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V. Appendix A – Resource Documents
   This appendix provides supplementary documents that are referenced or expand upon information provided in the document.

VI. Appendix B – Terms and Definitions (forthcoming)
   This appendix provides a list of terms and definitions used in the document.
The *Cannabis Environmental Best Management Practices Guide* (Guide) is the product of the Denver Environmental Health (DEH) Cannabis Sustainability Work Group (CSWG), an interdisciplinary collaborative sustainability work group convened in 2016 for the purpose of providing sector-specific sustainability resources and guidance to the local cannabis industry. The CSWG includes experts from cannabis business, sustainability science and engineering firms, legal experts and local government.

The Guide would not have been possible without the insight and efforts of CSWG members and peer reviewers. Particular thanks go to the development and review team:

Emily Backus, Denver Environmental Health

Duncan Campbell, Scale Microgrids

Alice Conowitz, Integral Consulting

Lindsey Coulter, Denver Environmental Health

Laura Davis, Good Chemistry

Catherine Drumheller, Oak Services

Nick Hice, Denver Relief Consulting

Kerra Jones, Denver Environmental Health

Brandy Keen, Surna

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CANNABIS SUSTAINABILITY SECTOR OVERVIEW

Under the leadership of Mayor Michael B. Hancock, Denver has committed to reduce greenhouse gas emissions 80 percent by 2050. 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 emissions targets.

National and international attention is increasingly being focused on the sustainability impacts of the cannabis industry in states where it 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.

Denver and Colorado businesses and local and state governments are collaborating with regional stakeholders, including municipal utilities, to create the Cannabis Sustainability Workgroup. The Workgroup will work to provide transparency and an objective basis for sustainability performance evaluation by collecting and analyzing aggregate sustainability performance data, including grid-based energy and water usage metrics. As additional data and case studies are completed and published, analytics will improve and provide the basis for standard sustainability performance metrics and evaluation.

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.

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. In addition, there are 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.
SEGMENT PROFILE – ENERGY EFFICIENCY & MANAGEMENT

OVERVIEW

Indoor cannabis cultivation is a resource-intensive process, with energy demands the highest contributor to the industry’s large 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 intimately familiar with the energy impacts of their grow spaces. Decisions relating to cultivation facility design should be driven by location specific metrics and cultivation processes. A common public perception of the cannabis industry as an energy-hog contributes to negative attention, and cultivation facilities (like all buildings) contribute to the greater community-wide impacts of energy use including air quality and greenhouse gas emissions. Active energy efficiency efforts can help cannabis businesses create positive improvements within their communities.

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:

<table>
<thead>
<tr>
<th>Function</th>
<th>Percentage of Total Facility Electricity Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC &amp; Dehumidification</td>
<td>51%</td>
</tr>
<tr>
<td>Lighting</td>
<td>38%</td>
</tr>
<tr>
<td>Space Heating (assuming electric heat)</td>
<td>5%</td>
</tr>
<tr>
<td>Water Handling</td>
<td>3%</td>
</tr>
<tr>
<td>CO2 Injection</td>
<td>2%</td>
</tr>
<tr>
<td>Drying/Curing</td>
<td>1%</td>
</tr>
</tbody>
</table>

1 [https://www.nw council.org/media/7130334/p7.pdf](https://www.nw council.org/media/7130334/p7.pdf)
There are three primary reasons that 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 their 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 can 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 – Producing electricity 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 electric demand grew at a rate of about 1.2 percent annually between 2012 and 2014, with 45 percent of that growth attributed to cannabis cultivation facilities.³

While there is no singular solution for cultivators that are looking to reduce facilities’ energy profile, the listed best practices are intended to provide a framework by which organizations can begin to develop a comprehensive energy management plan.

REGULATORY DRIVERS

Colorado state and local regulations in the Denver metro area significantly impact the methods of cannabis cultivation employed by growers, and the eventual per-gram energy use of cannabis grown. Denver’s zoning and other land use regulations require cannabis cultivation facilities to operate in industrially 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 property 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 operators are not idly sitting on their limited license. But these regulations can be problematic for businesses that want to construct high-tech greenhouses customized for cannabis cultivation. Instead, companies 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 and County of Denver has ambitious, community-wide energy and greenhouse gas emission targets. 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 for reaching targets. Denver’s goals include:

- Ensure 2020 greenhouse gas emissions are below 1990 levels
- Reduce emissions by 80 percent below 2005 levels by 2050

Denver City Council passed a new benchmarking ordinance, known as Energize Denver, in December 2016. 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

² http://www.utilitydive.com/news/marijuana-grow-houses-trigger-7-summer-outages-for-pacific-power/408741/
50,000 square feet are required to report, and buildings larger than 25,000 square feet will be required to report beginning in 2018. The data will be made publicly available on an online map published by Denver Environmental Health. The cannabis industry is expected to utilize two exemptions to the reporting requirements:

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

However, benchmarking laws are becoming more common throughout the US, and such exemptions may not apply in other localities. Voluntary participation in benchmarking programs such as Energize Denver can be a helpful tool for cannabis business owners to understand and compare their energy use as well as build positive relationships with local energy officials. See 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 their 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 who are looking to develop an effective M&V process.

Sustainability Aspects and Impacts
- Energy consumption
- Greenhouse Gas 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 their energy usage data both to make more strategic equipment and process decisions as well as contribute to an understanding of the current state of the industry.

Recommended metrics to track include:
- Grams/watt (lights 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/SF of cultivation space (efficiency) - measures space utilization efficiency per cycle and/or per strain
- Micromole/SF - lighting intensity measurement to identify when bulbs or fixtures must be replaced. Also can compare multiple lighting types
- Return on investment (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 cost and benefits over the cost 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>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Units</th>
<th>Notes</th>
<th>Average Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting Yield per</td>
<td>Used to compare lighting technologies and strains</td>
<td>grams / watt</td>
<td>Measure grams of flower and trim in dry weight&lt;br&gt;Use lighting wattages including ballasts&lt;br&gt;Measure over one grow cycle and annually</td>
<td>1.6g/W&lt;br&gt;Less than 1g/W - 8%&lt;br&gt;1g-1.49g/W - 16%&lt;br&gt;1.5g-1.99g/W - 8%&lt;br&gt;2g-2.49g/W - 10%&lt;br&gt;2.5+g/W - 3%&lt;br&gt;Unknown to Operation 51%</td>
</tr>
<tr>
<td>Watt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metric</td>
<td>Description</td>
<td>Units</td>
<td>Notes</td>
<td>Average Range</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Total Energy Efficiency</td>
<td>Identifies total production efficiency, helps identify trends in building</td>
<td>grams / kWhs</td>
<td>Measure monthly and annually Use total kWhs for building</td>
<td>Total dried product weight ÷ kWh/cycle = Yield per kWh</td>
</tr>
<tr>
<td>Space Utilization</td>
<td>Demonstrates if the cultivation space being maximized for production</td>
<td>grams / sqft</td>
<td>Use square footage of cultivation space only</td>
<td>39.5g/sq. ft.</td>
</tr>
<tr>
<td>Lighting Intensity</td>
<td>Measures whether the lights providing the desired PPFD Can help identify correct time to replace lights</td>
<td>micromoles / sqft</td>
<td>Measure at canopy Measure for each type of lighting, for each stage of growth</td>
<td>Currently unknown</td>
</tr>
<tr>
<td>Daily Light Interval</td>
<td>Measures the daily accumulation of PAR spectrum light reaching the plants</td>
<td>mol/m2/day</td>
<td>Formula: $\mu$Mol/M2S x 3600 s/hr x photoperiod(hrs/day) ÷ 1,000,000 $\mu$Mole/Mole = $\mu$Mol/M2/Day</td>
<td>Denver Outdoor Avg.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Winter 15-30 mol/m²/d⁻¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer 25-45 mol/m²/d⁻¹</td>
</tr>
<tr>
<td>Load Factor</td>
<td>Used to manage peak power demand, higher Load Factor reduces cost of energy</td>
<td>kWhs / (peak kW<em>days</em>24 hours per day)</td>
<td>Use monthly electricity figures, Days equals days in billing period</td>
<td>&lt; 0.50 = poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.50 - 0.65 = fair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt; 0.65 = good</td>
</tr>
</tbody>
</table>

**Obtaining Building Data from Xcel Energy**

Energy usage data can include 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, so 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, natural gas supplier account or from past bills. Xcel Energy’s My Account is a helpful online portal for monthly use figures and annual totals.

Xcel Energy has developed a data access portal which will allow tenants and building owners to automatically receive aggregate energy consumption data imported directly in their ENERGYSTAR Portfolio Manager account. ENERGYSTAR Portfolio Manager accounts must be set up prior to beginning the application.


**Portfolio Manager**

As mentioned above in the regulatory drivers section, 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, 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 minute or two each month.

Utility Interval Data
- Facilities with smart meters can request 15-minute interval data from their energy provider.
- Customers can also opt to pay for Xcel’s InfoWise service, which provides interval data and uses it 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 isn’t already in place.
- Cultivators can also install equipment to log energy data. This could be done concurrently with a BMS/EMS installation, or can be done solely for logging energy data. This 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 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. 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 to reveal and evaluate energy savings opportunities. As mentioned below, Xcel Energy offers related grants/incentives.

As the cultivation industry matures, the available 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.

Management Systems and Energy Audits
Building Management Systems / Energy Management Systems
Facility Managers looking for a comprehensive data solution should consider installing a Building Management System (BMS) or Energy Management System (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 the 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 —examples are e-mon and Power TakeOff.

Resources and Related References
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 or 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
- Greenhouse Gas 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, 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 in 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
- Greenhouse Gas 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 the lamp type, lighting system design is also critical to maximizing energy efficiency in the cultivation facilities, and time of use also plays a crucial role. Due to the operational impact of lighting choices for cultivators, a host of production related factors must also be considered in selecting 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 400nm and 700nm, the majority of the light spectrum used for photosynthesis. Note that 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
Operators have several choices when it comes to lighting technology. Historically, the top three lighting technologies used have been T5 fluorescent, metal halide (MH) and high-pressure sodium (HPS). Now there are 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 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.45

<table>
<thead>
<tr>
<th>Light Technology</th>
<th>General Use / Growth Stage</th>
<th>Spectrum</th>
<th>Rated Life - Hours</th>
<th>Intensity* - PPFD - µmole/s*m²</th>
<th>Efficacy - µmoles/J</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5 Fluorescent</td>
<td>Plant propagation - mothers and clones</td>
<td>Full spectrum with ability to fine tune colors</td>
<td>20,000</td>
<td>150 - 300</td>
<td>TBD</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>Vegetative growth</td>
<td>Full spectrum with blue and green peaks</td>
<td>6,000 - 15,000</td>
<td>500 - 800</td>
<td>TBD</td>
</tr>
<tr>
<td>Ceramic Metal Halide</td>
<td>Both stages of growth</td>
<td>Full spectrum, UV</td>
<td>20,000</td>
<td>800</td>
<td>1.46</td>
</tr>
<tr>
<td>High Pressure Sodium (single-ended)</td>
<td>Flower growth stage or both stages</td>
<td>Full spectrum with yellow and red peaks</td>
<td>5,000 - 20,000</td>
<td>700 - 900</td>
<td>1.16</td>
</tr>
<tr>
<td>High Pressure Sodium (double-ended)</td>
<td>Flower growth stage or both stages</td>
<td>Full spectrum with yellow and red peaks</td>
<td>5,000 - 20,000</td>
<td>700 - 900</td>
<td>1.70</td>
</tr>
<tr>
<td>Light Emitting Diode</td>
<td>All stages of growth</td>
<td>Full spectrum with ability to fine tune colors, UV</td>
<td>50,000</td>
<td>800 - 1200</td>
<td>1.70</td>
</tr>
<tr>
<td>Light Emitting Plasma</td>
<td>Vegetative growth or both stages</td>
<td>Full spectrum, UV</td>
<td>30,000</td>
<td>700 - 900</td>
<td>1.00</td>
</tr>
</tbody>
</table>

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

**Definitions**

**Photosynthetically Active Radiation (PAR):** The measure of light available for photosynthesis or light in the 400- to 700-nanometer (nm) wavelength range.

**Photosynthetic Photon Flux (PPF):** Total emitted number of photons per second in the PAR region. Units of measure: µMol/S.

**Photosynthetic Photon Flux Density (PPFD):** The number of photons in the PAR region emitted per M² per second. Units of measure: µMol/M²S

**Daily Light Interval:** The daily accumulation of light reaching the plants. Units: Moles per day.

**Formula:** µMol/M²S x 3600 s/hr x photoperiod(hrs/day) ÷ 1,000,000 µMole/Mole = Mol/M²Day

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Best Practices

System Design

When designing for indoor cultivation, it is important to know 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 it 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 operator 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 operator 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.

Increase Production to Maximize Efficiency

Racks

Many operators 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 a light are how many micromoles are hitting the canopy and the temperature of the canopy. Making sure the plants are consistently getting the right micromole level and temperature 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 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 1/8th inch. This heavy pruning will create

Greenhouses

Greenhouses will continue to take over a large portion of this 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, 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 come down in most geographies compared with an indoor operation, 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, operators 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.
larger top colas with enhanced terpene profile and higher potency.

*Trellising*

Trellis nets should be used in most grow systems to help maximize plant density. 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. Be sure to use non-combustible cables or chains.

*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 the reflector and decrease its efficiency. Use caution in cleaning as any wiping of the reflector will damage the finish. Dip the reflector in a 2 percent vinegar solution and let it air dry. Never wipe down the reflector. This should be done once every six months or more often if heavy accumulation of dust is noticed. Most manufacturers recommend replacing reflectors every 12 months along with the bulb. Tracking micromole levels at the canopy level will insure the proper amount of photons is hitting plants. Tracking light levels and only replacing reflectors when they are underperforming is a more sustainable approach.

Bulbs: Make sure lights are unplugged and have had at least 20 minutes to cool before cleaning or replacing. Use glass wipes to wipe down the bulb and lens if applicable. Wipe down lights once every two months or in between harvests. Do 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 hours remaining on their rated life 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 the electronic ballast. Magnetic ballasts are heavier, less efficient, create more heat and are much noisier than electronic ballasts. However, they may come with a longer warranty than electronic ballasts and they are less expensive. Magnetic ballasts are also easier to repair than electronic ballasts.

Electronic: Electronic ballasts have sensitive circuitry that is more difficult to repair. 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: Thoroughly check electrical cords for any damage, cuts or abrasions that could affect performance. Also, inspect cords 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 can last 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; however, most advanced LED manufacturers build lights without fans. These fans have moving parts that can fail and may need to be replaced. Operators 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 and Related References**

- Gavita Lighting - Lumens are for Humans
- Greenhouse Product News - Greenhouse Lighting Options
- ACF Greenhouses - Indoor Plant Grow Light Guide
- Plantozoid - T5 Grow Lights Guide
- Wikipedia - Metal Halide Lamp Spectrum
- Nelson and Bugbee - Economic Analysis of Greenhouse Lighting: Light
HVAC AND DEHUMIDIFICATION

Climate control systems can account for 50 percent or more of the total energy consumption in an indoor cultivation facility. 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. Further, proper climate design is critical to operational efficiency and biosecurity. In most cases, proper 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
- Greenhouse Gas 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 State of Colorado. 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’s important to note that typical HVAC systems are designed for comfort cooling and occupancy ventilation, and 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 should be considered when budget allows.

The act of cooling is not the addition of cold air, it is the removal of heat. The act of cooling is simply the exchange of heat, or absorbing BTUs from one location and putting them somewhere else. The more energy efficient the heat exchange, the more energy efficient the cooling system. BTU, or British Thermal Unit, is a measurement of heat. One BTU is the amount of thermal energy required to change the temperature of one pound of water one degree in one hour.

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, comparing the EER rating on a 100-ton chiller and the EER rating on a 3-ton mini-split air conditioner, it might appear that using 33 mini splits is more energy

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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 thirty-three 3-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.

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. These units are a viable option for very small-scale facilities (less than 1,000 square feet) 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, although 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 grower 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 ducted to the evaporator in the unit, 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. It 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, therefore 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-range 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 operators 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**

Generally speaking, water-cooled HVAC equipment (i.e., chillers, packaged unitary units, ground-source heat pumps) create a more energy-efficient heat removal 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. 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” is a term used to describe heating the space to allow the cooling system to run 24 hours a day to produce dehumidification without reducing temperatures in the space. Reheat allows for more energy-efficient dehumidification
via larger compressors; however, 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 in the space 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 fan coil units 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 a 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 very 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 size economizers are an energy-efficient solution, they create more problems in cultivation environments than they solve with regard to CO2 enrichment, biosecurity and odor control, and are generally not recommended (See “ventilation and CO2” 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 winter time energy consumption dramatically by bypassing the compressors entirely when temperatures drop below 40 degrees F, utilizing cold outdoor temperatures to chill the water in the system. 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. 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 reaches 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 CO₂

In many CO₂-enriched environments, ventilation or air side economization may waste significant amounts of CO₂ (which can work at cross purposes to the energy code and efficiency efforts overall). Operators should carefully weigh efficiency gains associated with ventilation against CO₂ waste to determine accurate costs and greenhouse gas emissions associated with both. Limiting ventilation can also be helpful to biosecurity efforts and minimizing exposure to contaminants, possibly reducing reliance on pesticides or fungicides.

Although common, CO₂ generators should not be used in modern indoor grow facilities. Generators contribute high levels of waste heat while operating and many are not vented properly, leading to dangerous indoor environments. Bottled CO₂ is a better substitute practice.

Design Standards

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) publishes commonly accepted HVAC standards for architects and engineers. As a starting point, facility owners may benefit from familiarizing themselves with ASHRAE 90.1, Energy Standard for Buildings, which is available for purchase through TechStreet. ASHRAE has also published an Advanced Energy Design Guide Series focused on reducing energy building use, which is available as a free PDF download here.

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 US Environmental Protection Agency 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, consider pints per kWh when evaluating for efficiency. 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.
● Seal spaces to reduce CO₂ exhaust, improve biosecurity and reduce odors emanating from the facility.
● Keep rooms warmer at night to manage latent load.
● Provide shade for rooftop units to reduce operating temperature and extend life.

Resources and Related References

ASHRAE

Air Conditioning, Refrigeration and Heating Institute

See sample Preventative Maintenance schedule in appendix.
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>
<thead>
<tr>
<th>Xcel Energy — Power Supply Mix for Colorado Customers 7</th>
<th>Total Generation Mix (%)</th>
<th>Median Lifecycle CO2 Emissions (grams/kwh) 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>52.7%</td>
<td>1001</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>25.3%</td>
<td>469</td>
</tr>
<tr>
<td>Wind</td>
<td>18.9%</td>
<td>12</td>
</tr>
<tr>
<td>Solar</td>
<td>1.2%</td>
<td>46</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>1.7%</td>
<td>4</td>
</tr>
<tr>
<td>Other*</td>
<td>0.2%</td>
<td>-</td>
</tr>
</tbody>
</table>

*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. 9 Note that onsite renewables such as PV may only offset 10 percent to 15 percent of the 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 that facility managers can consider 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 facility.

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.

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.

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9 [https://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3](https://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3)
Boulder County requires commercial marijuana growers to either offset their 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 marijuana cultivation practices with regards to energy use as well as 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 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 ensure they consult with an experienced technical specialist as part of their assessment process.

**Sustainability Aspects and Impacts**

- Greenhouse Gas Emissions
- Land use
- Climate
- Regional stakeholder alignment
- Operational and compliance budgets

**Process Description**

Performing a desktop feasibility study (aka 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 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, available [here](#). 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 deducting operating expenses versus capital expenses (depreciation).
### Best Practices

<table>
<thead>
<tr>
<th></th>
<th>Solar PV</th>
<th>Cogeneration (CHP)</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solar Photovoltaic Systems (Solar PV), convert sunlight into usable electricity. The two main components of a solar system are the panels and inverter(s). The solar panels use sunlight to generate electricity, and the inverter(s) converts 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, although 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 their utilities prior to beginning project design.</td>
<td>CHP systems work by utilizing a natural gas generator (engine, turbine, or fuel cell) to produce electricity and then repurpose the waste products to offset the facility’s HVAC and CO2 needs. When done properly, this process can reduce a cultivation facility’s emissions footprint by 25 percent to 45 percent, generate attractive economic returns for the organization and serve as reliable source of power during grid outages. While CHP systems offer an exciting value proposition to cultivators, 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 the support of a qualified third party to guide the process.</td>
<td>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 greatly 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; permitting and conformance with local zoning and building codes may prove challenging.</td>
</tr>
</tbody>
</table>

![Figure 2: Comparison of energy inputs and associated outputs of standard or grid energy use versus a Combined Heat and Power (CHP) system.](image)
Resources and Related References

National Renewable Energy Laboratory – Solar Energy Basics
Environmental Protection Agency - CHP Benefits
National Renewable Energy Laboratory – Commercial & Industrial Solar Best Practices
Environmental Protection Agency – CHP Best Practices
Xcel Energy - Distributed Generation Guidelines
Xcel Energy - Solar Information
Boulder County - Marijuana Energy Impact Offset Fund
**Off-Site Energy Supply**

An alternative option for cultivators looking to reduce the environmental footprint associated with the facility’s electricity production is to explore off-site energy supply opportunities. For Denver facilities served by Xcel Energy, there is one primary program that cultivators should investigate: [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; therefore, 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**

- Greenhouse Gas 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 of that array to Xcel. Xcel then credits the customer for that portion of that electricity on their 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 and Related References**

[Xcel Energy – Community Solar Program](#)

[Colorado Energy Office Community Solar Information](#)
SEGMENT PROFILE – WATER USAGE AND WATER QUALITY

OVERVIEW

Indoor cannabis cultivation within the City of 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.

![Flow diagram of water usage and quality](image)

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 or production unit theoretical minimum is currently available. However, the implementation of proactive operational efficiency and monitoring practices can readily address the potential water use and quality environmental impacts, while setting the stage for leadership in process integration of progressive technologies for use and cost optimization.

The sustainability impacts of water use and quality include:

1) Economic Competitiveness – The introduction of water use efficiency measures can lower operational costs by reducing direct resource purchase (i.e., lower volume = 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.

2) 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.

3) 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 Greenhouse Gas Emissions. [1] In addition, regional water resource concerns — such as the loss of agriculture in rural areas and the 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 recommendation for water filtration and purification, irrigation methods and automation, waste recycling and improving wastewater quality for an indoor cultivation facility.

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**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 wastewater 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.

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 use as wash water for outdoor irrigation on non-consumable plants. Review the [City of Denver Graywater Regulations](https://www.denvergov.org/content/denvergov/en/public-works/water-graywater/graywater-regulations.html) 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 AND 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 istap 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 the incoming water including carbon filtering, reverse osmosis and UV sterilization.

**Sustainability Aspects and Impacts**
- Water Conservation
- Water Quality

**Process Description**

According to the [Colorado State University Cooperative Extension](https://www.csuextension.colostate.edu), 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). (An ion is an electrically charged atom or groups of atoms. Cations carry a positive charge, and anions have a negative charge.)
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 produced during the filtering process. 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 and Related References**

- [Denver Water Quality Reports](https://www.denverwater.org/water-quality)
- [Colorado State University - Soil and Water Testing Laboratory](https://extension.colostate.edu)
IRRIGATION METHODS AND 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.

Sustainability Aspects and Impacts
- Water Conservation
- 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, the remaining water on the tray not absorbed by the plants is run off the back of the tray 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, Phytophthora, Fusarium), which can be done chemically or with 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 the operator 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 operators 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. Large-scale aeroponic systems operators 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 up nutrient solution 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. Most commonly used on smaller plants with a short crop cycle. The plants are
very sensitive to interruptions in the water cycle and electricity. 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. The aggressive aeration in the reservoir 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. Also, the total volume of water being applied to each plant can vary greatly, especially with if staff are inattentive.

Nevertheless, most cultivation operations use the hand watering method at some stage of plant growth. Operators must have good standard operating procedures and employee training for 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. Operators should consult with an irrigation specialist to help determine the correct emitter for their facilities, based on water pressure, length of irrigation runs, container sizes, number of plants to be irrigated at once, etc. Drip irrigation allows the operator 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 operators of drip irrigation systems water several times per day (pulse irrigation), delivering the total desired volume of water over a longer period. This allows the grower 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 grower specifications and can be run on programmed time schedules.

**Best Practices**

The selection of watering methods is highly influenced by an individual grower’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 larger than 2,500 square feet should seriously consider an automated watering system. Clear standard operating procedures and frequent training of staff with irrigation responsibilities is essential to ensuring that the chosen system operates optimally. The table below highlights some of the benefits and drawbacks of the three most commonly used irrigation methods:
### Irrigation Method

<table>
<thead>
<tr>
<th>Irrigation Method</th>
<th>Efficiency</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
</table>
| 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  
                      ● Water 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. Operators 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, operators should measure runoff to ensure that water is not being wasted. Set a low runoff target; 10 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. Growers 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 using what is provided, they may not need to be flushed too often.
Resources and Related References

Hydroponic and aeroponic system resources:

http://www.homehydrosystems.com/hydroponic-systems/aeroponics_systems.html

http://howtogrowmarijuana.com/aeroponics/

http://cch2o.com/under-current-hydroponic-system-info/

Drip Irrigation resources:


Procedure for flushing plants: http://www.americanag.com/Flushing-Potted-Plants.html

Information on managing electrical conductivity:
http://www.greenhousegrower.com/production/fertilization/understanding-plant-nutrition-managing-media-ec/
**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 a closed system for water use. Virtually all excess water runoff and water vapor can be captured and delivered back to the beginning of the watering process.

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

**Sustainability Aspects and Impacts**
- Water Conservation
- 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 be stored ready for the next round of watering.

The second water recycling method involves capturing HVAC condensate. Healthy cannabis plants transpire a majority of the applied water after each watering cycle naturally through the photosynthetic process. This water vapor passes through the cultivation room’s HVAC equipment and 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 RO quality) water that most operators 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.

Figure 4: Example of piped drainage from trays
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 the operator should know what they are trying remove from their irrigation water. Look for technologies that kill waterborne pathogens such as Pythium, Phytophora, 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 phytophora
- 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.
Resources and Related References

Rules and Regulations Governing Graywater Treatment Works

http://www.greenhousemag.com/article/gm1214-recycling-irrigation-water/


http://www.greenhousemag.com/article/disinfecting-recycled-irrigation-water/

http://cleanwater3.org/keyinfo.asp

Examples of UV purification products:
https://www.priva.com/us/products/vialux

Examples of copper purification products:
http://www.aqua-hort.dk/brochures/english.pdf
http://www.superioraqua.com/prod-frames.html

Examples of ECA products:
http://www.hortidaily.com/article/17803/ECA-water-alternative-to-chemical-disinfectants
https://royalbrinkman.com/mechanical-equipment/spare-parts/Irrigation-components/eca/eca-unit/eca-chlorinsitu-ii-150-g-h-084207663?returnurl=%2fsearch%3fq%3deca
**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 Conservation
- Indoor Air Quality

**Process Description**

Purifying water using reverse osmosis generates significant volumes (at least 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, 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 waste water.

**Best Practices**

- 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 with 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.
- Do not over-water crops as this can lead to unintended high levels of chemicals and suspended solids in sanitary drains.
- Do not dump any liquids into storm drains.

**Resources and Related References**

Green Seal Website

Eco Logo Website

Safer Choice (EPA) Website

**Additional Considerations**

Please keep in mind that 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. 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.
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 of their waste stream as possible. Cannabis operations should consider the source 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 schemes.

The sustainability impacts of waste management and diversion include:

1) 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.

2) 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 local 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 goals10.[1]

3) 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 and hazardous waste. Though cannabis waste is strictly regulated, this section will outline compliance best practices that will 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 given 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, then the rendered waste shall be:

10 Denver Office of Sustainability available at Denver 2020 Sustainability Goals
1. Disposed of at a solid waste site and disposal facility that has a Certificate of Designation from the local governing body;
2. Deposited at a compost facility that has a Certificate of Designation from the Department of Public Health and Environment; or
3. 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 Department of Public Health and Environment.
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.

Sustainability Aspects and Impacts

- Land Use
- Solid Waste
- Compliance
- Greenhouse Gas 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 (1) grinding the waste and letting the ground-up waste fall into a 55-gallon drum or other similar container that is capable of becoming air-tight when closed, (2) adding additional material to achieve a 50 percent marijuana-waste mix and (3) 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 short 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 fermenting 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 like odors and vermin linked to composting sites. The fermenting container will not attract flies because it is kept sealed.

Bokashi remains a largely unknown technology with numerous nuances. It is also new to regulators (MED, CDPHE and 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 either 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.

Place separate receptacles for compostable waste throughout the facility anywhere the waste is generated. 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.

**Resources and Related References**

Certifiably Green Denver composting resource sheet: offers general tips on composting and lists providers in the Denver area. [www.denvergov.org/certifiablygreen](http://www.denvergov.org/certifiablygreen)

Information on the Bokashi method and resources for getting started. [http://www.bokashicycle.com/](http://www.bokashicycle.com/)

**Additional Considerations**

Incorporating composting into a facility requires an additional waste receptacle outdoors. 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.
**Universal and 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
- Compliance

**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).

Any generation of regulated hazardous wastes must be disclosed to the Colorado Department of Public Health and Environment. 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, consider the following:
- Is there a plan in place for how to deal 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 material 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 include:

• Planning usage of pesticides and chemicals
  o 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.
• Prepare only the amount needed for each application.
• If applying or handling pesticides, lawfully adhere to all pesticide label instructions. It is also recommended that at least one employee has obtained a Colorado Department of Agriculture Private Applicator license. More information can be found at https://www.colorado.gov/pacific/agplants/private-pesticide-applicators

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

Resources and Related References

Generator Assistance Program: The Colorado Department of Public Health and Environment offers free on-site assistance for hazardous waste generators. Call 303-692-3415 or visit https://www.colorado.gov/pacific/cdphe/GAP for more information.

Hazardous and Solid Waste are governed by the Resource Conservation and Recovery Act (RCRA) through the EPA: https://www.epa.gov/RCRA


Solid Waste Regulations: http://www.colorado.gov/pacific/cdphe/solid-waste-regulations


Hazardous Waste Management and Guidance: www.colorado.gov/pacific/cdphe/hwguidance

Marijuana Enforcement by the Colorado Department of Revenue:

Mercury-Containing Lighting: www.colorado.gov/pacific/cdphe/mercury

Universal Wastes (includes pesticides, aerosols, batteries, mercury-containing lighting, etc.): www.colorado.gov/pacific/sites/default/files/HM_hw-universal-waste-rule_0.pdf
**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
- Compliance
- 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, widely used for packaging flower. Containers 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 PET plastic film, is typically not accepted in mixed recycling programs. Re-sealable 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 and silicone insert. While some of these materials are technically recyclable, recycling sorting 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 makes 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**

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 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 their 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 and Related References

<table>
<thead>
<tr>
<th>Sources of Environmentally Preferable Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
</tr>
<tr>
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</tr>
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<td>Recycled Content</td>
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<td>Higher Standard Packaging</td>
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<td>higherstandardpackaging.com</td>
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<tr>
<td>Elevate Packaging</td>
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<tr>
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<tr>
<td>Sana Packaging</td>
</tr>
<tr>
<td><a href="http://www.sanapackaging.com">www.sanapackaging.com</a></td>
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</table>

Rules for packaging and labeling are defined in the R1000 series of rules within the Marijuana Enforcement Division’s [Permanent Retail Marijuana Rules](https://example.com) (1 CCR 212-2).

**Definition of Sustainable Packaging**

**Framework for Sustainable Food Packaging Design**

**Additional Considerations**

Packaging materials and design 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 PLA plastic and turned into product packaging.
**RECYCLING**

Denver’s recycling rate of 18 percent falls well below the 34 percent national average. Currently recycling in Denver is not mandatory, helping lead to low rates of waste diversion. However, businesses can benefit from the proper sourcing, separating and diverting of recyclable materials. Single-stream collection and hauling is the practice of choice by 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.

**Sustainability Aspects and Impacts**

- Solid Waste
- Resource Use

**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**

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.

**Resources and Related References**

Denver Recycles directory of recycling service providers

Use signage provided by your 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 provided by a local waste hauler are available in the appendix.

**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.
Sample Energy Audit Form

| Name: | |

**Grow Type:**
- Cultivation Sq. Ft.
- Building Type
- Building Age

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

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<th>Month</th>
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<th>Water (gallons)</th>
<th>Production (Dried Wt.)</th>
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<td>June</td>
<td></td>
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<td>July</td>
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<td>September</td>
<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
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### Growing System

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<th>Cycle Duration</th>
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### Equipment

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<td>Exhaust/Intake Fans</td>
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<tr>
<td>Misc.</td>
<td></td>
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</table>
HVAC Sample Preventative Maintenance Checklist:

- Check alignment and operations of blower components.
- Lubricate bearings as needed.
- Verify air flow via supply / return temperature delta.
- Check belt and or belts. Change as needed (biannually minimum).
- Replace filters / check evap coil conditions (quarterly minimum).
- Verify thermostat operations in heating and cooling.
- Tighten lugs on electrical components as needed, and verify no loose wiring exist.
- Check condition of heat exchanger.
- Check safeties while verifying operations of heating and cooling.
- Verify operating pressures in cooling to aid in diagnosis of any potential issues and or refrigerant leaks.
- Check conditions of condensing coils and clean as needed.
- Perform visual inspection of equipment and note any issues and or damages.
- Record and notify customer of any worn or damaged components. Recommend additional work if needed to aid preventing future operational issues.

Source: AABLE HVAC, LLC  510 E. 51st Ave. #205, Denver, CO 80216
### ELECTRICITY BILL EXAMPLE

**SERVICE ADDRESS:**

**NEXT READ DATE:**

**ELECTRICITY SERVICE DETAILS**

**PREMISES NUMBER:**

**INVOICE NUMBER:**

**METER READING INFORMATION**

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<th>Usage</th>
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<td>453885 kWh</td>
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<tr>
<td></td>
<td></td>
<td>Demand</td>
<td>Actual</td>
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<td></td>
<td></td>
<td>Browsable Demand</td>
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**APPENDIX A: RESOURCE DOCUMENTS**

**GAS BILL EXAMPLE**

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**NATURAL GAS SERVICE DETAILS**

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<table>
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<th>METER READING INFORMATION</th>
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**NATURAL GAS CHARGES**

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<th>RATE</th>
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Subtotal $967.91

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Total $1,073.21

Premises Total $36,863.23
Irrigation Water Quality Criteria  
by R.H. Follett and P.N. Soltanpour

There are four basic criteria for evaluating water quality for irrigation purposes:
1. Total soluble salt content (salinity hazard).
2. Relative proportion of sodium cations (Na+) to other cations (sodium hazard). (An ion is an electrically charged atom or groups of atoms. Cations carry a positive charge, and anions have a negative charge.)
3. Excessive concentration of elements that causes ionic imbalance in plants or toxicity.
4. Bicarbonate anion (HCO$_3^-$) concentration as related to calcium (Ca++) plus magnesium (Mg++) cations.

The first two criteria are of major concern in Colorado and are used by the Colorado State University Soil Testing Laboratory in determining irrigation water quality.

There also are many non-water factors to consider in deciding the usefulness of water for a specific situation. These include soil texture and structure, drainage conditions, gypsum and lime content of the soil, salt and sodium tolerance of the crop, and irrigation method and management.

Salinity Hazard
Excess salt increases the osmotic pressure of the soil solution that can result in a physiological drought condition. Even though the field appears to have plenty of moisture, the plants wilt because insufficient water is absorbed by the roots to replace that lost from transpiration.

The total soluble salt content of irrigation water generally is measured either by determining its electrical conductivity (EC), reported as micromhos per centimeter, or by determining the actual salt content in parts per million (ppm). Table 1 presents the basic guidelines for water use relative to its salt content.

Sodium Hazard
The sodium hazard of irrigation water usually is expressed as the sodium adsorption ratio (SAR). This is the proportion of Na+ to Ca++ plus Mg++ in the water. The following formula is used to calculate SAR:

$$\text{SAR} = \sqrt{\frac{\text{Na}^+}{\text{Ca}^{++} + \text{Mg}^{++}}}$$

Ions in the equation are expressed in milliequivalents per liter. Although sodium contributes directly to the total salinity and may be toxic to sensitive crops, such as fruit trees, the main problem
with a high sodium concentration is its effect on the physical properties of soil.

Avoid using water with an SAR value greater than 10 if it will be the only source of irrigation water for long periods. This is true even if the total salt content is relatively low.

If the soil contains an appreciable amount of gypsum, a SAR value of 10 may be exceeded somewhat. The gypsum content of the soil can be determined by the Colorado State University Soil Testing Laboratory.

Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action.

**Toxic Elements**

Direct toxicity to crops may result from some specific chemical element in irrigation water. The actual concentration of an element in water that will cause toxic symptoms varies depending on the crop.

When an element is added to the soil through irrigation, it may be inactivated by chemical reactions, or it may build up in the soil until it reaches a toxic level. An element at a given concentration in water may be immediately toxic to a crop or it may require a number of years to accumulate in the soil before it becomes toxic.

There is a long list of elements that can cause a toxic effect on crops, including boron, chlorine and others. Table 2 shows the interpretation of boron results, and Table 3 of chlorine results.

**Bicarbonate Concentration**

Waters high in bicarbonate (HCO$_3^-$) will tend to precipitate calcium carbonate (CaCO$_3$) and magnesium carbonate (MgCO$_3$) when the soil solution concentrates through evapotranspiration. This means that the SAR value will increase — the relative proportion of sodium ions becoming greater. This, in turn, will increase the sodium hazard of the water to a level greater than indicated by the SAR value.

**Recent Findings**

Irrigation water high in chloride (Cl$^-$) and/or sulfate (SO$_4^{--}$) ions reduce phosphorus availability to plants and reduce the concentration of organic acids in plants to suboptimal levels.

**References**


United States Salinity Laboratory Staff. 1969. *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Agricultural Handbook 60.
# 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: 11/3/2016  
Date Reported: 11/8/2016

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

**IRRIGATION WATER ANALYSIS**

"Routine Package" and "Metals" and "Individual Element" Analysis

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<tr>
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<th>Results</th>
<th>Results</th>
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<td><strong>mg/L</strong></td>
<td><strong>µmhos/cm</strong></td>
<td><strong>meq/L</strong></td>
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<td>Phosphorus</td>
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<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Selenium</td>
<td>*</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>0.06</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>* Not requested</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Salinity**  
SAR 0.8  
Hazard Low  

**COMMENTS:**  
This is good quality water for irrigation.