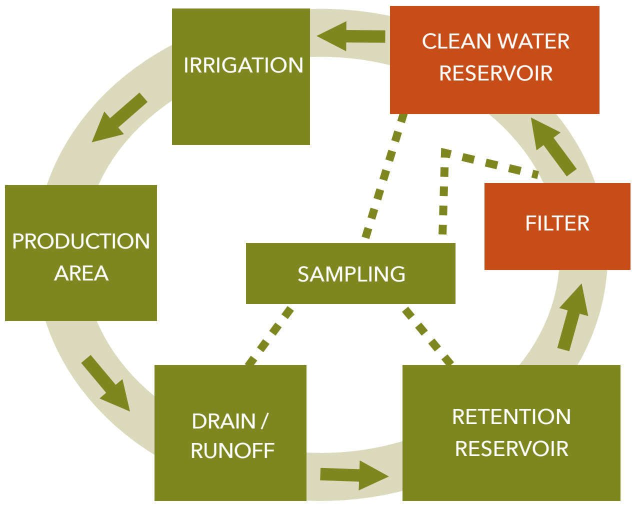
Procedure for flushing plants:

- American Agriculture - Flushing Potted Plants

WATER RECYCLING

The agriculture industry by nature requires significant amounts of water, which may stress local watersheds. Indoor agriculture is similarly water intensive, yet cultivating cannabis in controlled indoor environments provides multiple opportunities for water efficiencies and water recycling. Indoor cultivation rooms can be thought of as closed systems for water use. Virtually all excess water runoff and water vapor can be captured and delivered back to the beginning of the watering process.

Figure 5: Irrigation water recapture process



Note: This water re-use practice is not to be confused with Denver's updated graywater regulations. Graywater – which includes wash water, shower water and sink water – can only be applied to outdoor landscapes, not re-used indoors nor applied to consumable crops.

Sustainability Aspects and Impacts

- Water consumption
- Water quality

Process Description

Water applied to cannabis plants through hand watering, flood trays or drip methods can be easily captured in two complementary ways. First, applying water onto plants generally produces some amount of excess water which 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 the photosynthetic process. This water vapor passes through the cultivation room's HVAC equipment and is expelled to the outdoor environment. While passing through a cooling, ventilation and/or dehumidification unit, the water vapor condenses back to relatively clean liquid water and can be easily 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. 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: Very clean (almost reverse osmosis quality) water that most cultivators are not taking advantage of.
- Through piping: This method can be somewhat costly, compared to the cost of water, but well worth the investment, especially when there is a need to dilute captured nutrified water from other areas of the facility.
- Through a sediment filter: This method removes much of the larger-sized organic and inorganic material from the water.
- Pipe captured water to a holding tank.

Recaptured water must be purified again. There are several options available, but 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, Phytopthora, 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 phytopthora.
- Electrochemically Activated Water (ECA).
- Water storage located immediately above-stream of the water filtering process.

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.

Figure 6: Example of piped drainage from trays

Figure 7: Piped drainage running into floor sink

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

Figure 9: Sediment Filter

Figure 10: Hortamax Vitalite UV Filter

Figure 11: Brinkman ECA System

Resources:

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

Examples of UV purification products:

- Hortimax Growing Solutions
- Superior Aqua Systems

Examples of copper purification products:

- Aqua-Hort
- Priva Vialux Line Water Disinfection

Examples of ECA products:

- Horti-Daily
- Royal Brinkman

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 may be largely unnecessary.

Sustainability Aspects and Impacts

- Water quality
- Water consumption
- Indoor air quality
- Employee well-being

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.

Resources:

- Green Seal
- Eco Logo
- EPA Safer Choice

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.

WASTE MANAGEMENT & DIVERSION

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 compliant packaging that minimizes materials or by implementing package collection.

The sustainability impacts of waste management and diversion include:

- **Economic Competitiveness:** Operational efficiencies required for overall solid waste reduction result in budget optimization through reduced raw materials procurement and disposal costs. Reduction of raw material use and material re-use results in consumables reduction and solid waste output reduction. This waste reduction is linked to water and energy usage levels, so the implementation of efficiency strategies for the water and energy sustainability factors can result in lower consumable use and subsequent solid waste reduction.
- **Community Relations:** Waste reduction and diversion creates a point of outreach with the community by reassuring neighborhood residents that a cannabis cultivation operation is a responsible environmental partner, committed to the health and well-being of the local area. In addition, because land use impacts and 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.[10]
- **Environmental Impacts:** As water and energy are inextricably linked, consumable use reduction is enabled through optimization of operational processes related to water and energy, such as those discussed in the energy and water sections of this manual. In addition, 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 agricultural inputs, equipment, and product packaging and can be categorized as either organic, recyclable, universal or hazardous waste. Though cannabis waste is strictly regulated, this section will outline compliance best practices that minimize the industry's environmental impacts from waste.

REGULATORY DRIVERS

Waste from cannabis cultivation facilities in Colorado is strictly regulated. Colorado's Retail and Medical Marijuana Rules include multiple provisions that either encourage or create challenges to reducing the environmental impact of waste from this industry. For example, the rules explicitly allow plant waste to be disposed of in a compost facility, encouraging that practice. On the other hand, the requirement to render plant waste unusable by mixing it with other wastes can create a barrier to composting if a facility does not have enough other compostable waste to mix with plant waste material.

Under Colorado Marijuana Enforcement Division regulations, after the marijuana waste is made unusable and unrecognizable, the rendered waste shall be:

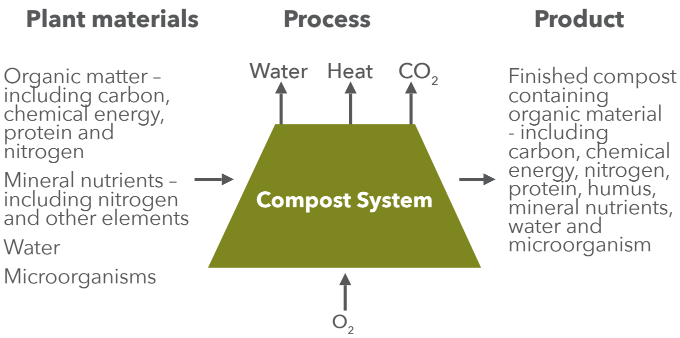
- Disposed of at a solid waste site and disposal facility that has a Certificate of Designation from the local governing body.
- Deposited at a compost facility that has a Certificate of Designation from the Department of Public Health and Environment or...
- Composted on-site at a facility owned by the generator of the waste and operated in compliance with the Regulations Pertaining to Solid Waste Sites and Facilities (6 CCR 1007-2, Part 1) in the Colorado Department of Public Health and Environment (CDPHE).

[10] Denver 2020 Sustainability Goals.

ORGANIC WASTE MANAGEMENT

Organic wastes represent a significant component of the cannabis production waste stream. Unusable plant material, soil and other growing media, paper and food waste are all compostable in commercial compost facilities. Alternatively, plant and food waste can be processed on or off site using Bokashi fermentation. 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



Sustainability Aspects and Impacts

- Land use
- Solid waste
- Operational and compliance budgets
- Climate
- GHG emissions

Process Description

Bokashi Fermentation

Plant waste can be treated onsite 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 air-tight when closed, adding additional material to achieve a 50 percent 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 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 offsite facility. Micro-organisms 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 like 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 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.

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. The most sustainable way to accomplish this is by grinding 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.

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.

Paper or cardboard that cannot be recycled due to contamination should be discarded with the 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 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 micro-organisms should be held in a manner that prevents the growth of these micro-organisms as required by MED Rule R504 Health and Safety Requirements.

Resources:

Certifiably Green Denver Composting Resource Sheet

Bokashi Fermentation Method and Resources

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.

Sustainability Aspects and Impacts

- Materials use
- Water quality
- Employee well-being
- Operational and compliance budgets

Process Description

Regulatory requirements for any given business depend on 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).

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' by-products 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 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.

Any generation of regulated hazardous wastes must be disclosed to CDPHE. Cultivators must obtain an EPA identification number before wastes 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?

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.
  - Purchase materials in smaller quantities and buy 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.
- 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.
  - Purchase lamps and ballasts with the longest burn time possible to reduce the frequency of replacement.
  - Consider LED lighting, which does not become hazardous waste at the end of its life.
  - Recycle universal waste lamps, ballasts and batteries with a qualified recycler.

Resources:

- CDPHE Generator Assistance Program
- EPA Resource Conservation and Recovery Act (RCRA)
- Colorado Hazardous Waste Generator Handbook
- CDPHE Solid Waste Regulations
- 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 non-recyclable product packaging reduces overall impact and can be attractive to customers.

Sustainability Aspects and Impacts

- Materials use
- Operational and compliance budgets
- Solid waste
- Community relations

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. Versions with child-proof caps are available, eliminating the need for an additional exit package.
- **Mylar Bags:** Used to package a variety of products, typically 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.
- **Pre-Roll Tubes:** Narrow plastic tubes, typically made from 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.

Best Practices

Cultivators should:

- Choose packaging that is lightweight, as lightweight materials require less fuel to ship, reducing the associated emissions.
- 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. 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.

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.

Resources:

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
Elevate Packaging	www.elevatepackaging.com	Yes	Yes	Yes
Sun Grown Packaging	www.sungrownpackaging.com	Yes	Yes	Yes
Sana Packaging	www.sanapackaging.com	Yes	Yes	No

- Marijuana Enforcement Division Permanent Retail Marijuana Rules
- Sustainable Packaging Coalition - Definition of Sustainable Packaging
- Framework for Sustainable Food Packaging Design

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 recyclable, compostable and innovative material options. One future opportunity would be to make cannabis packaging closed-loop, whereby cannabis plant waste is used as a feedstock for polylactic acid (PLA) plastic and turned into product packaging.

RECYCLING

Denver's recycling rate of 18 percent falls well below the 34 percent 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.

Figure 13: Diversion Totals for Denver 2016

IN 2016 DENVER
RECYCLED & COMPOSTED
ABOUT 45,000 TONS OF WASTE

LAST YEAR ALONE DENVER RECYCLED ENOUGH TO:

SAVE 548,000 TREES

SAVE 5.5 MILLION GALLONS OF OIL

KEEP 9,000 TRUCK LOADS OF TRASH OUT OF THE LANDFILL

SAVE 182 MILLION GALLONS OF WATER

Sustainability Aspects and Impacts

- Energy consumption
- GHG emissions
- Water consumption
- Solid Waste Generation
- Climate
- Ecosystems
- Water quality
- Community Relations
- Operational and compliance budgets

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 benefit.

Best Practices

Cultivators should:

- Make sure recyclables are clean, dry, and separated from solid waste items like 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.

Examples of Recycle, Compost, General Signage are available through local waste hauler websites.

Additional 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. Two-way communication between haulers and businesses is necessary to ensure that business managers stay up to date on the correct recycling processes.

[11] CoPIRG and EcoCycle

INTEGRATED PEST MANAGEMENT

INTRODUCTION

The goal of an Integrated Pest Management program is to apply a combination of control methods to prevent, reduce, or maintain pest populations at non-damaging levels by utilizing a variety of mechanical, physical, and biological controls. An effective IPM program, implemented and monitored by a facility's Director of Cultivation (or equivalent role), can eliminate potential levels of crop damage, mitigate risk, and control pests. Early identification of pest infestations is critical. All staff that work in the cultivation area should be trained in and responsible for plant inspection and pest identification.

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

OVERVIEW

An effective IPM program requires the use of Standard Operating Procedures (SOPs) for a number of processes, including daily/weekly inspection, identification, logging and immediate control of pests. All data shall be recorded in a pest and disease monitoring log to track pest presence or population. The ideal cannabis cultivation environment is one with tightly sealed and positively pressured sterile rooms under strict ventilation control and monitoring. This includes consideration for certain biosafety level inclusions to mitigate odor pests, and disease. Facility air handling intake points should be equipped with bird screen and 2-inch MERV 8 pre-filter and HEPA filters capable of capturing at least 99.95% of particulates. IPM programs are typically structured to follow the multi-variable approach outlined below:

1. Prevention, which includes general cleanliness; using new, sterile media with each batch; always using clean, sterile tools; cultivating disease-resistant plants; focusing on the health of plants (proper nutrient levels and avoiding stress); and impeccably controlling climate;
2. Biological controls (natural predators and parasites)
3. Removal of infected plants;
4. Organic controls;
5. **Synthetic controls should never be used, unless approved by the appropriate regulatory agency (in Colorado, the Colorado Department of Agriculture).**

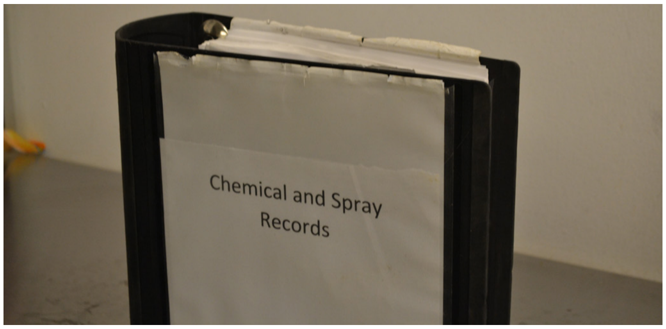
Pest control is approached as a progression of steps, with prevention as the first and most important step in controlling pests. The logical progression of methods in accomplishing IPM includes prevention, suppression, and eradication. Prevention methods utilized include:

- Cultural practices such as: spacing, pruning, and sanitation, as well as staff access prevention and mitigation
- Evaluating the cost of prevention in relation to yield and quality improvements (economic threshold)
- Observational practices ensuring cultivation areas are properly sealed;
- Maintaining a controlled environment and removing pest habitats
- Trap setting
- Pest scouting
- Requiring that room-specific uniforms be used by staff in each space
- Suppression methods that include cultural practices, such as pruning and immediate removal of diseased plants, biological controls, and low-dose natural oils
- Eradication methods that include increased natural oil dose and increased biological controls, if approved by the Department

BIOLOGICAL CONTROL AGENT (BCA) PLAN

In nearly all cases, production of cannabis crops relies on the use of biological control agents ("BCAs"), as the goal of zero pesticide residues is favorable for product quality and patient health. BCAs provide a desirable solution for insect and mite control due to their ability to effectively kill, and keep at bay, common insect and mite pests on cannabis crops. BCAs demand a proactive strategy in which action is taken prior to insect and mite pest presence or at the first sign of presence. BCAs work by preventing the buildup of these pest populations. Control of moderate insect and mite pest populations may be achieved with BCAs, but this reactive control will come with a higher price tag and greater effort. For greatest success, use of BCAs will be an active endeavor from the time of first planting.

Crops are scouted, and release rates are adjusted, based on detected insect and mite pests and the observance of any expanding populations. It is also important to maintain proper fertility and general health of the crop to avoid extra stressors that will make crops more susceptible to insect and mite pests. Successful use of BCAs requires dedicated scouting and strong recordkeeping for both pest and BCA populations throughout the crop. BCAs will effectively prevent the establishment of insect and mite pest populations when the BCAs are released early. Best control will be achieved by layering several BCAs to provide control against multiple life stages of the insect and mite pests or to simply augment the BCA activity. For indoor medicinal crops, the need to layer the BCAs for greatest impact is significant, as rescue treatment options are very limited or prohibited at certain crop stages. It is also important to recognize that releases must be planned and executed over the entire crop, not just early in the crop.



Considerations:

Before using any prevention, suppression, or eradication methods, facility staff must consider the:

- Status of infestation;
- Location, size and density of infestation;
- Potential to spread;
- Pest and crop life cycle stage;
- Regulatory considerations;
- Public perception;
- Environmental impacts;
- Previous results of measures; and
- Measurability.

IPM methodologies include quarantining all new cannabis plants or products entering the facility for 21 days, documenting any pest populations, outbreaks, treatment methods, and treatment results. Pest-monitoring traps shall be utilized and grow media will never be reused under any circumstances. As part of the IPM program, the cultivator will proactively manage any identified pest outbreaks prior to the issuance of a treatment order. Good facility maintenance practices include keeping facility areas clean, dry, orderly, and free of clutter or trash. The facility managers should ensure the proper repair and maintenance of cracks, window frames, door frames, drain areas, and floor joints with sealant to limit pest movement. Eradicating any weeds or pest habitats surrounding the facility and utilizing appropriate traps and baits on a regular basis are good practices.

CULTURAL CONTROLS

Because of the sensitive nature of the cannabis plants and the inability to utilize synthetic controls to control pests, maintaining a culture of cleanliness is essential. This includes:

- A requirement that all staff who work within a restricted access area enter through a locker area where they are required to remove all street clothes and shower prior to their shift;
- Require staff to wear a company-provided uniform, which includes shoes that must never be worn outside of the restricted access area;
- Place foot baths with a mild bleach solution outside of every door that enters into a room where cannabis plants are present. Require staff to place the soles of their shoes into these rubber mats prior to entering the room and upon exit;
- Place adhesive tacky mats outside of every door that enters into a room where cannabis is in process during harvest, drying and curing, extraction, processing, manufacturing, packaging and labeling and storage. Require staff to step both feet onto these mats prior to entering the room and upon exit.

Third-Party Pest Management

Many companies choose to contract with a local certified environmentally conscious pest management company to maintain regular inspections and rodent traps, and to preventatively spray (the exterior of the building) in compliance with all applicable regulations.

PESTICIDES

When all other aspects of IPM have not been enough to control pests and diseases, chemical controls may be necessary. The use of pesticides on cannabis is strictly regulated in Colorado by the Department of Agriculture (CDA). CDA maintains an updated list of approved pesticides and rules for use on their website.

In addition to consulting state and local pesticide rules, operators should first consider products listed by the Organic Materials Review Institute for prevention and control of pests and diseases. Along with OMRI-listed EPA-registered products, an operator may consider using a natural oil or combination of oils, usually found on a 25b (aka "minimum risk") labeled product.

EPA-registered pesticides have gone through extensive testing and are required to list all active ingredients on the label. It is preferred that if a registered pesticide is used that it is labeled in a way that:

1. All active ingredients of the pesticide product are exempt from the requirements of a tolerance, as established under 40 C.F.R. Part 180, Subparts D and E, and;
2. The pesticide product label allows use on the intended site of application. The term "site" for purposes of this Rule includes any location or crop to which the application is made, and;
3. The pesticide product label expressly allows use on crops or plants intended for human consumption, and;
4. The active ingredients of the pesticide product are allowed for use on tobacco by the Environmental Protection Agency.

(from 3-30-2016 Colorado Department of Agriculture Pesticide Applicators Act rule update - Use of Pesticides in Cannabis; attached)

When allowed by the local and state regulatory bodies, use of synthetic pesticides may be considered as a last resort. If the use of organic and natural pesticides hasn't been enough to control the pest or disease and the economic threshold for the destruction of the crop by the pest has been reached, the operator may decide to use a synthetic pesticide. However, EPA-registered synthetic pesticides are technically illegal to use on cannabis since there is no current EPA labeling with cannabis listed as a crop/site.

It's worth noting that any use of pesticides, organic or otherwise, while potentially aiding in the control of pests or diseases, can have longer lasting impacts to concentrates made from the treated plant material. All users should do thorough testing of treated product with their concentrate manufacturer to ensure usage doesn't affect concentrate color, consistency or flavor. This is true even if the product is used as specified on the label or even if label rates are decreased and PHI (post-harvest interval) exceed label recommendations.

WORKER PROTECTION STANDARDS

The EPA's Agricultural Worker Protection Standard (WPS) is aimed at reducing the risk of pesticide poisoning and injury among agricultural workers and pesticide handlers. It is a pesticide safety training program that is mandated for all agricultural workers who have the potential for pesticide exposure. Cannabis cultivators who use pesticides must maintain a WPS program and ensure all proper training as well as provide all necessary personal protective equipment. The Colorado Department of Public Health and Environment has developed a Guide to Worker Safety and Health in the Marijuana Industry which covers several pesticide-related topics and may be of use to operators.

HELPFUL LINKS

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

Organic Materials Review Institute Lists:
https://www.omri.org/omri-lists

EPA registered pesticide information:
https://www.epa.gov/pesticide-registration/registration-information-type-pesticide

EPA Minimum Risk Pesticide information:
https://www.epa.gov/minimum-risk-pesticides

National Pesticide Information Center, organic pesticide ingredients information:
http://npic.orst.edu/ingred/organic.html

EPA Worker Protection Standard information:
https://www.epa.gov/pesticide-worker-safety/agricultural-worker-protection-standard-wps

https://www.epa.gov/pesticide-worker-safety/pesticide-worker-protection-standard-how-comply-manual

Colorado marijuana occupational safety and health resources:
https://www.colorado.gov/pacific/cdphe/marijuana-occupational-safety-and-health

Sustainability Aspects and Impacts

- Effluent discharge
- Regulatory compliance
- Indoor air quality
- Employee well-being
- Regional stakeholder alignment
- Ecosystems
- Water quality
- Community Relations
- Operational and compliance budgets

AIR QUALITY

INTRODUCTION

The cannabis industry directly impacts air quality in two predominant operations; plant growth cultivation and Marijuana Infused Product (MIP) facilities. At cultivation facilities, the natural growth of cannabis plants and other processes emit terpenes which are VOCs known for their strong odors. At MIP facilities, the evaporation of solvents and other processes in the production cycle result in Volatile Organic Compound (VOC) emissions. VOC's 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 VOCs 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.

CULTIVATION FACILITIES

As cannabis plants grow, they release a distinctive range of odors which are made up of different types of VOCs called terpenes. Activities during the cultivation or production cycle that release significant odors also release elevated VOCs during that time. 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. Highly reactive, ozone forming terpenes commonly emitted from cannabis cultivation include: isoprene, pinene, carene, limonene, myrcene, and terpinolene.

REGULATORY DRIVERS

The State of Colorado designates cultivation facilities as an agricultural activity. State regulation, 25- 7- 109(8)(a), C.R.S. provides the Colorado Air Quality Control Commission the authority to regulate certain agricultural production. Cannabis cultivation may be exempt from both state Air Pollution Emission Notice (APEN) and Permitting requirements, unless they are considered a "major source" of air emissions.

In the City and County of 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.

Sustainability Aspects and Impacts

- Odor control
- Regulatory compliance
- Indoor air quality
- Community relations
- Employee well-being
- Regional stakeholder alignment
- Operational and compliance budgets

CARBON FILTRATION – BEST OPTION FOR CONTROLLING ODORS AND VOCS

Carbon filtration is currently the best control technology for reducing VOC emissions from cannabis cultivation facilities. Carbon filters are simple to install, inexpensive, effective, and reliable when properly maintained and replaced. These filters work by using an absorption process where porous carbon surfaces chemically attract and trap VOCs along with other gas phase contaminants. Depending on the filter system, carbon filtration can remove 50% - 98% of VOCs. As the filter ages, less carbon surface area is available to trap VOCs; 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.

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 must be properly sized according to the space needed for volume and air-flow requirements. Maintaining an optimal environment can require multiple filters. 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 can remove 50 - 98% of VOC emissions. This improves public health 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 with cannabis industry experience.
- Get information from the manufacturer about the effectiveness of the filter at removing VOCs 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.
- 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.
- 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.

ADDITIONAL ODOR CONTROL METHODS -
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 which 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 oils and liquids from plant compounds and mist them into the exhaust air at cultivation facilities to neutralize odorous VOCs. Contact your odor control supplier about the effectiveness of VOC reduction as it will 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 system and ducting to ensure it is operating optimally and that the airflow is properly controlled. Keep windows and doors closed in cultivation areas, 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 (i.e. evenings, windy days, and cloudy days). Avoid purging air during times that have the highest risk of ozone formation (i.e. mornings, sunny and hot days, and stagnant weather).
- 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 that facility is producing; this is especially true during the flowering phase of cultivation. Proper air circulation is critical for maintaining temperature and humidity control.
- Have a documented system in place for recording and responding to odor complaints in compliance with Denver's Odor Ordinance.
- 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 PROCESS

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: www.colorado.gov/cdphe/greencannabis. The Colorado Small Business Assistance Program can also help you calculate your annual air emissions for free by calling 303-692-3175.

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

Sustainability Aspects and Impacts

- Effluent discharge
- Regulatory compliance
- Indoor air quality
- Energy consumption
- GHG emissions
- Water quality
- Community relations
- Employee well-being
- Operational and compliance budgets
- Climate

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 which improve their air quality impacts, bolster their reputations as stewards of the environment, and control their odor as well as air quality emissions.

CARBON FOOTPRINTING

INTRODUCTION

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 makes companies more competitive for a wide variety of reasons, including significant financial savings, brand reputation, and increased employee and customer satisfaction. A recent report from Goldman Sachs[1] 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.[2]

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 how you can create reductions, but it also contributes to the local community and reduces the environmental impact of the industry.

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 footprinting 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 that is also a strategic planning document will lead to a better incorporation of carbon reduction strategies and provide 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 greenhouse gases emitted during the production process and operations of a cannabis company. These GHGs can include Methane, Nitrous Oxide, Butane, Propane, and many other gases, but will usually be expressed as Carbon Dioxide Equivalent or CO_2e. For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2 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 CO_2e 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.

[1] "GS Sustain". Goldman Sachs 2007 http://www.natcapsolutions.org/Presidio/Articles/Climate/GoldmanSachsReport_v2007.pdf

[2] 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

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 supplementation 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 which both 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 as far 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 the materials between phases.

According to an analysis conducted by Evan Mills in 2012, for each kilogram of cannabis produced, roughly 4,600 kg of CO2 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.

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 goes 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 make 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 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

Calculating a carbon footprint can be a complex process that requires time and analytical proficiency. 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 chart outlines some of the unique carbon emission sources in different types of facilities:

DISPENSARIES	MIPs	GROWS
Customer Transit	Butane/Propane/ CO_2 Usage & Ventilation	CO_2 Supplementation
Packaging	Delivery & Courier Services	Delivery & Courier Services
Vendors & Products	Manufacturing Waste	Soil & Fertilizers
Retail Waste	Manufacturing Equipment	Water

Tracking metrics over time

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, ROI, repeat customer generation, etc.) and look for general trends and correlations.

Reduction Strategies

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 return on investment and contribute 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. This 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 thanks to efficiency upgrades. Examples of efficiency and zero carbon upgrades are discussed more in-depth in other sections of this guide, and include:

- High-efficiency lighting and HVAC systems
- Increased insulation in facilities
- Heat recapture systems on operational machinery
- On-site renewable energy
- Electric or natural gas fleet vehicles
- Composting and/or recycling
- Sourcing carbon neutral ingredients
- Carbon neutral, recyclable, or compostable packaging
- Solventless extraction methods

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 (i.e. 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 towards 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.

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. Alternatively, renewable energy credits can be purchased from organizations like carbonfund.org or carbon credits from the Colorado Carbon Fund, which funds Colorado-based carbon projects. Though these options are helpful in the short term, they have fewer long-term benefits than carbon reduction strategies and projects.

Examples of calculations for the various scopes:

1. Scope 1 Example: Company A uses 140 gallons of gas per year on company-owned vehicles used at the site of operations.
    a. The EPA conversion rate for gallons of gas to grams of carbon:
        i. 8,887 grams of CO_2/gallon of gasoline.
    b. Use this conversion rate and multiply by gallons of gasoline used that year:
        i. 140 gal X 8,887g CO_2 = 1,244,180 grams of carbon.
        ii. This number can also be represented as 1,244.18 kilograms of CO_2 or 1.24 metric tons of CO_2. It is up to the analyzer to determine the best metric to use. The metric system is the globally recognized standard for reporting, as opposed to pounds and tons.
2. Scope 2 Example: Company A uses 2,000 kWh monthly of electricity in their grow operation.
    a. The EPA conversion rate for kWh to CO_2 is 740 grams per kWh.
    b. Take the conversion rate and multiply it by the number of kWhs emitted annually.
        i. 2000 kWh X 12 months X 744g CO_2 = 17,856,000 grams of carbon.
        ii. Again, this number can be represented as 17,856 kilograms of CO_2 or 17.86 metric tons of CO_2.
        iii. NOTE: these numbers are derived from EPA standards that do not take into account regional variations. It is very important to source regionally based emission factors annually as well as CO_2 equivalences to get the most accurate reading for all emissions associated with an organization's operations. For Denver all electricity emissions are available on an annual basis from Xcel's community energy reports. This emission factor changes every year as the generation of electricity comes from more renewable sources.
3. Scope 3 Example: Staff from company A drive a total of 200 miles commuting to and from work.
    a. The EPA conversion rate for miles to CO_2e is 408 grams of CO_2e per mile.
        i. 200 miles X 408g CO_2e = 81,600 grams of CO_2e or 81.6 kilograms of CO_2e.

Cannabis is unique for calculating carbon footprints in that it uses CO_2 to grow; therefore, a negative value can be applied to the overall carbon footprint of the operation. Unfortunately, at this time no concrete numbers exist for the carbon sequestration capacity of cannabis, so for now we can extrapolate the sequestration performance of hemp. Hemp sequesters 22 tons of CO_2 per hectare.[1] This number can be used to determine the carbon sink of a grow operation.

[1] *The Role of Industrial Hemp in Carbon Farming,* James Vosper BSCHons, FRGS

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.[1] 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 more energy efficient and have been shown to reduce production costs by 30 percent compared to indoor grow facilities. 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 towards 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 to 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 free-standing or gutter-connected. Free-standing 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 are 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 on the plants, creating an ideal environment for disease.

Considerations

FREE-STANDING GREENHOUSES	GUTTER-CONNECTED GREENHOUSES
Easier to provide separate grow environments as each house is controlled by its own heating/cooling system.	Reduced heating costs (up to 25%) as surface area to floor area ratio is lower.
Individual houses are easier to build and maintain.	Less land is needed. About 30% more growing space can be placed on the same amount of land area.
Ideal for non-level sites.	Heating and cooling can be centralized.
	More cost effective for areas greater than 10,000 sq. ft.

[1] *State of the Industry Report. 2018. Cannabis Business Times.*

Greenhouse Decision-Making

When deciding to grow in a greenhouse there are a multitude of factors to consider. 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 non-rural 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 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 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 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, heats up the thermal mass, and then the glazed panels 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 of fans for ventilation. 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 efficiency 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.
- Weather strip doors, vents, fan openings.
- Lubricate 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 AMCA standards and have a Ventilation Efficiency Ratio greater than 15.
- Use the largest diameter fans with the smallest motor that meets ventilation requirements.

SAMPLE ENERGY AUDIT FORM

Name:	

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

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

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

Growing System

Grow Medium Description:

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

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

SAMPLE WATER QUALITY REPORT

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

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

SOURCE: Arapahoe City **LAB #** W519 I

"Metals" and "Individual Element" Analysis

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

* Not requested

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

Billing:

SOURCE: Arapahoe City

IRRIGATION WATER ANALYSIS

"Routine Package"

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

SAR 0.8 Salinity Hazard Low Sodium Hazard Low

COMMENTS: This is good quality water for irrigation.

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.
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.
CO_2	Carbon Dioxide: CO_2 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 DDPHE 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.
DDPHE	Denver Department of Public Health & Environment: The DDPHE works with city, state and community partners to conduct education, community engagement, and enforcement to ensure healthy people, healthy pets and a sustainable environment.
Denver's Climate Action Plan 2015	Denver's Climate Action Plan 2015 is a document developed that sets forth Denver's goals, priorities, and strategies to meet the 2020 Sustainability Goals and to reduce greenhouse gas emissions 80 percent from its 2005 baseline by 2050.
EAS	Engineering Assistance Study: An EAS is conducted to identify and evaluate energy savings opportunities.

EC	Electrical Conductivity: EC is the potential for material to conduct electricity (i.e. the potential for an electrical current to move through water.)
ECA	Electrochemically Activated Water: ECA is water mixed with food-grade salt fed through a reactor that electrically charges the salt water to produce disinfect or detergent solutions.
EER	Energy Efficiency Ratio: The EER is the ratio of cooling capacity to power input.
EMS	Energy Management System: A system that monitors the environment of a facility and which may be used to alert to alert facility managers about broken or malfunctioning equipment.
Energize Denver	A benchmark ordinance requiring owners/operators of large commercial and multifamily buildings to annually assess and report the buildings' energy performance using the free ENERGYSTAR Portfolio Manager tool.
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
HCO_{3-}	Bicarbonate anion
HPS	High Pressure Sodium
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
$mol/m^2/day$	mole per square meter per day
$mol/m^2/S$	mole per square meter per Siemens
mol/µmol	mole per micromole
µmol/mol	micromole per mole
µmol/SF	micromole per square foot
$\mu mol/m^{-2} s^{-1}$	micromole per square meter and second (PPFD unit)
MSW	Municipal Solid Waste: MSW is non-hazardous waste, such as household trash.
Na^+	Sodium cation
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.

DENVER
PUBLIC HEALTH & ENVIRONMENT
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