THE 2018

CANNABIS ENERGY REPORT

CO-AUTHORED BY:

SCALE MICROGRID SOLUTIONS

RESOURCE INNOVATION INSTITUTE

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LETTER FROM THE PUBLISHER

New Frontier Data is proud to present ***The Cannabis Energy Report: The Current and Evolving State of Cannabis Energy Consumption.***

As energy consumption and carbon-emission levels have become critical issues within the cannabis industry, stakeholders have been forced to rely on data and analysis based on research published prior to the deployment of medical and adult-use programs across 31 U.S. states and the District of Columbia (D.C.).

Though the cannabis industry at large is not a major consumer of energy relative to high-user industries such as the automotive, steel, or medical-care industries, its energy use is significant, and important to its consumers. Although this report focused primarily on electricity-based energy consumption, based on the analysis of the data in the dataset, energy use in the cannabis industry requires further study, particularly given that electricity-based energy consumption is expected to increase 162% from 2017 to 2022. Understanding consumption data becomes vital in planning for the industry's future.

While energy providers, regulators, and legislators are looking for credible data on cannabis cultivation energy consumption, many other key stakeholders need such data. Operators, investors, supply-chain and services providers are all leveraging data in the emerging space: As the industry continues to expand in both scale and reach, that intelligence represents a tremendous opportunity for further such research.

By analyzing energy usage and costs, a business can assess its standing relative to others within cannabis and in other sectors. By establishing and tracking key indicators, including annual production, annual electricity consumption, canopy area, cultivation type and lighting used, a company can identify its cost drivers and develop ways to reduce them. Given the fixed costs in cannabis production, the ability to identify and reduce electrical use can offer considerable competitive advantages.

New Frontier Data's mission is to elevate the discussion around the legal cannabis industry globally by providing unbiased, vetted information and educating stakeholders to make informed decisions. We provide individuals and organizations operating, researching, or investing amid the cannabis industry with unparalleled access to actionable industry intelligence and insight, helping each to leverage the power of big data to succeed in a fast-paced and dynamic market.

As the global leader in big data analytics for legal cannabis markets, New Frontier Data is dedicated to publishing reports of the highest industry caliber. We hope that you enjoy all the benefits of this one as you shape your strategy and action plan within the cannabis industry!

Strength in Knowledge™

Giadha Aguirre de Carcer
Founder & Chief Executive Officer, New Frontier Data

EXECUTIVE SUMMARY

The purpose of this report is to inform public policy, utility program design and industry best practices by providing a data-driven, contemporary, and comprehensive assessment of the cannabis industry's electricity-based energy use and associated carbon impacts.

The 2018 Cannabis Energy Report is the combination of two original works: The first includes the U.S. cultivation estimates for both the illicit and legal markets (all estimates being based on New Frontier Data's analysis of legalized production in legal states, as well as careful assessment of illicit activities in the non-legalized market); the second work includes energy consumption metrics based on data input by cultivators to the PowerScore tool. The total U.S. industry electricity consumption estimates, and the estimated electricity-based carbon emissions, are derived from those two sources.

The City of Denver was on the verge of missing its energy reduction goals. Upon investigation, it was found that the nascent cannabis industry was consuming 4% of the city's overall electrical capacity. The City of Arcata, Calif., proposed restrictions on cannabis businesses as residential consumers were facing higher electric bills. The influx of cannabis businesses was suspected of causing a spike in consumption, and resultant higher residential energy prices. Such anecdotes are common in areas with emerging cannabis operations. However, is cannabis really the cause of all these issues? The fact is, there has been little reliable and recent data on energy usage available to confirm these assumptions, until now. This report is a fresh look at the electricity-based energy data that fuels this industry.

Energy consumption and carbon emission levels have become critical issues among stakeholders in the cannabis industry. Stakeholders have been forced to rely on data and analysis based on research published prior to the deployment of medical and adult-use programs across the 31 states and the District of Columbia (D.C.). New Frontier Data has teamed up with both Scale Microgrid Solutions and Resource Innovation Institute to perform a comprehensive study on energy consumption and electricity-based carbon emissions in cannabis cultivation.

The analysis contained in this report has been performed using data aggregated by Resource Innovation Institute's Cannabis PowerScore (PowerScore) tool. The online tool collects self-reported operational data and cultivation characteristics (annual production, annual electricity consumption, canopy area, cultivation type, lighting type, etc.). Submitters benefit by instantly seeing their energy ranking relative to the rest of the dataset. As the largest canna-

> **"The fact is, there has been little reliable and recent data on energy usage ... until now.**

bis-specific energy use dataset, PowerScore has been an invaluable tool, and such tools will become increasingly important to the industry as it grows.

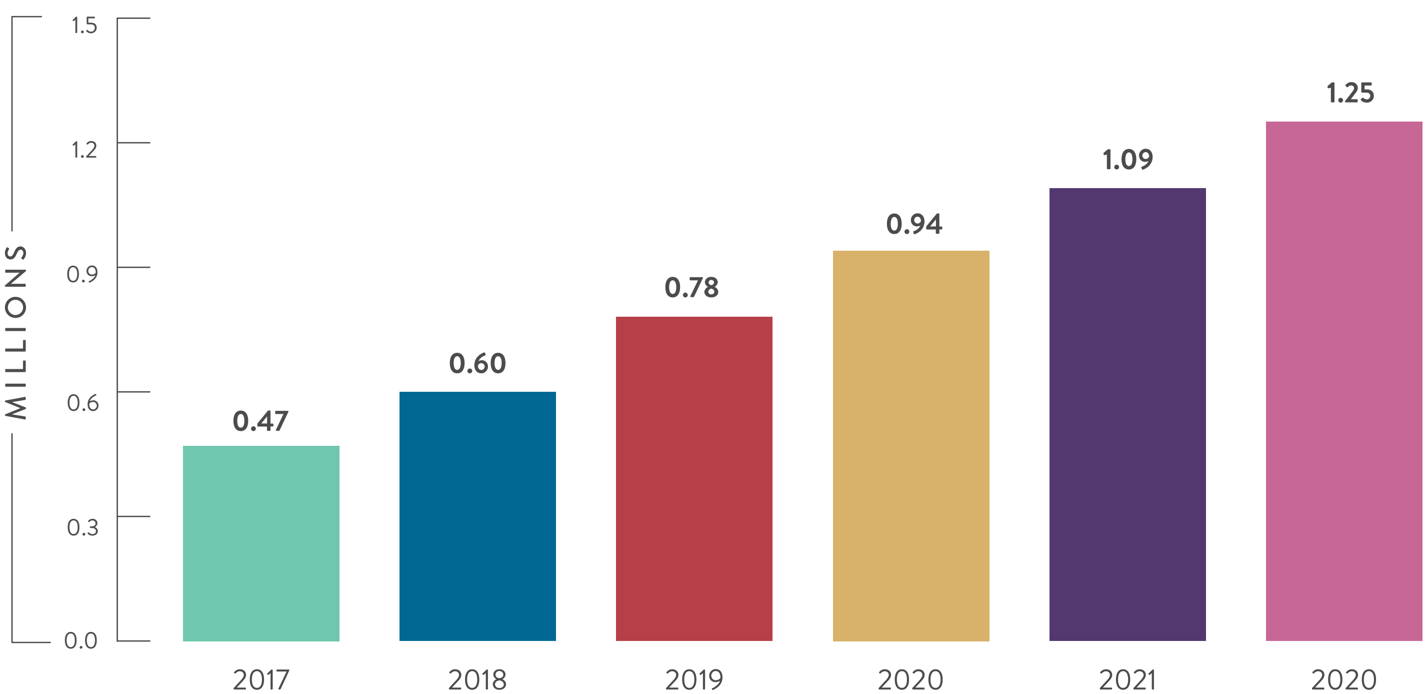
DATA FROM THIS ANALYSIS IS SUMMARIZED INTO THREE CATEGORIES

1. A summary of responses from the 81 cultivators (more than 1% of all legal licensees in the U.S.) who had submitted data at the time of this report;
2. A summary estimate of the total electricity consumed in the cultivation process (note: consumption of non-electricity fuels was not included in the data set);
3. A summary estimate of the total carbon intensity resulting from electricity consumption by U.S. cannabis cultivation.
4. Forecasts of future consumption, emissions, and recommendations for investors, operators, and regulators are also included in this report.

Summary of Findings

- Legal cannabis cultivation in the U.S. consumes an estimated 1.1 million megawatt hours (MWh) of electricity-based energy.
  - That is enough electricity to power 92,500 homes for a year, or a community the size of Newark, N.J., or Anaheim, Calif.

TOTAL ELECTRICITY-BASED CO_2 EMISSIONS FROM LEGAL CULTIVATION (TONS)



Source: New Frontier Data

- Legal cannabis electricity consumption is forecast to increase 162% from 2017 to 2022.
- Combined with illicit production, cannabis cultivation consumed an estimated 4.1 million MWh of electricity in 2017.
  - That is roughly the total electricity generated annually by the Hoover Dam.
- Legal cultivation generated an estimated 472,000 tons of electricity-based carbon equivalent emissions in 2017. That is expected to increase as the legal markets expand over the next five years.
  - It is the equivalent emission of 92,660 cars a year, or enough to produce 35,351 tons of beef.
- Most illicit cannabis production comes from the western U.S., and is exported throughout the country.

Key Takeaways and Recommendations

- Energy consumption by legal cannabis cultivation is increasing significantly as more states launch medical and adult-use programs.
- 25% of all energy consumption is from legal operations, while illicit operations are still a factor in forecasting energy demand.

> **“Legal cannabis electricity consumption is forecast to increase 162% from 2017 to 2022.**

- Metrics such as grams per kilowatt hour (kWh), kWh per square foot, grams of output per square foot, electrical cost per square foot, and pounds of electricity-based carbon per gram can all serve as basis points for analysis to drive operational efficiencies.

Industry Should

- Track and benchmark energy performance as a critical profit indicator (grams/kWh and energy share of Cost of Goods Sold (COGS) per CannabisPowerScore.org).
- Evaluate energy-efficient and renewable energy technologies.
- Prioritize energy retrofits of cultivation facilities to ensure competitiveness.
- Carefully consider outdoor and mixed-light options when developing new cultivation facilities.
- Engage in policy discussions to ensure that energy and carbon regulations are workable for industry.
- Invest in the development of data-driven, peer-reviewed, best practices that can support industry evolution and scale.

Governments Should

- Invest in research on energy consumption and climate impact, with urgency on baseline studies.
- Invest in best practices associated with energy efficiency and renewable energy.
- Invest in technology demonstrations to objectively identify the most effective approaches to lowering energy use at scale.
- Adapt building codes for applicability to controlled environment agriculture.
- Consider policies that envision transitioning defunct cannabis cultivation facilities

into indoor agriculture operations that promote regional food security.

- Promote policies that support an energy-efficient, low-carbon regulated industry to outperform illicit distribution.
- Support development of peer-reviewed standards and certification programs that provide independent verification of natural resource performance.

Utilities Should

- Invest in research on energy consumption, with urgency on baseline studies.
- Invest in best practices associated with energy efficiency and renewable energy.
- Invest in technology demonstration.
- Develop programs and incentives that appeal to the cannabis industry, and provide effective outreach, starting with the hookup stage.
- Address energy issues related to residential cultivation.

As cannabis production, energy consumption, and carbon emissions increase over the next five years, policies and industry best practices will be needed to drive efficiencies and reduce emissions. The Cannabis PowerScore tool will help facilitate these policies and best practices and provide data in an environment where previously little data has been available.

This report provides the analysis of cannabis-cultivation electricity consumption and electricity-based carbon emissions associated with the production of cannabis. With forecasts for future consumption and emissions, as well as recommendations for investors, operators, and others, this report is intended to serve as a resource for key stakeholders in the industry, and lay a foundation for future analysis.

ABOUT NEW FRONTIER DATA

New Frontier Data provides objective, rigorous and comprehensive analysis and reporting about the nascent and underserved cannabis industry worldwide. New Frontier Data's analytics and reports have been cited in over 69 countries around the world to inform industry leaders, investors, policymakers and others. New Frontier Data, the premiere and only Big Data shop in the sector, looks beyond plant cultivation and distribution to raise the industry bar and improve visibility into what will inevitably soon be a mature and more complex global market. Founded in 2014, New Frontier Data is headquartered in Washington, D.C. and has additional offices in Denver, Colorado.

New Frontier Data does not take a position on the merits of cannabis legalization. Rather, its mission and mandate are to inform cannabis-related policy and business decisions through rigorous, issue-neutral and comprehensive analysis of the legal cannabis industry. For more information about New Frontier Data please visit: NewFrontierData.com.

Mission

New Frontier Data's mission is to elevate the discussion around the legal cannabis industry globally by providing unbiased vetted information and educating stakeholders to make informed decisions.

Core Values

- Honesty
- Loyalty
- Respect

Vision

Be the Global Big Data & Intelligence Authority for the Cannabis Industry.

Commitment to Our Clients

The trusted one-stop shop for actionable cannabis intelligence, New Frontier Data provides individuals and organizations operating, researching or investing in the cannabis industry with unparalleled access to actionable industry intelligence and insight, helping them leverage the power of big data to succeed in a fast-paced and dynamic market.

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Resource Innovation Institute

As an objective nonprofit organization, Resource Innovation Institute (RII) quantifies the natural resource impacts of regulated cannabis and advises governments, utilities and stakeholders to make sense of the resource impacts of cannabis, its integration into communities, and how to productively solve resource-related market challenges. Through tools like the Cannabis PowerScore, RII points the way to an efficient industry future. The Cannabis PowerScore is a DIY energy audit that helps cultivators maximize energy efficiency while optimizing plant yields, consistency and quality. Through events such as RII's Efficient Yields workshop series, we create venues for the exchange of education and best practices with a focus on establishing industry standards that drive conservation.

About Scale Microgrid Solutions

Scale Microgrid Solutions (SMS) is a distributed energy company that specializes in commercial and industrial energy projects that utilize solar photovoltaic (PV), cogeneration, battery storage, and backup power. SMS is particularly focused on solving the energy challenges of the controlled environment agriculture, indoor farming, and cannabis industries.

INTRODUCTION

Why Energy is Important

Sustainability has been a central issue in business and government over the past decade, with focus on energy consumption, resource management, environmental impact of industrial activity, and consumer behavior. Discussions about efficiencies have become more common. Consumers are voting with their wallets, showing preferences for businesses that include some sustainability practices in their operations. As cost reductions and cost competitiveness become significant differentiating factors among businesses and consumers, businesses are beginning to brand sustainable practices. Governments are also tightening their focus on environmental impact and efficiency as means for reducing emissions while reducing the costs of essential services to their citizenry, along with optimizing costs to manage the effects of environmental and climate change.

> **“Consumers are voting with their wallets, showing preferences for businesses that include some sustainability practices in their operations.**

Larger bodies have attempted to address conservation and sustainability issues on a macro level. For example, the European Union (EU) has implemented a cap-and-trade program to reduce the carbon footprints of its member states, international treaties have been proposed to address environmental issues, and large multinational corporations have created environmentally friendly policies in pursuit of creating competitive advantages.

On a smaller scale, state and provincial governments in North America are also developing policies to reduce waste and drive more sustainable practices. Even individuals and small businesses are working to reduce costs and create efficiencies.

As focus on such areas has intensified, there is a growing body of data and research to inform policymaker decisions on environmental regulations. Although there are some sectors with robust energy data, some industries lag either due to a lack of commercial necessity or the fact that they are part of new, emerging markets. One such emerging market with limited data on sustainability, efficiency, and resource management is the cannabis industry.

While cannabis is one of the fastest-growing industries in North America, there is a dearth of data on many of its market aspects. The industry lacks credible data on major topics, such as energy consumption, water usage, carbon emissions, job creation, or impacts on health and public safety, during this critical period in the industry's foundation. As a result, policymakers, regulators, energy providers, investors, and operators have struggled to make well-informed decisions using limited data sets and outdated research. Without reliably credible data, policymakers may inadvertently restrict the growth of the nascent industry, fail to address the regulators' objectives, or erect such high barriers to entry that firms choose not to participate in the industry. It is a difficult task in striking a balance between public safety, economic growth, and environmental impact.

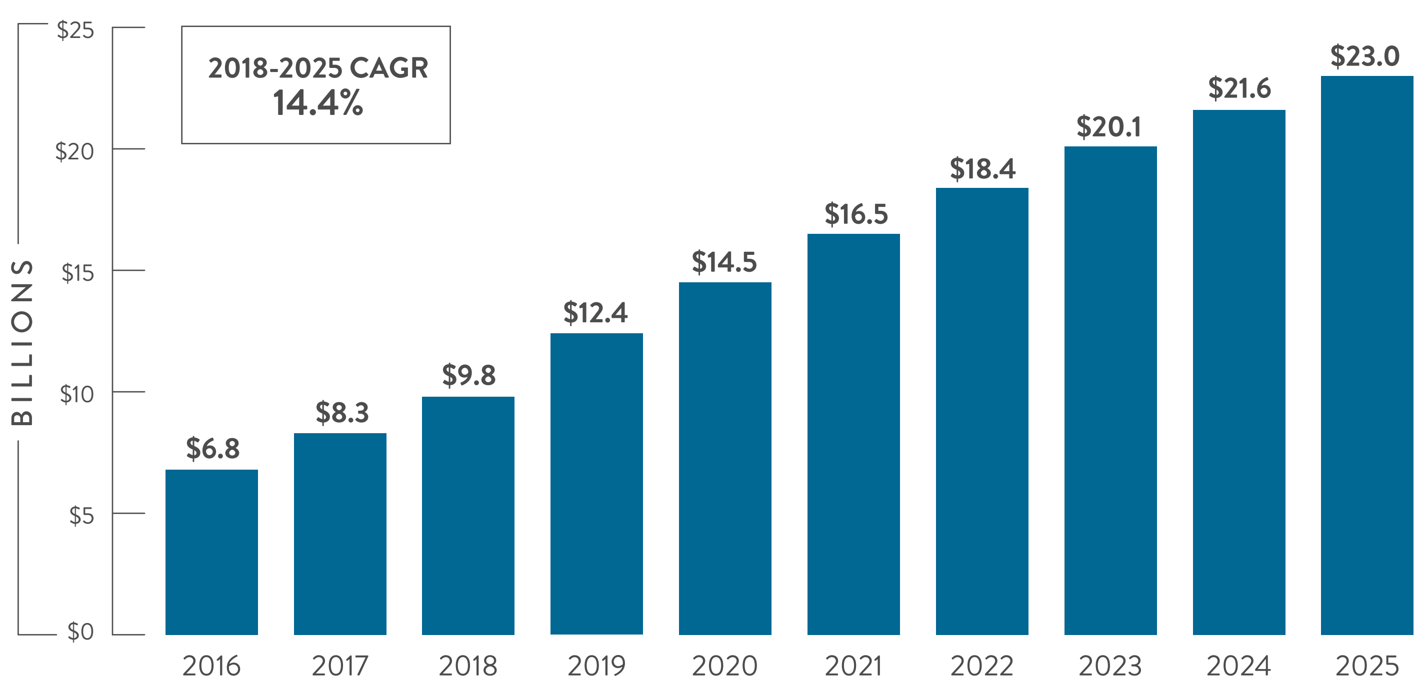
Sizing the Market

Just how big is this market? Based on forecasts developed by New Frontier Data, the overall market for legal cannabis is $9.8 billion in 2018 and will conservatively increase to $23.0 billion by 2025. Such growth has increased the size and complexity of the supply chain and the energy usage rate, and dramatically expanded the industry's carbon footprint.

As more states transition from illicit markets to legal medical markets or fully legal markets (medical and adult-use), demand for legal cannabis will continue to increase. The increase will further fuel demand for energy needed to produce the products.

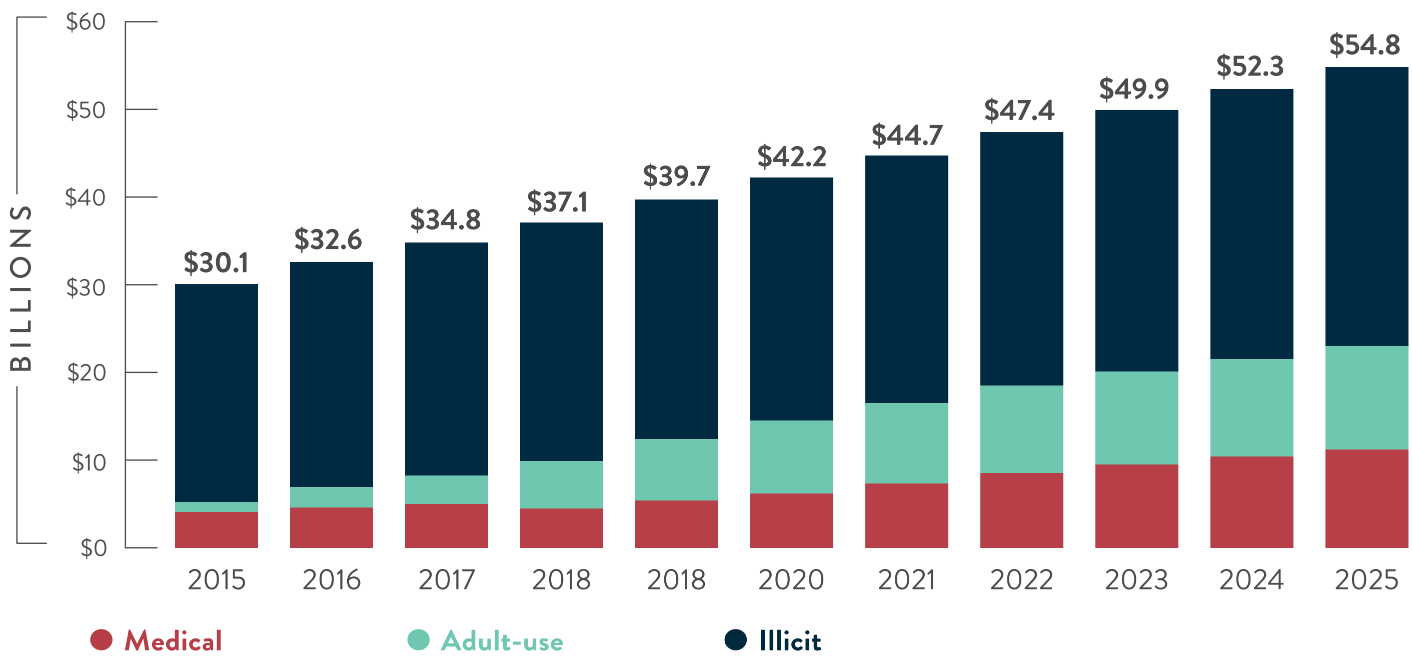
Since cultivation is one of the most energy-intensive aspects of the cannabis industry's supply chain, this report provides insight into energy consumption in North American cannabis cul-

TOTAL U.S. LEGAL CANNABIS DEMAND



Source: New Frontier Data

U.S. CANNABIS MARKET GROWTH: LEGAL AND ILLICIT



Source: New Frontier Data

tivation using Cannabis PowerScore data on the industry's electricity consumption and electricity-related greenhouse emissions. The aim is to identify opportunities that will drive more efficiencies within cannabis operations, and to establish a foundation for future research.

It should be noted that some findings in this report are transferable to crops beyond cannabis, to the entire emerging field of controlled environment agriculture (CEA), often referred to as indoor agriculture or vertical farming. While this report's focus is on commercial cultivation based on data from producers in both medical and adult-use markets, future reports will examine other aspects of the supply chain, such as extraction.

Cannabis Energy Research and the Importance of Contemporary Data

In the spring of 2012, Evan Mills published a report titled "The Carbon Footprint of Indoor Cannabis Production".[1] The groundbreaking study examined the energy consumption required for an indoor cannabis operation, and highlighted concerns that the industry's energy consumption levels were left unchecked. With little research available at the time of the report, the Mills study became the de facto reference for cannabis energy estimates.

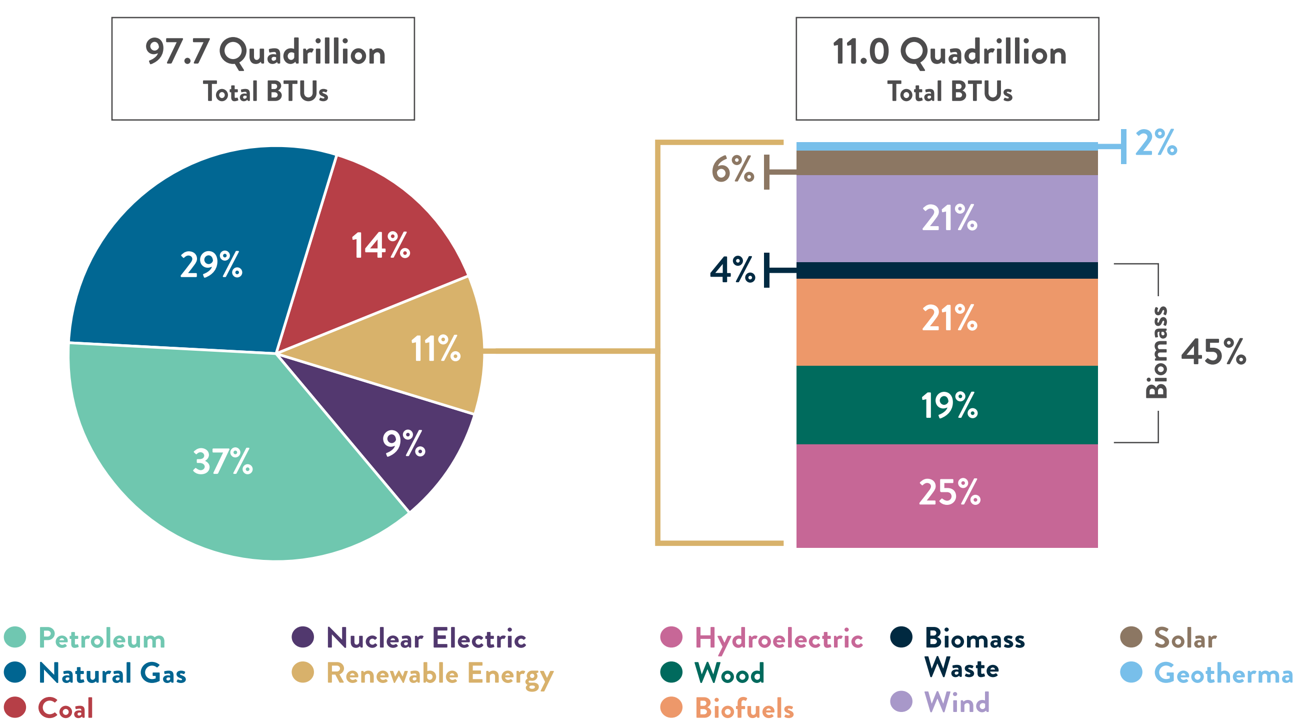
1. *Mills, E., "The Carbon Footprint of Indoor Cannabis Production", (2012)*

Since the Mills study's publication in 2012, the market has expanded dramatically. Support for cannabis legalization has hit an all-time high, with 6 in 10 Americans now supporting full legalization. Such support has propelled the expansion of legal markets: Nine states plus D.C. have deployed statewide legal adult-use programs, and 31 states plus D.C. have approved medical cannabis programs.

The volume of growers has increased significantly in order to support the demand. As legal production has scaled, growing techniques have evolved. New technologies and innovations are being developed to increase operational efficiency and to lower costs. The accelerating adoption of LED lighting is one example of innovation that has had significant impact on energy consumption in cultivation. In 2012, horticultural LED lighting usage was in its infancy. Now in 2018, states such as Massachusetts are effectively requiring the use of LED lighting in grow facilities, a development that could not have been foreseen in the Mills study. This report aims to build on Mills' work by providing a contemporary assessment of energy consumption in cannabis, while accounting for the sweeping changes that have transformed the cannabis industry in the years since that study's publication.

As the cannabis industry has grown over the past five years, energy providers have been working to predict the industry's energy demand. They

U.S. ENERGY CONSUMPTION BY ENERGY SOURCE



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, Monthly Energy Review, Table 1.3 and Table 10.1, April 2018, preliminary data.

have struggled to keep pace with the industry's energy needs, both in terms of infrastructure development and fulfillment of growers' energy needs. Consequently, energy demand in some cases has outstripped supply, and both residential and commercial utility rates have increased as a result. As some utility ratepayers chafe at rising energy prices, legislators and policymakers have been forced to intervene to prevent all energy consumers from being liable for the industry's surging use.

> **Support for cannabis legalization has hit an all-time high, with 6 in 10 Americans now supporting full legalization.**

Without a credible data set to use in the formulation of policy, legislators have had few sources of reliable and vetted information, and relied on third-party sources, such as news reports. In Oregon for example, early legislative debates referenced news reports of higher energy prices in California's Humboldt and Colorado's Boulder county, leading cannabis production regions in each state. The news reports alleged that increased demand for energy was caused by indoor cannabis cultivation. Such reports were then used as a basis for a proposal to track energy consumption across the spectrum of cannabis-related businesses, highlighting the importance of developing current and accurate data about energy use.

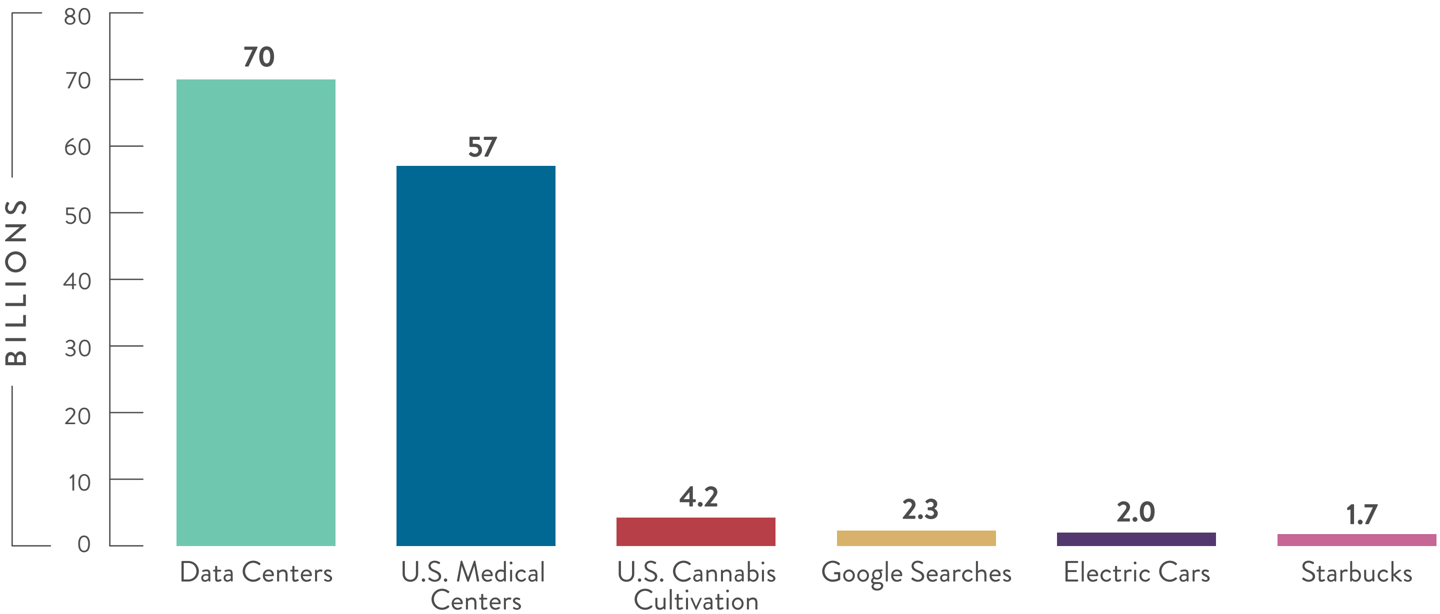
Cannabis regulatory policies vary widely across states, and even within counties or cities. Local government bans or moratoria on licensing cannabis businesses, for example, have forced businesses to concentrate into small geographic areas. When production facilities are concentrated in a relatively small community, the high energy demand is magnified. Stress on substations and transformers occur, and local governments are forced to address infrastructure deficiencies.

While energy providers, regulators, and legislators are examples of groups that are looking for credible data on cannabis cultivation energy consumption, there are many other key stakeholders needing such data. Operators, investors, supply-chain and services providers are all leveraging data in the emerging space. As the industry continues to expand in both scale and reach, it represents a tremendous opportunity for further research.

Given that the development of the cannabis market is still in an early stage, energy providers and policymakers alike (i.e., all stakeholders) are attempting to draw comparisons to other markets to develop a frame of reference (e.g., medical centers, paper mills, server farms, etc.). Although there are industries that consume significantly more electricity than does cannabis, the industry's energy consumption is not insignificant, and it is growing. The cannabis industry's energy use is sufficiently large to warrant substantive research into ways to reduce and optimize its energy use.

Energy Consumption and the Drive for Efficiency

Energy efficiency is important on multiple fronts: It can not only reduce costs for an operation, but kWh PER YEAR



Source: New Frontier Data.

McDonalds: statista.com/statistics/535913/energy-consumption-at-mcdonalds-restaurants/

Medical Centers: eia.gov/consumption/commercial/reports/2007/large-hospital.php

Data centers: datacenterknowledge.com/archives/2016/06/27/heres-how-much-energy-all-us-data-centers-consume

Starbucks: starbucks.com/responsibility/global-report/environmental-stewardship/energy-conservation

Google: techland.time.com/2011/09/09/6-things-youd-never-guess-about-googles-energy-use/

also serve as a tactical differentiator against less efficient competitors. Energy is often cited as the second-highest cost driver (after labor) for North American cultivators growing in controlled environments. As the market evolves and pricing commoditization accelerates, lowering operational costs will become an increasingly important differentiator between successful and uncompetitive operations. Energy efficiency reduces a grower's operating expenses and allows those savings to be passed on to the consumer. That consideration could give the most energy-efficient producers important advantages in increasingly crowded wholesale or retail markets.

Controlling energy use and maximizing efficiency can also improve product quality and operational effectiveness. Like genetics, effectively managing the inputs into a controlled grow environment - such as energy - can be a critical factor in generating consistent results. Consistency will become increasingly important in a commoditized market where consumers are demanding replicable and consistent outcomes. Indeed, brand loyalty will hinge, in part, on the consistency of the consumers' experience, and energy and environmental controls will play key roles in maintaining consistency in product offerings.

Energy predictability and management will also serve to enhance the reputation of the cultivation community. Energy delivery is a local issue. Service disruptions and outages, caused by the failure to appropriately load-balance delivery, can have devastating effects on businesses. An entity can suffer not only in terms of product loss, but also from the negative impact on the reputation and standing of the business within the community.

As investors channel record-breaking investments into building and acquiring cultivation facilities, businesses can leverage their energy efficiency and lower-energy-usage data to improve their competitiveness and attract capital. Operational efficiency is increasingly being used to determine which growers are not only most competitive today but will continue to be competitive even as the market reaches saturation and wholesale prices of cannabis crater. Cultivators who "futureproof" their operations by focusing on operational efficiency will become the most attractive investment and acquisition targets as the market matures.

The Cannabis PowerScore Tool

Recognizing the profound impact that energy will have on the future of cannabis, the Resource Innovation Institute developed the Cannabis PowerScore to show how individual operations compare to the industry, and to identify areas to reduce costs and drive efficiencies. For example, if a cultivator compares its operation to similar operators' and discovers that it consumes more electricity than others, the cultivator can take corrective actions to reduce consumption, lower costs, and increase margins. This tool can also be leveraged by regulators to assess reasonable energy consumption to use as a foundation for regulatory policy. As regulators establish policies meant to cap electricity consumption on a per-square-foot basis, the Cannabis PowerScore tool can help provide data about the level of current consumption. Doing so will help refine policy without significantly impacting the growth of nascent industry; as the industry matures, energy research and data collection will increase significantly in importance and impact.

> **"Energy is often cited as the second highest cost driver (after labor) for North American cultivators growing in controlled environments.**

Overall, energy consumption usage data plays a vital role in the cannabis industry. It can be used by cultivators to increase their competitiveness in the marketplace and reduce their impact on the environment. It can also be used by investors to differentiate opportunities and assess value in a complex decision-making environment. Data on energy-consumption patterns can help energy providers forecast both demand and infrastructural requirements, and help policymakers make informed, evidence-based decisions. Given the importance of the data, and how quickly the industry has evolved, this report serves as a resource for operators, investors, policymakers, and other stakeholders to utilize now, as well as to further establish a foundation for others to build upon as the industry grows and matures.

METHODOLOGY

The data contained in this report comes from multiple sources. The primary source of data is the Resource Innovation Institute's Cannabis PowerScore tool. Cultivators throughout North America entered data ranging from harvest data and yields, to type of equipment used, to monthly expenditures on electricity. Scale Microgrid Solutions then consolidated, analyzed, and formulated observations about the information. New Frontier Data used its extensive knowledge of the industry to help summarize the overall market, contextualize the data, and develop industry forecasts.

The teams then collaborated to evaluate the data findings and articulate the most salient items to benefit readers of this report, and have the greatest impact for operators, energy suppliers, investors and policymakers.

Other notable items:

Residential vs Commercial

- The analysis contained in this report reflects data specific to commercial cultivators and is not reflective of production or electricity consumption associated with residential cultivation.

Total U.S. Cultivation Operations

- 81 individual cultivation operations provided inputs into this report.
- Given approximately 7,865 legal cultivation licenses issued throughout the U.S., sample size is more than 1% of the total licenses in the U.S.
- While it should not be inferred that this is a definitive and comprehensive study, it is a sufficiently significant sample to serve as a credible basis for analysis.
- Furthermore, the broad distribution of participation of growers by geography, type, and size ensures a robust representation view of the types of operators that are participating in the industry.

Total U.S. Cultivation Output

- Output was calculated based on the numbers of past month and past year cannabis consumers according to the Substance Abuse and Mental Health Administration's (SAMSHA) National Survey on Drug Use and Health (NSDUH).
- Total output associated with each user was calculated based on historical records of cultivation output and sell-through from both Colorado and Oregon.
- Output required for consumption was then applied to the number of past month users and past year users in each state.

Total Energy Consumption Estimates

- Total electricity consumption estimates were based on the total cultivation output associated with the demand in each state (grams), broken down by the percentage of grow type (i.e., indoor, greenhouse, outdoor).

- Once the pounds of production were estimated by cultivation type, the kWh per gram from PowerScore's analysis was then applied to each cultivation type, by state.
- Allocations by legal and illicit markets were done on a percentage basis.

Total Carbon Intensity

- Total U.S. industry electricity-based carbon emissions were calculated by taking the total pounds of production required to support the demand in each state, allocating the pounds to each cultivation type, incorporating the electricity productivity for each cultivation type, adjusting by that state's CO_2e emissions factor, and summing the values.
- Allocations by legal and illicit were done on a percentage basis.

About the Energy Supply Chain

It is important to note that there is additional energy embedded within the supply chain and other processes that is not accounted for in this analysis. The estimates in this report do not include other areas such as the energy used for transportation, production of CO_2 for carbon fertilization, production of extracts and derivatives, or irrigation water production and treatment outside the facility. The analysis in this report focuses specifically on grid-based electricity used in cultivation.

The Use of Mean Versus Median

Given the relatively limited number of the cultivators providing inputs into the cannabis PowerScore tool, and the large distribution in the responses, the authors of this report used the mean (not the median) in the analysis of the key metrics. The use of mean instead of median was meant to address the possible influence of values at the extreme end of the response ranges. As the number of cultivators entering data into the PowerScore tool increases, we plan in future updates to update the analysis to reflect the best-fit approach based on the expanded data set.

About the Cannabis PowerScore

Conclusions in this report were drawn from the Resource Innovation Institute (RII)'s Cannabis PowerScore dataset. The Cannabis PowerScore is a survey tool designed and vetted by RII's Technical Advisory Committee to provide cannabis operators and cultivators with knowledge of their energy performance as compared to other grow operations. The tool captures detailed information about technologies and techniques used across each stage of cultivation in a variety of geographies and grow settings, along with square footage of flowering canopy, amount of product produced, and annual utility bill data. All data is kept anonymous.

ENERGY IN CANNABIS CULTIVATION

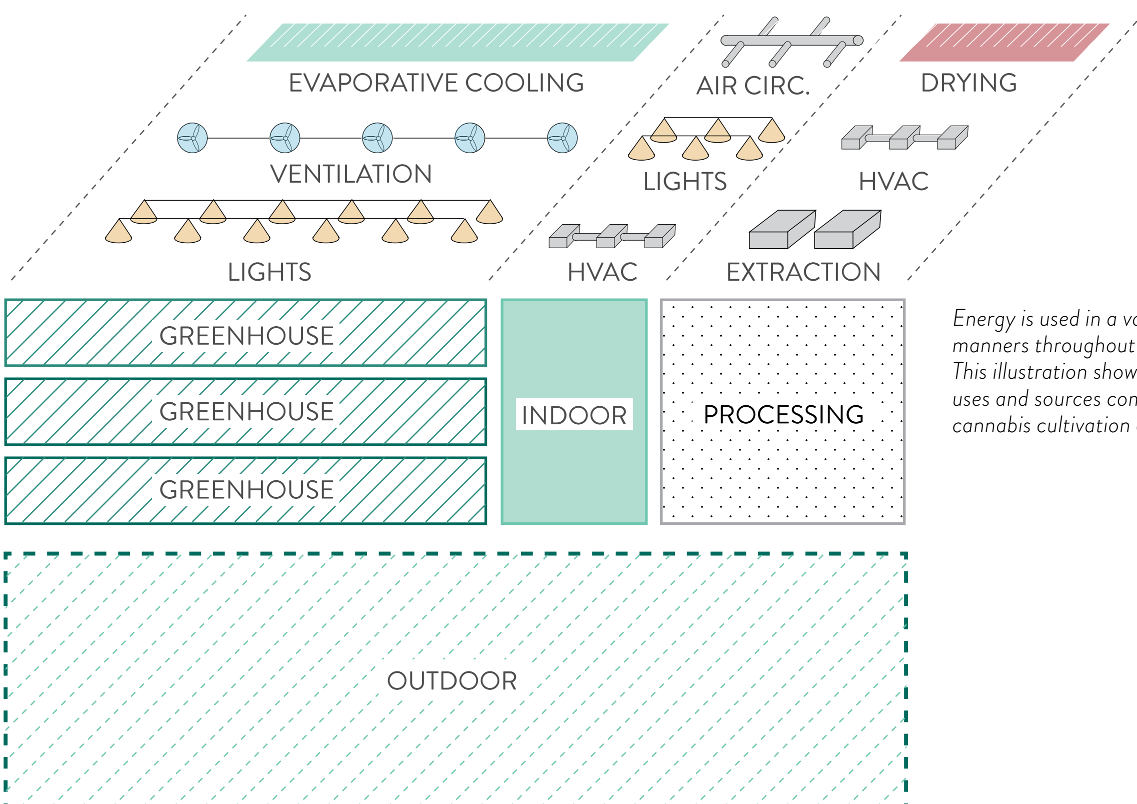
HOW IS CANNABIS GROWN?

For centuries, cannabis was grown exclusively outdoors. With a wide range of cultivars, the highly adaptable plant thrives in many climates around the world. When the United States government classified marijuana as a Schedule I drug in the early 1970s, underground growers moved their grow operations into buildings in an attempt to avoid federal prosecution. Thus began the significant relationship between energy use and cannabis cultivation.

Today, as U.S. states and countries such as Canada legalize cannabis, the plant is grown in a variety of settings, from the outdoors to greenhouses to warehouses, often in more than one manner on an individual property.

Cannabis is on the vanguard of the more recent trend of Controlled Environment Agriculture (CEA), which strives to replicate the natural conditions of temperature, air movement, light intensity, and humidity while increasing annual harvests and minimizing pests and diseases.

USES OF ENERGY IN CANNABIS CULTIVATION OPERATIONS



Energy is used in a variety of stages and manners throughout cannabis cultivation. This illustration shows the range of process uses and sources commonly found in cannabis cultivation operations.

WHERE IS ENERGY USED IN CANNABIS CULTIVATION?

Energy use is prevalent throughout most cultivation operations, from lighting to temperature control to dehumidification. However, the intensity of energy use varies widely based on cultivation methodology and operational efficiency.

NON-GRID SOURCES OF ENERGY USED IN CANNABIS CULTIVATION

While this report primarily studies electricity use, many sources of energy are used in cannabis cultivation. Additional research should be done to more fully understand usage of non-grid fuel sources.

UTILITY PROGRAMS AND INCENTIVES

Energy utilities often provide financial incentives to their customers to motivate a selection of energy efficient technologies with the goal of stabilizing energy infrastructure and pricing. Incentives are typically key elements in programs that subdue the need to build additional costly generation facilities by driving conservation among large energy consumers. In mature markets where savings are predictable, incentives are generally prescriptive, meaning dollar amounts are set on certain technologies based on expected savings. Given the relative lack of history and data, incentives for cannabis operations are generally determined based on custom modeling of energy saved.

LIGHTING: ITS USE AND ENERGY IMPACT

Lighting is a critical driver of energy consumption in indoor cultivation operations. Lighting demand in indoor cannabis cultivation operations is 70 times more energy intensive than commercial office buildings.[1] Additionally, given this intensity, the lights create heat, which combines with plant transpiration to become humidity, thereby resulting in a need for dehumidification which then requires additional energy to manage.

Indoor cultivation has a long history of High Intensity Discharge (HID) lighting use, particularly High-Pressure Sodium (HPS). However, over the years, ranges of products have been developed based on grower preferences on intensity and spectral composition.

In greenhouse settings, supplemental lighting is used along with blackout (light deprivation) curtains to mimic summer sunlight patterns and extend the number of harvests per year.

A range of lights are used in three main production stages:

Propagation

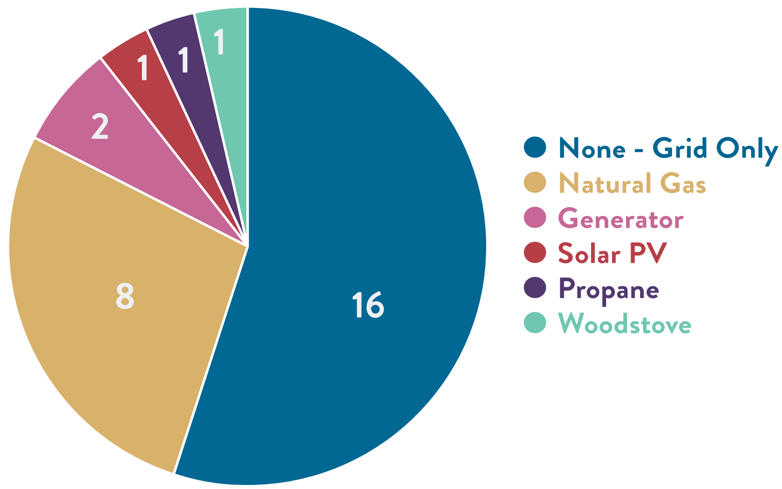
The propagation phase is the initial start of the cannabis production process. Plant propagation is the process of replicating a genetic strain. The most common propagation technique is cloning from living genetic stock. In cloning, small cuttings are taken from a large mother plant and, through the rooting process, are transformed into indi-

1. *Amplified Farms 2017: Indoor Horticulture Lighting Study, Sacramento Municipal Utility District, March 14, 2018*

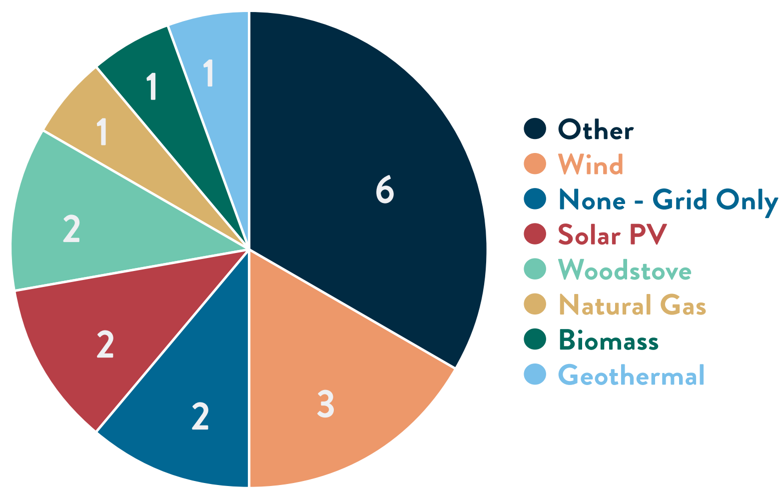
SOURCES OF NON-GRID ENERGY IN CANNABIS CULTIVATION OPERATIONS

A study of farms that filled out the Cannabis PowerScore survey found a range of sources of energy use beyond utility electricity. It should be noted that this issue deserves further research to quantify the amounts of each source used, and to determine a full carbon footprint.

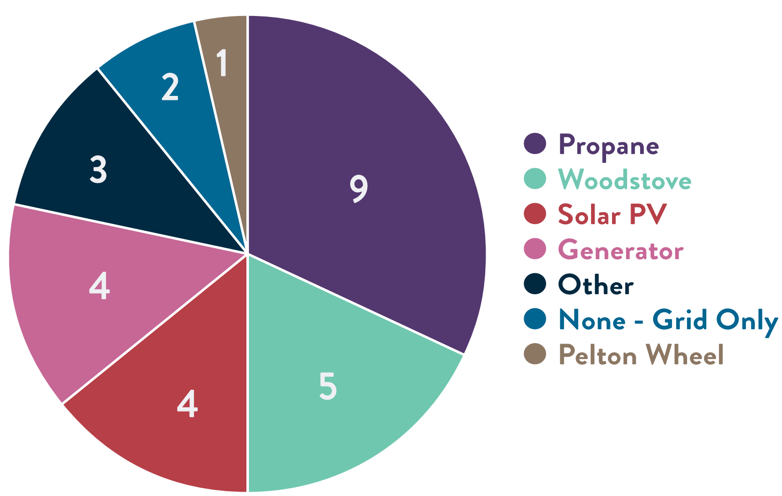
Sources of Energy: Indoor (n=27)



Sources of Energy: Greenhouse/ Mixed (n=13)



Sources of Energy: Outdoor (n=17)



vidual plants of the same genetic profile as the mother stock. Clone plants are in the range of 4"-8" in stature and can be consolidated together into trays for planting. During this stage of the plant's life it takes up the smallest footprint and uses the least amount of resources. Clone plants are generally kept under lower-wattage lights 18-24 hours a day in anticipation of the next cycle. This stage generally represents about 5% of total indoor cultivation area and less than 5% of overall electricity use.

Vegetative

Once the clones have rooted and hardened off, they are transplanted to a vegetative area that has higher intensity light and different environmental conditions. In this stage, the plants are vigorously growing in size and need much more area and resources (light, water, nutrients, soil, maintenance). Mother plants, from which clones are cut, are most often kept in vegetative growing areas as well. Outdoor farms often "veg" indoors under artificial light until transferring the mature plants in fields under the summer sun for the flowering stage. Historically, growers have preferred high-intensity discharge (HID) lights and metal-halide (MH) lamps in the vegetative stage, though many are now turning to LED and CMH fixtures. Lights are generally on 18 hours per day in this stage, which represents roughly 25% of total cultivation area. Depending on strain and grower preference, plants remain in the vegetative stage for 2-6 weeks, with indoor vegetative cycles seeming to average 2-3 weeks and greenhouse seeming to average 4-6 weeks. The vegetative stage makes up roughly 20% of total indoor cultivation space and consumes an estimated 30-40% of total electricity use. Common light types are HPS (double-ended and single-ended), MH, CMH and LED.

LIGHTING BY STAGE OF CULTIVATION

	Clone	Vegetative	Flower
Duration	1-2 weeks	2-6 weeks (2-3 indoor; 4-6 greenhouse)	7-11 weeks
Light Types Used	CFL, T5, T8, LED	HPS (double-ended & single-ended), CMH, MH, LED	HPS (double-ended & single-ended), CMH, MH, LED
Light Schedule (hours on)	18-24	18	12
Lighting Power Density	5-40 watts / sq. ft	15-70 watts / sq. ft	40-70 watts / sq. ft

Sources: SMUD, Energy Trust of Oregon, Calyx King Consulting

Flowering

The final stage of the plant's life cycle is the flowering phase. In indoor environments, once the daily light schedule is switched to 12 hours of light per day the plant undergoes a hormonal response to switch from vegetative growth to flower proliferation. As the plant rapidly adds biomass, its photosynthesis rates peak during this phase and the plant consumes the highest amounts of light, CO_2, and water. And because the plant is consuming the most at this point, this is generally the phase of production representing the highest energy intensity and the most overall energy consumption. It is also the stage with the largest square footage and the highest value crops. As a result, growers and investors are frequently risk-averse to forms of lighting other than the historically dominant HPS. It could be argued that double-ended HPS is the industry standard for indoor flowering, though the mix appears to be changing as cost pressures increase and perceptions of LED performance improve. Lights are generally on 12 hours per day in this stage, which represents about 70% of total cultivation area. The flowering stage is responsible for roughly 50-65% of total facility electricity consumption. Depending on strain and grower preference, plants remain in the flowering stage for 7-11 weeks, with 9 weeks being a rough average. Light types used include HPS (double-ended and single-ended) and CMH, though MH and LED are.

HORTICULTURE LIGHTING TERMS AND WHY THEY ARE IMPORTANT

To understand what energy efficiency means in the context of horticultural lighting, it is important to note that horticulture lighting is designed to influence a plant's growth rather than a human's visibility. Human lighting performance is commonly measured in lumens, whereas horticultural lighting performance is measured using the following terms:

- **Photosynthetically Active Radiation (PAR)*:** Light that falls between the range needed for photosynthesis (400-700 nanometers).
- **Photosynthetic Photon Flux (PPF)*:** The total amount of PAR produced in a second, measured in micromoles per second (μmol/s).
- **Photosynthetic Photon Flux Density (PPFD)[2]:** The total amount of PAR that reaches the plant surface, measured in micromoles per square meter per second (μmol / [m[^2]]^/ s).
- **Photon Efficacy:** Measures how efficiently a horticulture lighting system converts energy into photons of PAR, measured in micromoles per Joule (μmol/J).
  NOTE: Photon Efficacy is a separate term referring to the percentage of PAR produced that is actually delivered to the canopy.[3]

LIGHT FIXTURE PATTERNS AND LIGHTING POWER DENSITY

Where artificial light is used, there are relatively standard patterns for spacing between light fixtures relative to the canopy below. These patterns have been established relative to the required photosynthetic photon flux density (PPFD) values, which are meant to recreate the natural sunlight intensities that trigger photosynthesis during each stage of growth.

2. Amplified Farms 2017: Indoor Horticulture Lighting Study, Sacramento Municipal Utility District, March 14, 2018

3. Horticultural Lighting Systems: Understanding the Numbers, Fluence, 2018

TYPICAL LIGHT FIXTURE DISTRIBUTION IN CANNABIS CULTIVATION

Fixture patterns can vary by sole-source or supplemental designs, or by stage of cultivation. Most flowering rooms, however, are typically on a 4'x4' pattern, meaning one light is hung for every 16 square feet of canopy. It should be pointed out that some cultivators prefer 4x5 or 5x5 patterns indoors.

Lighting Power Density (LPD) is a formula of watts of lighting per square foot and has been used as a basis for regulating energy consumption. However, it does not measure the lighting intensity required to activate plant growth at each cultivation stage. Likewise, it does not fully account for a facility's efficient use of energy, particularly given the lack of studies verifying the interactive effects between lighting and HVAC in highly controlled agricultural environments.

It should be noted that a facility-wide LPD can be calculated by inserting each room's percentage of total cultivation space to create an overall weighted average. The Massachusetts Cannabis Control Commission clarified its regulation by using this methodology in its updated guidelines. It also should be noted that an LPD of 36 watts per square foot can be achieved in a variety of arrangements of fixture wattages and light fixture distribution.

LED LIGHTING TRENDS

LED lighting technologies are increasingly incorporated into cultivation operations and are becoming preferred in programs and policies developed by utilities and governments. Yet much of the market is unaware how best to integrate them for optimal outcomes.

While market share is challenging to predict in a highly dynamic marketplace, cost pressures and quality improvements are driving some capture from HIDs to more efficient lights, including LEDs. It is estimated that LEDs capture less than 10% of the overall cannabis lighting market.

Despite the currently low share, LEDs are increasingly used in cannabis cultivation for a variety of reasons, including:

- **Spectral composition** – LED color spectra can be calibrated to meet grower preferences, from white to pink to purple;
- **Efficiency over HPS** - as measured by photon efficiency in micromoles per Joule, μmol/J;
- **Proximity to canopy** - enabling space efficiency and vertical stacking; and
- **Improved HVAC efficiencies** - improved lighting efficiency produces less heat, resulting in less HVAC load.

Despite the promise of energy savings, LEDs still suffer from the perception of subpar performance exacerbated by early use of non-agricultural LEDs for cultivation. It is difficult to say if this is due to the inferior performance of certain products or certain manufacturers or untrained cultivators or oversized HVAC equipment, or some combination. User errors are likely due to assumptions of "one-to-one" replacement approaches that do not adequately adjust for light intensities (PPFD), water use, nutrient delivery, HVAC set-up, etc.

Despite years of manufacturer R&D and grower input, there is still very little objective information on best practices associated with cultivating under LED lights. This has been a challenge for early adopters to LED technology.[4]

That said, one commonly agreed upon best practice is to regularly monitor light levels with a high-quality light meter to ensure sufficient PPFD for the relevant growth stage. Furthermore, the limited data on best practices has done little to slow the adoption of LEDs among growers who are aggressively focused on lowering their production costs.

HORTICULTURAL LIGHTING STANDARD AND QUALIFIED PRODUCT LIST

The DesignLights Consortium (DLC), a non-profit organization that collaborates with utilities, manufacturers and governments to accelerate adoption of high-performing lighting solutions, recently issued a set of testing and performance requirements that will enable horticultural lighting products to be on a DLC Qualified Product List (QPL).[5] What this means is that purchasers of horticultural lighting will benefit from an independent evaluation of product performance claims, so they can move away from the current "buyer

4. *LED and HID Horticultural Luminaire Testing Report, Leora Radetsky, Lighting Research Center, Rensselaer Polytechnic Institute, May 3, 2018*

5. *Testing and Reporting Requirements for LED-based Horticultural Lighting, DesignLights Consortium, Oct 1, 2018*

beware" dynamic of LED lighting in cannabis. This QPL's standardized and verified performance data will also allow utilities to more easily and rapidly issue incentives for energy savings without time-consuming per-facility custom evaluations.

HVAC: ITS USE AND ENERGY IMPACT

Maintaining precise control of temperature, relative humidity, and ventilation are critical to managing plant health, and thus to quality and yield. Areas of particular concern in controlled environments include protecting against mold and mildew growth that can occur when humidity gets too high, maintaining appropriate conditions at the leaf level to drive consistent plant growth, and filtering out any airborne contaminants.

Poorly designed mechanical systems can increase energy consumption by up to 50%. Decisions by growers about temperature and relative humidity setpoints have a major impact on how large the HVAC system must be to meet the demand; therefore, design conditions must be carefully considered when trying to operate a facility with optimal efficiency.

HVAC energy use is driven by cooling the heat gained from lighting, removing moisture from the plant's evapotranspiration process, circulation and mixing of the air, along with filtration of the air for odors and contaminants. As part of overall temperature and humidity regulation, indoor HVAC systems also often include reheat in phases when lights are off. The preferred form of reheat should be reclaimed energy from the cooling/dehumidification process and not new energy, such as electric reheat, which adds to the energy consumption. While managing excess heat is generally the primary need application of HVAC systems in indoor environments, it should be pointed out that greenhouses often require heating in winter months via natural gas and other fuels, particularly in colder climates. This heating often represents the largest energy cost in greenhouses and, in certain climates, can force costs above those seen indoors. While this report is focused on electricity use, future reports will also explore non-grid energy sources.

“ Poorly designed mechanical systems can increase energy consumption by up to 50%.

HVAC SHARE OF ENERGY CONSUMPTION AND COST

The share of cultivation-related electricity consumption represented by HVAC can vary greatly based on geography, seasonality, and facility activities (e.g., if processing is onsite), though it is typically 25-50% of total electricity consumption. In addition, climate control systems can be the largest capital expenditure associated with a cultivation facility aside from the real estate itself.[6]

6. surna.com/content/uploads/2017/12/Technology-Comparison-Rev-5.pdf

COMMON HVAC SYSTEMS

There are six major groupings of HVAC systems used in cannabis cultivation. Their energy performance and environmental control capabilities are highly influenced by design, installation, operation, and maintenance. Additional research is needed to better understand how to optimize HVAC in controlled environment agriculture.

	Indoor	Greenhouse
Cooling	• Split Unit(s) • Rooftop/Packaged Unit(s) • Variable Refrigerant Flow (VRF) Systems • Central Chiller(s) - Hydronic fan coils or air handlers	• Evaporative Cooling (wet wall) • Sealed Environment With Indoor Solution
Dehumidification	• Portable Units • Not Dedicated - Reheat (conventional) • Not Dedicated - Reheat (reclaimed waste heat) • Dedicated Dehumidification Units • Fully Integrated Cooling + Dehumidification	• None - Ventilation Only • Dessicant Dehumidification • Sealed Environment With Indoor Solution
Heating	• None - Sufficient Heat from Lighting • Natural Gas - Direct Fired Units • Natural Gas - Ducted Furnace • Natural Gas - Hydronic Boiler + Fancoils • Geothermal - Heat Pump	• Natural Gas - Direct Fired Units • Natural Gas - Hydronic Boiler + Fancoils • Natural Gas - Hydronic Radiant Floor/Slab • Geothermal - Ground Air Exchange • Geothermal - Heat Pump

Source: HVAC Systems and Grow Room Energy Usage, Desert Aire, January 2018

Despite the enormous upfront and operating expenses, HVAC equipment is often installed poorly and operated inefficiently. There are several reasons for this:

- Cultivators incorporated HVAC systems in the era of prohibition, and therefore developed a naive understanding of how to use HVAC to control environments. They are, however, generally untrained in the intricacies that result in high-performing systems. Many operators of newly regulated facilities are simply trying to scale up what worked for them when profit margins were much higher and when systems were not designed with energy efficiency as a consideration.
- Likewise, cultivators have not seemed to place high importance on proper installation, commissioning, and servicing of the equipment. Properly designed equipment installed poorly or not commissioned will only increase energy consumption.
- HVAC systems are often selected without the understanding that sensible (cooling) and latent (moisture) factors are interrelated. The HVAC system must integrate the control of both modes if the highest energy efficiency is to be achieved.
- The HVAC industry is accustomed to designing buildings for humans, not for

plants. When growers give large ranges of desired temperatures, HVAC engineers often install oversized equipment, or attempt to make systems adherent to building codes intended for comfort cooling instead of process cooling, resulting in higher up-front and ongoing costs, as well as poor performance, especially associated with dehumidification.

- It should be noted that HVAC efficiency challenges are not unique to cannabis and are prevalent throughout most commercial and industrial settings.

NEED TO BETTER UNDERSTAND HVAC BEST PRACTICES AND INTERACTIVE EFFECTS BETWEEN LIGHTING AND HVAC

There are essentially no commonly accepted best practices for HVAC design, installation, operation, and maintenance in cannabis. The industry would be well served if peer-reviewed best practices were developed.

It should also be noted that indoor agricultural settings are operated very differently from human-occupied environments. Therefore, these settings should be evaluated differently, and existing commercial HVAC expertise and knowhow may not be entirely applicable. For example, while the impact of lighting on space conditioning loads is highly predictable in human indoor environments, the specific interactive effects between lighting and HVAC in controlled agriculture environments are relatively unstudied. In addition, because energy loads attributed to HVAC in indoor grow environments are year-round and constant, and because dehumidification is extensively used, the SEER (Seasonal Energy Efficiency Ratio) rating typically applied to air conditioning equipment used in human-occupied buildings is an inadequate measure of system efficiency in indoor cannabis cultivation.

An important point regarding LEDs and controlled humid environments is that, generally, the rejected heat from HID fixtures is in large part needed to offset the evaporative cooling effect of the evapotranspiration process. Hence, the reduced rejected heat from LEDs may lead to negative heating savings. In other words, to "close the loop" on the thermodynamics of a mostly-closed-off flower room, heat will be needed.

Therefore, when retrofitting from HID to LED lighting, overall energy use should decrease through reduced cooling, though there may be additional energy use associated with filling in lost heat required to return the room to a suitable temperature for plant growth. Some HVAC and dehumidification options are better able to cope with the lesser rejected heat than others.

Meanwhile, the ranges of requested room and leaf temperatures that growers make to HVAC professionals is all over the board, a swing of 10+ degrees and 15%+ relative humidity, leading to commonly oversized systems. Developing best practices will be an increasingly important issue as mature markets like Colorado and Washington look to retrofit facilities to drive down costs.

TECHNIQUES, TECHNOLOGIES AND TRENDS

Several emerging technologies, along with newer cultivation techniques and trends, are indicating opportunities for increased efficiency.

Automation

Many uses of energy can be cut by monitoring building system performance, automating controls and reacting to alerts about needed adjustments.

Heat recovery

Some operations are recovering rejected heat from cooling systems for dehumidification.

Combined Heat and Power (CHP)

CHP systems produce electricity, heat, and CO_2 simultaneously at very high efficiencies. These systems are widely deployed in advanced greenhouses outside of the cannabis industry. They also can be used for indoor operations by converting heat output to chilled water via absorption chilling.

Engine Driven Chillers

These chillers use natural gas engines, rather than electric motors, to drive the system's compressor. While they are not by definition more efficient than traditional chillers, they are deployed to reduce electrical costs and/or when growers do not have a sufficient incoming electrical service for their projected load. If the engine's waste heat is captured, which isn't always the case, efficiency can exceed that of traditional systems.

Water-Side Economization

In chilled water systems, fluid coolers are being incorporated in colder climates to replace compressors during cold weather. Fluid coolers utilize cold outside conditions to maintain chilled water temperature, enabling high energy consumption compressors to be replaced with fans. The result is "free cooling" without needing to ventilate the facility as with air-sided economization. More energy infrastructure is required, as the design has to accommodate the power requirements for both the compressors and the fluid cooler; however, overall consumption associated with cooling and dehumidification can be significantly reduced.

Vertical Stacking

Indoor grow environments are increasingly optimizing floor space by placing plants on racks that are stacked on top of each other. Because of lower heat, LEDs can be placed closer to the plant canopy than HIDs. This take on indoor agriculture is experiencing growth outside of cannabis cultivation as well.

Micropropagation/Tissue Culture

Micropropagation, or tissue culture, is a technique used increasingly in cannabis cultivation, as with other crops. It offers the promise of significantly reduced square footage associated with storing clone and mother plants, thereby increasing overall production efficiency.

Grower Interest in Connecting with Utilities

Despite decades of tense relations between growers and utilities, cannabis operators are increasingly interested in connecting with utilities to understand how to get support on saving energy. Utilities would be well served to reach out to this unique class of heavy-consuming customers.[7]

7. *Harvesting Energy Savings in Indoor Agriculture Facilities: Quick Wins for Cultivators and Utilities, David Podorson, September 11, 2015*

ENERGY BENCHMARKS

The 2018 Cannabis Energy Report is the combination of two original works: The first includes the U.S. cultivation estimates for both the illicit and legal markets (all estimates being based on New Frontier Data's analysis of legalized production in legal states, as well as careful assessment of illicit activities in the non-legalized market); the second work includes energy consumption metrics based on data input by cultivators to the PowerScore tool. The total U.S. industry electricity consumption estimates, and the estimated electricity-based carbon emissions, are derived from those two sources.

DATA SUBMISSIONS BY FLOWERING LIGHTING TYPE

HPS	39
LED	12
CMH	2
HPS/LED	2
HPS/MH	2
MH	1
HPS/LED/CMH	1

Background and Methodology

This section of the report attempts to provide benchmark performance standards and explores potential causes of performance variation. As described on pages 16 and 18, all analysis herein has been performed using data aggregated by the Resource Innovation Institute's Cannabis PowerScore tool. This online tool collects self-reported performance data and cultivation characteristics (annual production, annual electricity consumption, canopy area, cultivation type, lighting type, etc.), and submitters see benefit by instantly being shown their energy ranking relative to the rest of the dataset.

STUDY LIMITATIONS

There are a few potential limitations to the data that ought to be highlighted. First, this is user-reported data that carries risk of being either submitted in error or with a different interpretation than the

DATA SUBMISSIONS BY CULTIVATION TYPE AND STATE

	Total	CA	CO	MA	MI	NV	OH	OR	VT	WA
Indoor	34	4	3	3	2	1	1	18	0	2
Greenhouse/Hybrid/Mixed	27	0	0	0	0	0	1	20	1	5
Outdoor	20	7	0	0	0	0	0	13	0	0

tool's creators intended. For example, a user might have a cultivation facility with two electric meters, however reported annual consumption may only be from one meter. Or, a user's submission of annual production by mass could have been wet, rather than fully dried weight. In an attempt to minimize this source of error, the authors of this report have removed outlier submissions with the guidance of Kelson Redding working with Energy-Trust of Oregon.

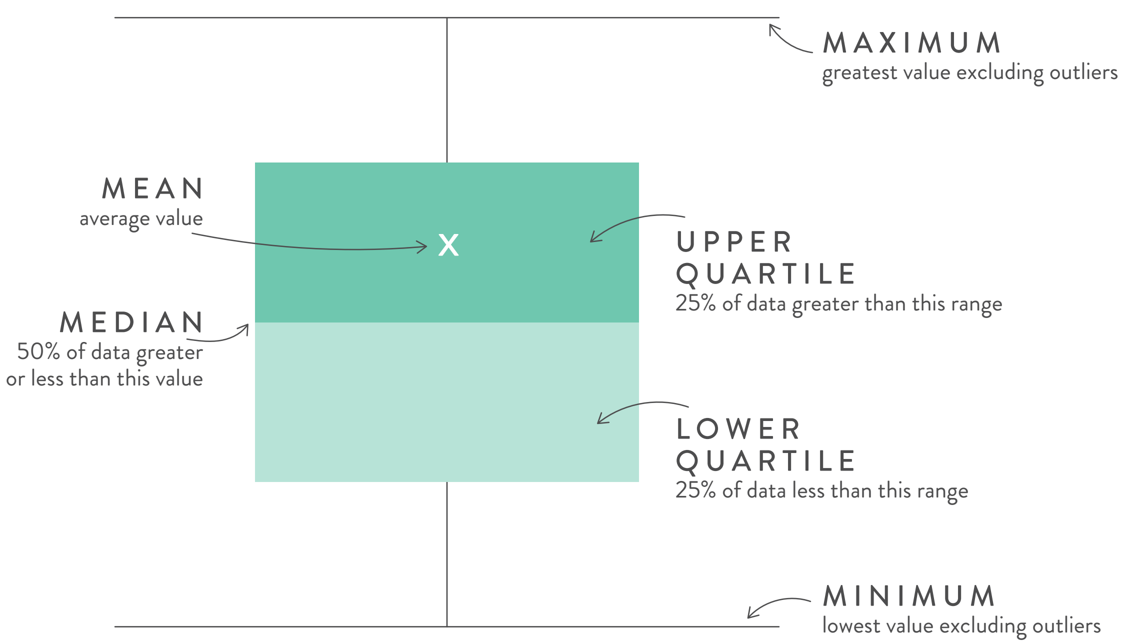
Additionally, because users submit data to Power-Score on their own accord, and are not compelled to by their regulators, there is potential for a submission bias wherein the data overrepresents cultivators who are actively engaged in improving their energy and environmental performance. While, for this work, little can be done to correct this potential source of error, future iterations of this work will hopefully utilize a much larger and less potentially biased dataset as state regulators begin to track the industry's energy and environmental performance.

A final point to highlight is that PowerScore does not request quantified consumption of energy sources other than electricity. This likely has a significant impact for greenhouses that use natural gas or other combustion sources for heating.

A broad characterization of the PowerScore dataset is shown above. Note the large number of Oregon based submissions. Future iterations of this report will focus on aggregating a broader geographical distribution of data.

The following sections will make extensive use of bloxplots (box and whisker plots). A guide to interpreting this chart has been included below.

BOXPLOT EXAMPLE



Key Benchmarks

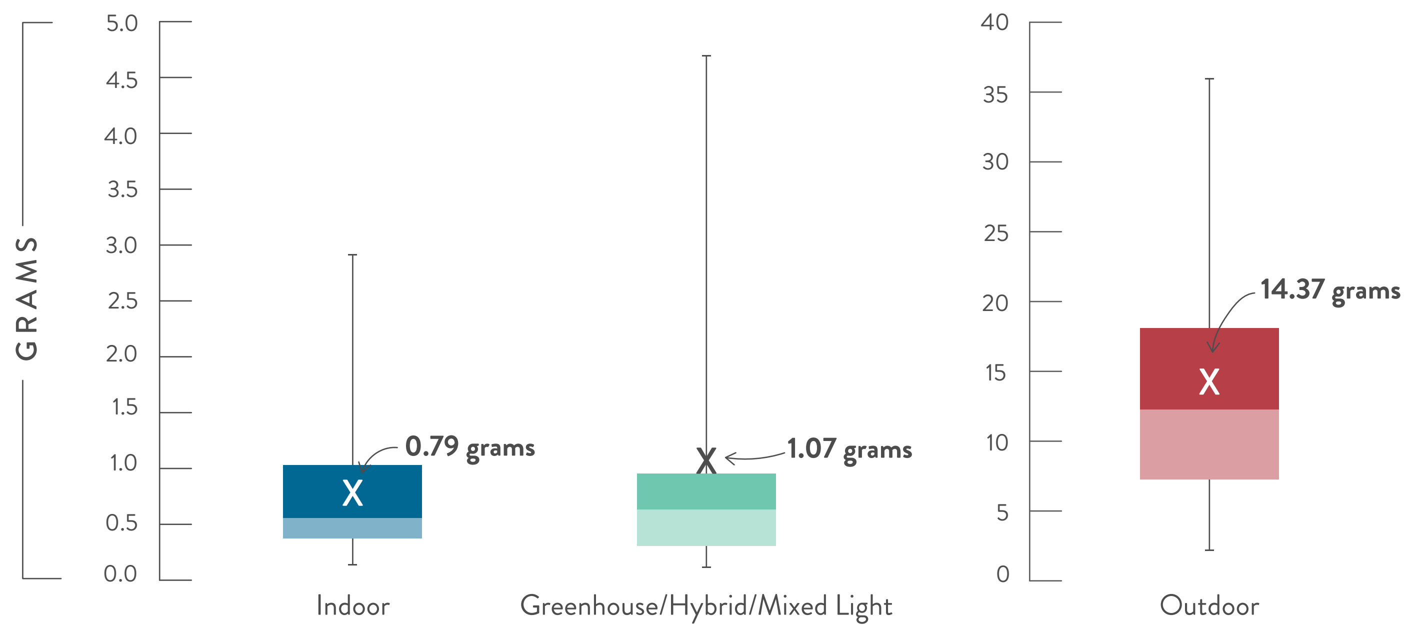
The table below shows the five key metrics for tracking a cultivation organization's electricity performance, and the average Cannabis PowerScore data by cultivation type. More detail is provided on each metric in the following sections.

It is important to note that there is additional energy embedded within the supply chain and other processes that is not accounted for in this analysis. The estimates in this report do not include other areas such as the energy used for transportation, production of CO_2 for carbon fertilization, production of extracts and derivatives, or irrigation water production and treatment outside the facility. The analysis in this report focuses specifically on grid-based electricity used in cultivation.

KEY BENCHMARKS

Cultivation Type	Electricity Productivity (grams/kWh)	Electricity Intensity (kWh/sq.ft.)	Production Intensity (grams/sq.ft.)	Electricity Cost ($/gram)	Carbon Intensity (lbs.-CO_2e/gram)
Indoor	0.8	262	174	0.24	1.24
Greenhouse / Hybrid / Mixed Light	1.1	134	48	0.21	0.72
Outdoor	14.4	2	29	0.01	0.05

ELECTRICITY PRODUCTIVITY (GRAMS/kWh)



Electricity Productivity (grams/kWh)

Of all metrics relevant to electricity consumption, electricity productivity best represents how efficiently a cultivator is using electricity to produce cannabis. This metric represents a cultivator's cannabis output relative to its electricity input. Over a 12-month period, cannabis output is measured in grams of dry flower produced, and electricity input is measured in kilowatt-hours (kWh) consumed. Organizations utilizing this metric should limit electricity input (typically recorded via utility bills) captured in this metric to that which is applied toward the cultivation process, as opposed to attached retail operations, warehouse/distribution, etc.

RII's Cannabis PowerScore data shows average electricity productivities of 0.8, 1.1, and 14.4 grams per kWh for indoor, greenhouse/hybrid/mixed-light, and outdoor cultivation operations respectively. As expected, this immature and fragmented industry exhibits a wide distribution of this metric, despite the exclusion of outliers. The boxplot above shows minimum, first quartile, median, mean, third quartile, and maximum performance by cultivation type.

LIGHTING AND ENERGY PRODUCTIVITY

The Cannabis PowerScore dataset also shows that a cultivator's lighting choices can impact electricity productivity. While there was not sufficient data to generate meaningful insights on various lighting types' impact in greenhouses, there was sufficient indoor cultivation data. Indoor operations using HPS flowering lights show an average electricity productivity of 0.6 grams per kWh, while indoor operations using LED flowering lights show an average more than twice that, at 1.4 grams per kWh. It is important to note that this difference cannot be attributed only to the use of LEDs. Cultivators who use LEDs are also likely more informed of other efficiency measures related to HVAC design, building envelope, controls/automation, etc.

Lighting Type (Indoor)	HPS	LED
Average Electricity Productivity (grams/kWh)	0.6	1.4

Additionally, the Cannabis PowerScore dataset shows a cultivator's location (indicated by their state) can have a meaningful impact on electric-

AVERAGE ELECTRICITY PRODUCTIVITY BY STATE

STATE (INDOOR)	CA	CO	MA	MI	NV	OH	OR	VT	WA
Average Electricity Productivity (grams/kWh)	0.68	1.53	1.89	1.00	0.56	n/a	0.58	n/a	1.22

NOTE: It is important to note that a cultivation site's electricity intensity appears to be significantly impacted by lighting type choice. While there was not enough data to generate meaningful insights on lighting type's impact in greenhouses, there was sufficient indoor cultivation data.

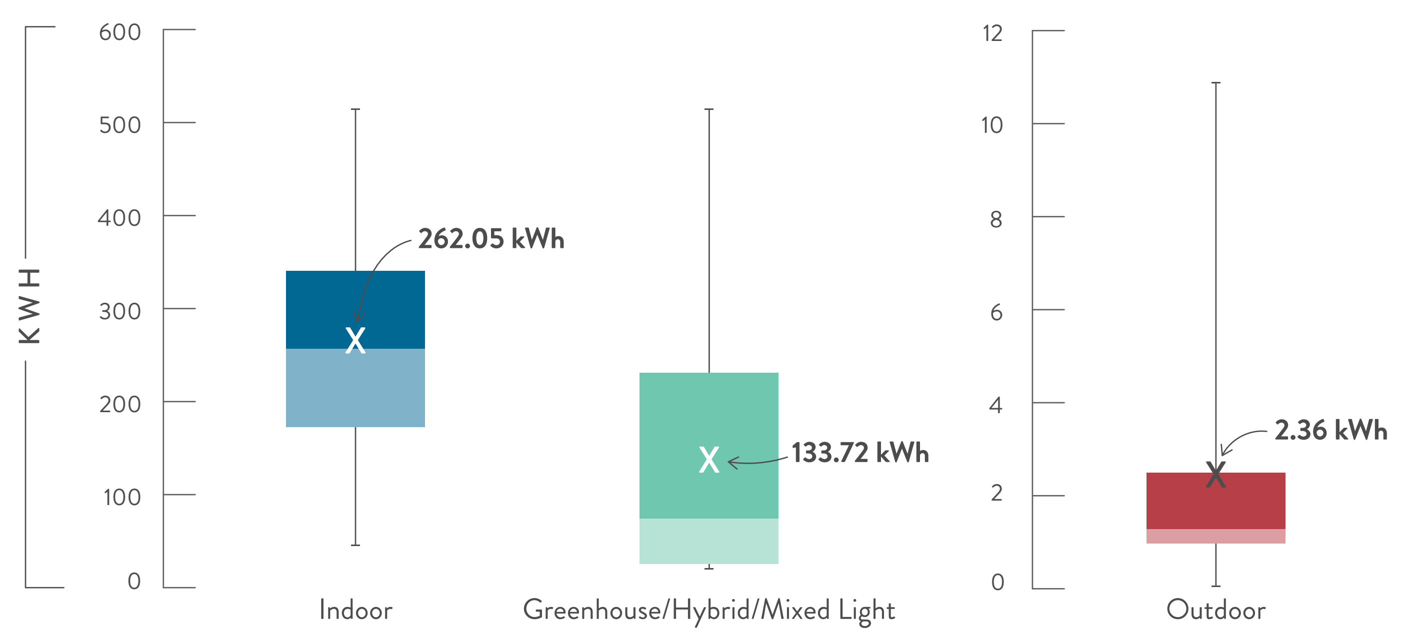
ity efficacy. While it is difficult to attribute the underlying causes of these discrepancies, local climate (HVAC requirements), market dynamics, and regulatory choices are likely key drivers. It is also important that the dataset is quite strong in Oregon, while much weaker in other states, so the authors of this report encourage readers to consider how far to extrapolate each state's results.

Electricity Intensity (kWh/sq. ft.)

This metric describes a cultivation facility's electricity consumption per unit of area. Energy industry professionals are likely familiar with energy use intensity (EUI), a metric used for characterizing building energy consumption and often used in benchmarking exercises. While this is similar, it typically includes all energy use (not exclusively electricity) divided by total building area, whereas this version of the metric focuses specifically on annual electricity consumption and uses flowering canopy (rather than total building area) as the relevant definition of area. In addition, this metric is specific to on-site energy consumption, as opposed to versions of EUI that account for the original sources of energy, such as the fuel used in powerplants.

Also, when applying any metric with area in the denominator, it is worth considering how a given site's utilization might impact results. Consider a new facility that is still ramping up production, or one that reduces output in response to low prices during the outdoor harvest months. Compared to a facility of identical size and efficiency that operates at 100% utilization, the electricity intensity at the lower utilization facility will be lower despite electricity productivity being the same. This dynamic is likely expressed in some of the Cannabis PowerScore data.

ELECTRICITY INTENSITY (kWh/SQFT)



This metric, while not a stand-in for what most people think of as efficiency, is particularly valuable for utilities who are tasked with anticipating a proposed facility's energy consumption and reducing existing facility's energy consumption. It can also be used (with discretion) to compare facilities of equivalent cultivation types (indoor, greenhouse, etc.).

Cannabis PowerScore data indicates average electricity intensities of 262, 134, and 2 kWh per square foot of flowering canopy for indoor, greenhouse/hybrid/mixed light, and outdoor cultivation sites respectively. The distribution is also quite large but generally comports with the expectations of cannabis industry experts and existing research.[1]

The boxplot shows minimum, first quartile, median, mean, third quartile and maximum electricity intensity by cultivation type.

Indoor operations using HPS flowering lights show an average electricity intensity of 282 kWh per square foot, while indoor operations using LED flowering lights show an average of 173 grams kWh per square foot per year.

Lighting Type (Indoor)	HPS	LED
Average Electricity Intensity (kWh/sq. ft.)	282	173

Additionally, the Cannabis PowerScore dataset shows a cultivator's location (indicated by their state) can have a meaningful impact on electricity intensity. While it is difficult to attribute the underlying causes of these discrepancies, regulators' market design decisions (such as plant count and square foot caps) likely play a large role, in addition to local climate and market dynamics. It is also important that the dataset is quite strong in Oregon, while much weaker in other states.

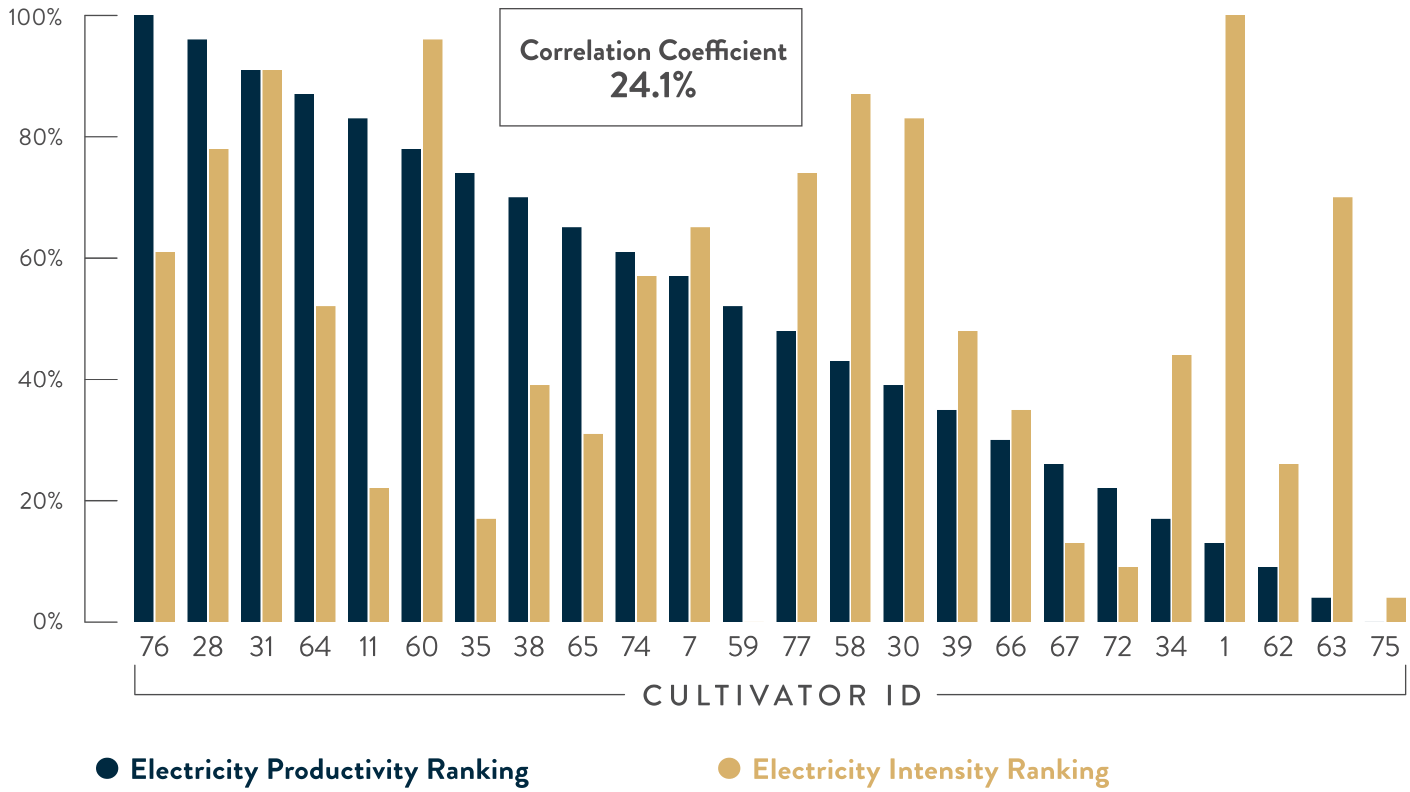
It is worth pointing out that electricity intensity performance does not necessarily track with electricity productivity performance. Although electricity intensity is commonly used as the primary metric of energy consumption at cultivation facilities and is implied to be a measure of efficiency, it does not describe inputs versus outputs as a proxy for efficiency should. The chart below illustrates this, showing the ranked electricity productivity and electricity intensity Cannabis

AVERAGE ELECTRICITY INTENSITY BY STATE

STATE (INDOOR)	CA	CO	MA	MI	NV	OH	OR	VT	WA
Average Electricity Intensity (kWh/sq. ft.)	241	272	143	381	514	n/a	263	n/a	154

1. nwcouncil.org/sites/default/files/2018_0612_p4.pdf, assets.bouldercounty.org/wp-content/uploads/2018/04/BCEIOF-DSM-Study-Phase-1.pdf

ELECTRICITY PRODUCTIVITY RANKING VS. ELECTRICITY INTENSITY RANKING



PowerScore submissions from indoor cultivators. Note how few submissions have similar electricity productivity and electricity intensity percent rankings. While a cultivation facility may consume a disproportionate amount of electricity for its operations, it may also produce a disproportionately large amount of cannabis. There may also be seasonal utilization differences between facilities that skew electricity intensity as a comparative metric. Alone, electricity intensity cannot be a meaningful measure of energy performance. It must be paired with a metric that considers the operation's cannabis output, such as electricity productivity or production intensity.

Production Intensity (grams/sq. ft.)

This metric describes an operation's cannabis output per unit of area. While not a measure of energy consumption, this metric is a valuable description of productivity that can supplement electricity intensity. Cannabis output is measured in grams of dry flower produced over a 12-month period, and area is defined as square feet of flowering canopy.

Cannabis PowerScore data indicates average production intensities of 174, 48, and 29 grams per square foot for indoor, greenhouse/hybrid/mixed light, and outdoor cultivation types, respectively.

The boxplot below shows minimum, quartile 1, median, mean, quartile 3, and maximum performance by cultivation type.

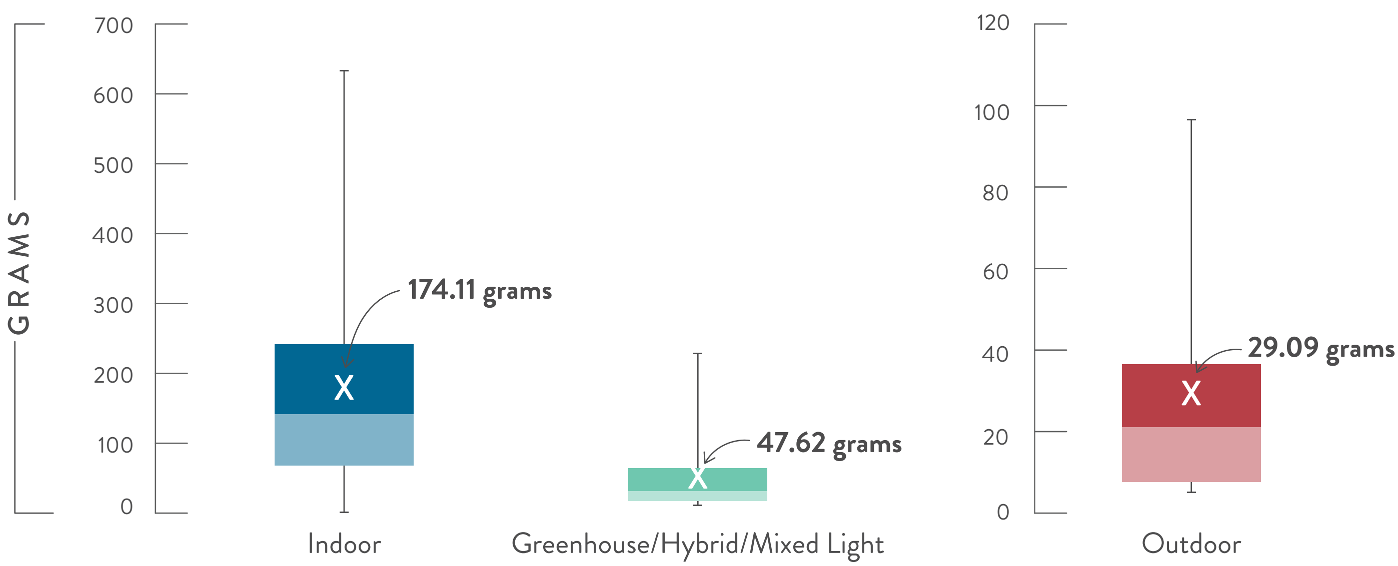
Indoor operations using HPS flowering lights show an average production intensity of 144 grams per square foot, while indoor operations using LED flowering lights show an average of 209 grams per square foot.

This result may contradict commonly touted industry wisdom that LED flowered cultivations are unable match the output of their HPS peers. It is important to note, however, that this difference cannot be attributed only to the use of LEDs, as this data only demonstrates that cultivators who use LEDs are likely to have a higher production intensity than their peers.

Lighting Type (Indoor)	HPS	LED
Average Production Intensity (grams/sq. ft.)	144	209

While some of the output numbers reported appear to be high, the seasoned industry professionals that served as peer reviewers for the report felt that they still fell within acceptable ranges given the wide variability in facility performance. The report focuses on output and flowering canopy size (rather than output associated with

PRODUCTION INTENSITY (GRAMS/SQFT)



AVERAGE PRODUCTION INTENSITY BY STATE

STATE (INDOOR)	CA	CO	MA	MI	NV	OH	OR	VT	WA
Average Production Intensity (grams/sq. ft.)	188	343	270	173	286	n/a	142	n/a	120

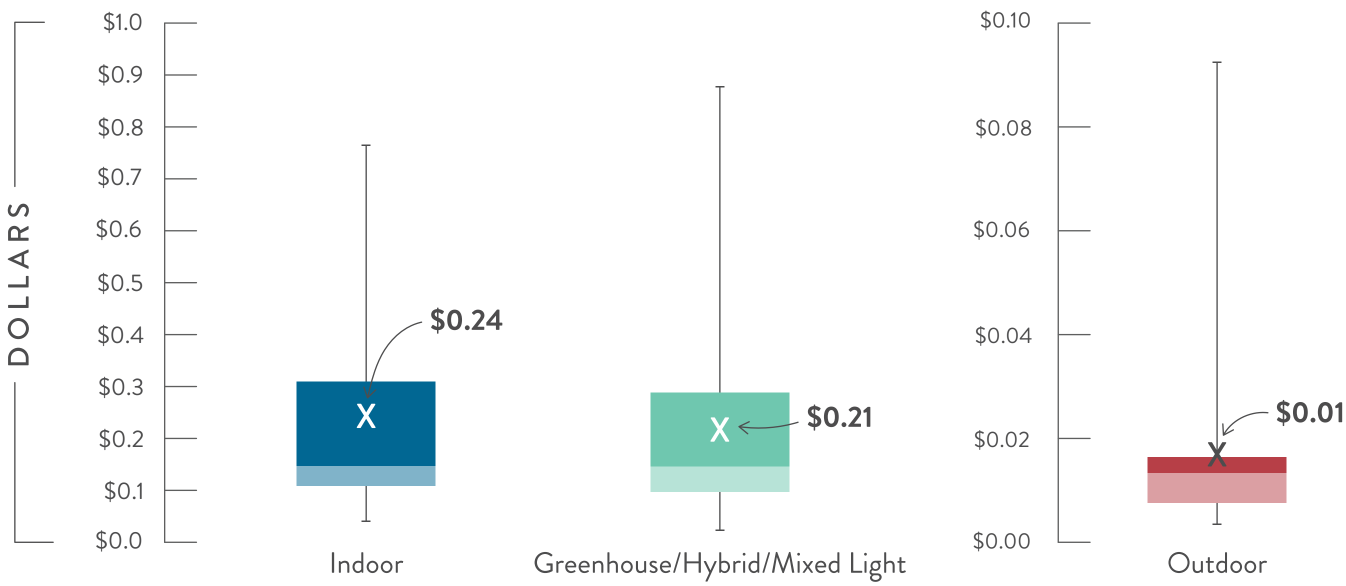
the entire facility) since cultivation facilities utilize their propagation and vegetation areas differently. Therefore, flowering canopy area is used as the basis for comparing facilities, as it the one consistent metric across all facility types.

Additionally, the Cannabis PowerScore dataset shows a cultivator's location (indicated by their state) may have a meaningful impact on production intensity. While it is difficult to attribute the underlying causes of these discrepancies, land prices, facility prices and regulators' market design decisions (such as plant count and square foot caps) likely have a significant impact.

Electricity Cost ($/gram)

This metric describes the cost of electricity specific to cultivation activities per unit of cannabis produced. Measured in cost incurred by gram produced, electricity cost is of great importance in competitive markets, where unit costs are a key determinant of market success. For this report, electricity costs were derived from electricity productivity by applying a state-by-state average commercial electricity retail price, from the Energy Information Administration, to each submission.

ELECTRICITY COST ($/GRAM)



AVERAGE ELECTRICITY COST BY STATE

STATE (INDOOR)	CA	CO	MA	MI	NV	OH	OR	VT	WA
Electricity Cost ($/gram)	0.40	0.34	n/a	0.11	0.14	n/a	0.24	n/a	0.10

Cannabis PowerScore data indicates average electricity costs of 0.24, 0.21, and 0.01 dollars per gram for indoor, greenhouse/hybrid/mixed light, and outdoor cultivation types respectively. The boxplot above shows minimum, quartile 1, median, mean, quartile 3, and maximum costs by cultivation type.

As expected, electricity cost is significantly impacted by the state in which the cultivator operates. Indoor cultivation facilities in California, where average commercial retail electricity prices were 15.89 cents per kWh, had the highest derived electricity cost.

Carbon Intensity (lbs.-CO_2e/gram)

Regulators are becoming increasingly concerned with the cannabis industry's carbon footprint. As such, it is important to develop metrics that describe the carbon emissions embedded into a unit of cannabis. For the purposes of this study, electricity-based carbon emissions have been quantified by adjusting electricity productivity with the carbon content of the electricity used in a given cultivation operation – data supplied by the Environmental Protection Agency's eGRID 2016 dataset. This results in a metric comprised of pounds of electricity-based carbon dioxide equivalent per gram of cannabis produced.

Cannabis PowerScore submissions show electricity-based carbon intensities of 1.24, 0.72, and 0.05 pounds of carbon dioxide equivalent per gram of cannabis for indoor, greenhouse/hybrid/mixed light, and outdoor sites, respectively. The boxplot below shows minimum, quartile 1, median, mean, quartile 3, and maximum costs by cultivation type.

Note that because Cannabis PowerScore does not collect natural gas consumption data, a large portion of the energy-based carbon footprint – of greenhouses using natural gas for winter heating – is not accounted for in this analysis.

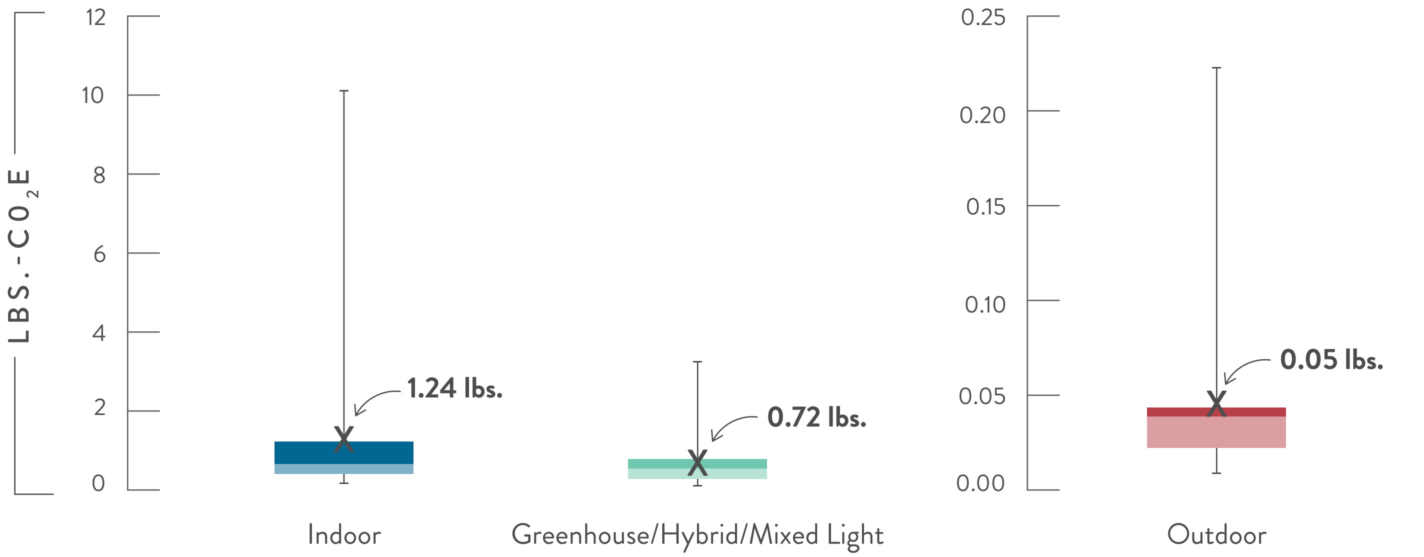
The Cannabis PowerScore data for indoor cultivation shows that the state of residence has a strong impact on electricity-based carbon intensity. In Colorado, where coal generation provides 55% of the state's power, intensity was highest. In Washington and Oregon, where hydropower is 69% and 57% respectively, intensity was lowest.

For detailed Oregon data, see Oregon Electricity Resource mix.

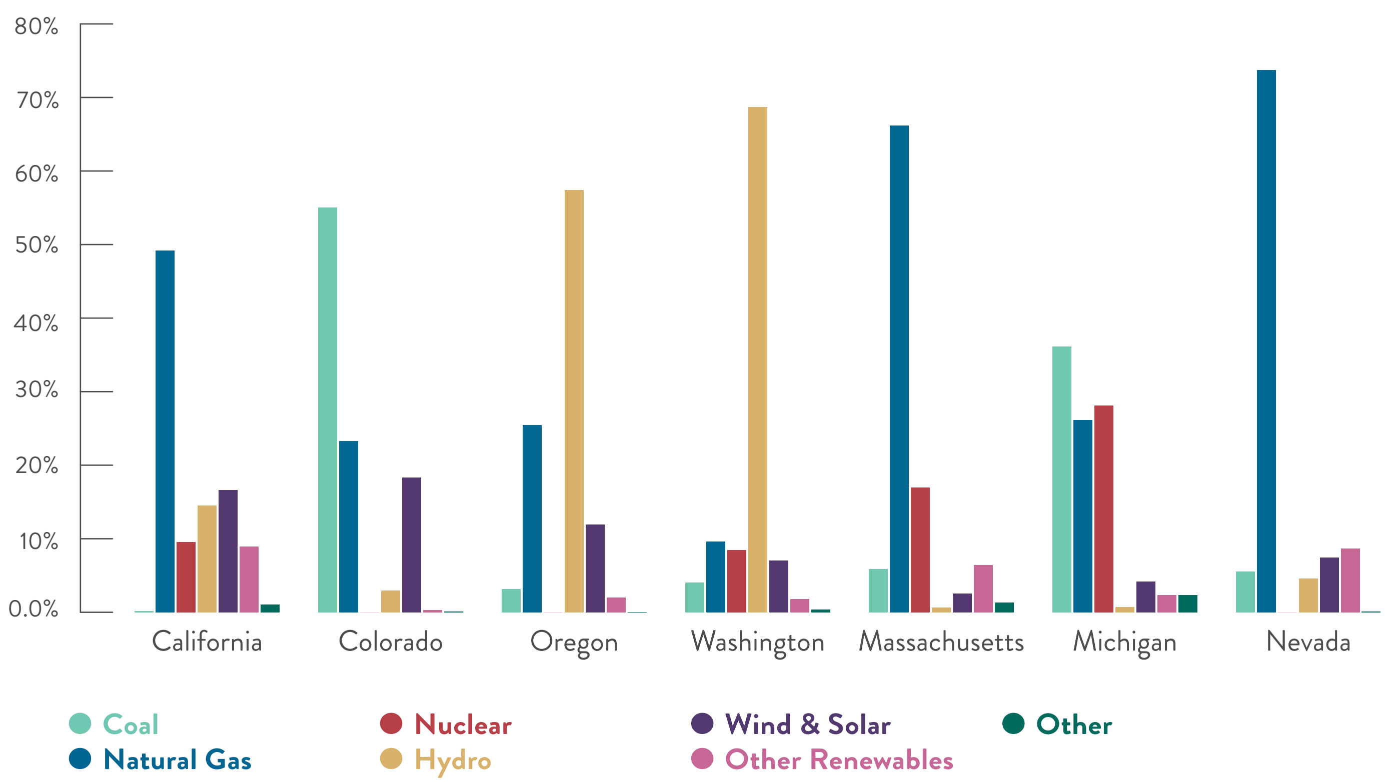
AVERAGE CARBON INTENSITY BY STATE

STATE (INDOOR)	CA	CO	MA	MI	NV	OH	OR	VT	WA
Carbon Intensity (lbs.-CO_2e/gram)	1.2	5.3	n/a	1.2	1.5	n/a	0.9	n/a	0.2

CARBON INTENSITY (LBS.-CO_2E/GRAM)



STATE ELECTRICITY RESOURCE MIX (2016)



TOTAL INDUSTRY ELECTRICITY CONSUMPTION

The analysis contained in this report reflects data specific to commercial cultivators and is not reflective of production or electricity consumption associated with residential cultivation

Cannabis Electricity Consumption, Carbon Emissions and Future Outlook

Building on the data collected by the Cannabis PowerScore tool, we examined the electricity consumption and electricity-based carbon emissions associated with the U.S. industry as whole and estimate the total energy consumption for each state.

POWER CONSUMPTION INTENSITY BY GROW TYPE

Production Type	Consumption per Gram (kWh/G)
Indoor	1.27
Greenhouse	0.94
Outdoor	0.07

REQUIRED ENERGY FOR CULTIVATION COMPARED TO OTHER INDUSTRIES

Products	kWh of Energy Required to Produce
1 Gram of Cannabis	1.27
1 Bottle of Beer	0.20

Below is a summary of the results of our analysis of power consumption intensity by different grow types:

HOW DOES ALL OF THIS ENERGY COMPARE TO OTHER INDUSTRIES?

While indoor production is more labor intensive than greenhouse or outdoor, the total amount of energy to produce one gram of cannabis is roughly equivalent to the energy required to produce a six-pack of beer.

Given the pervasive the use of cannabis in North America, the industry's energy demand is accumulating quickly.

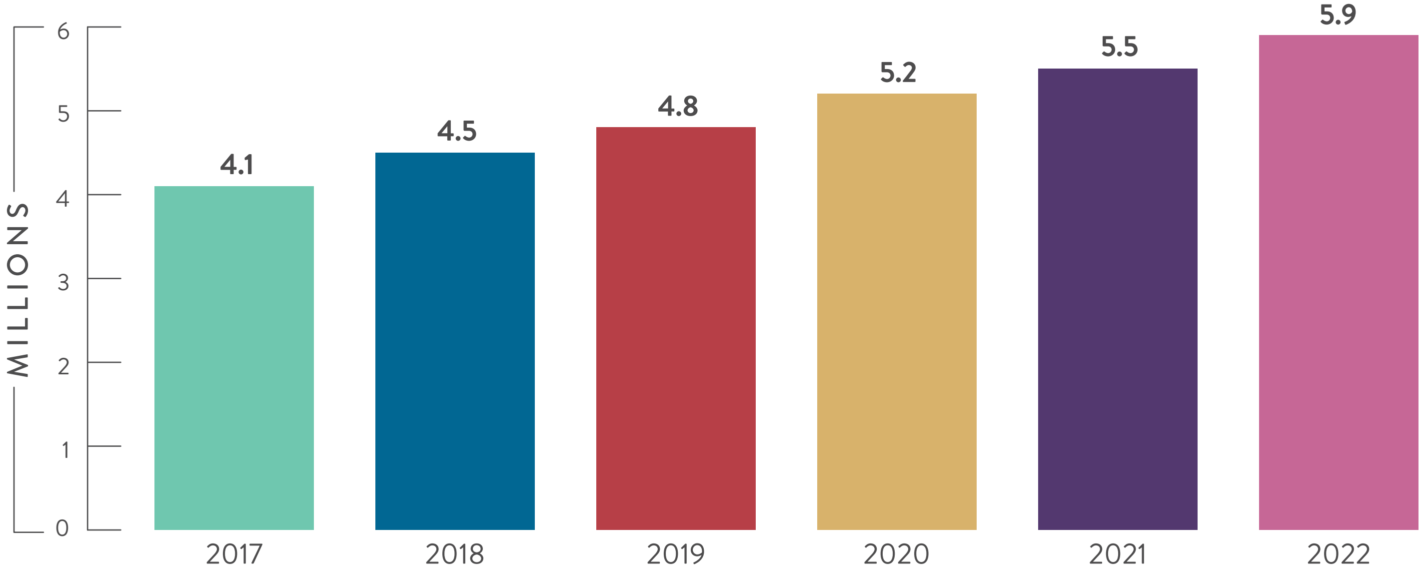
In 2017, the U.S. produced an estimated total of 16.4 million pounds of cannabis for consumption. This figure excludes excess inventory builds.

The U.S. cultivation estimates for both the illicit and legal markets are original works based on proprietary models created by New Frontier Data. All estimates are based on New Frontier Data's analysis of legal productions in legal states, as well as a careful assessment of illicit activities in the non-legalized market.

Correspondingly, in 2017, the U.S. used an estimated total of 4.2 million megawatt-hours of electricity, to produce 16.4 million pounds of cannabis for consumption.

The 4.2 million MWh include all areas of cannabis cultivation (both legal and illicit) and considers cultivation types. Given the nature of illicit activity, estimates between legal and illicit production will vary and as such will be subject to error.

TOTAL ELECTRICITY USAGE FOR U.S. CULTIVATION (MWh)



Although a majority of growers across the U.S., in multiple surveys, indicate that they cultivate in either indoor or greenhouse facilities, the volume of outdoor production in California and Oregon heavily influences the total percentage of energy usage by outdoor means.

Outdoor cultivation accounts for an excess of 50% of the total U.S. production and supply. A majority of the supply, however, is in the illicit market which is exported to other states. In legal markets, however, indoor and greenhouse production is more prevalent.

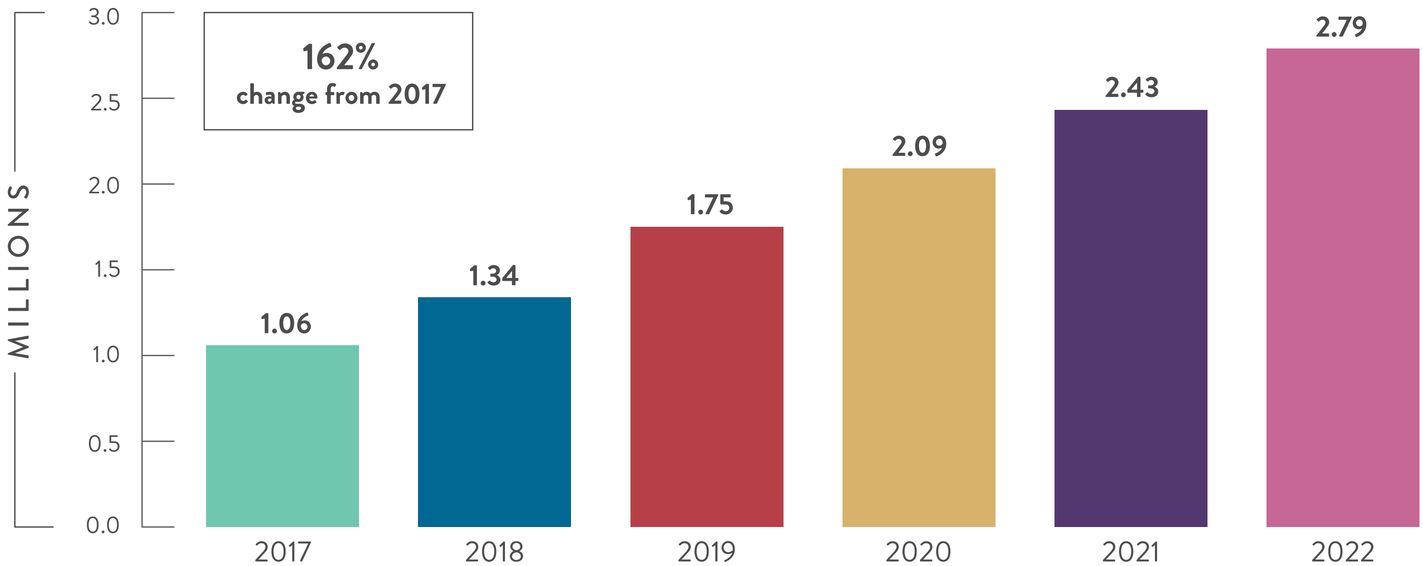
The total electricity consumed by the legal cannabis market in the U.S. in 2017 is estimated to be 1.1 million MWh. Assuming no changes in efficiency, electricity usage in states where cannabis is currently legal is expected to climb 162% to 2.8 million MWh by 2022.

In 2017, approximately 60% of electricity usage in legal cannabis cultivation was associated with indoor production, while 37% was associated with greenhouse production.

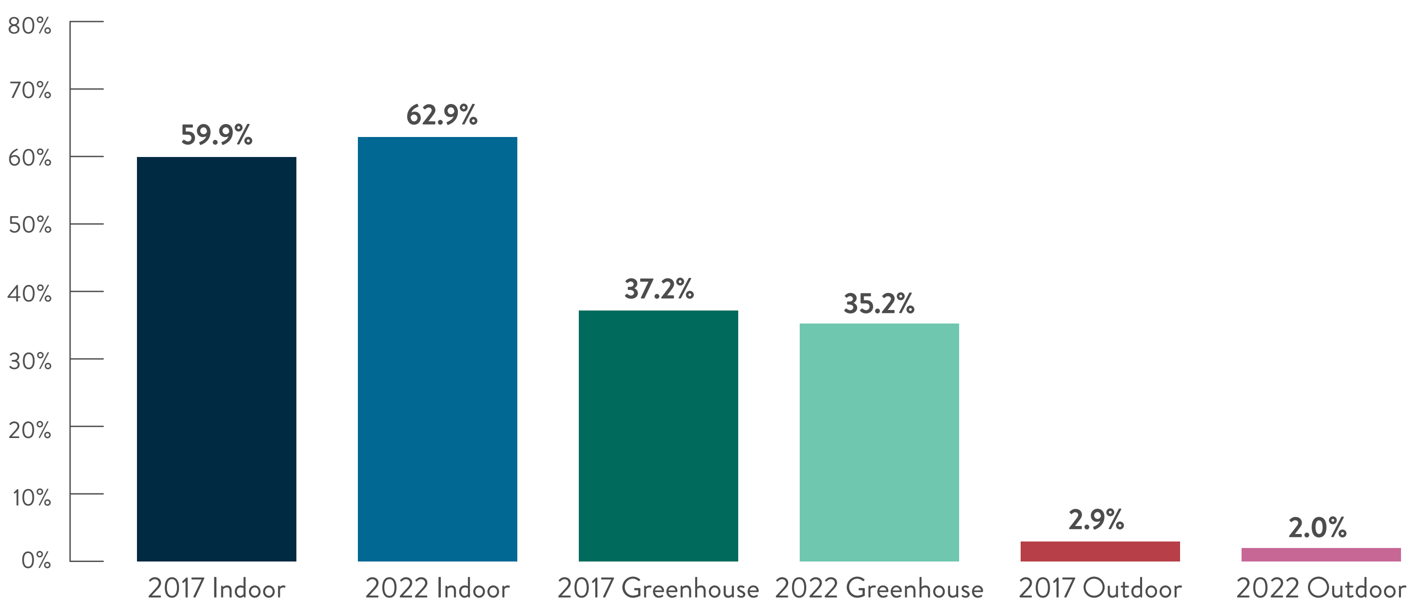
On a state-by-state basis, total energy consumption is highest in the states with the greatest legal demand or with extreme climates. While California has the largest amount of illicit supply in the country, it also has the largest amount of electricity consumption out of all of the legal states.

While cannabis production is legal for either medical or adult-use in 31 states and D.C., every state has some form of illicit activity which is supported within the state, and some form of illicit importation from other states. The chart on page 45 highlights the amount of production and electricity consumption associated with supply that is

TOTAL ELECTRICITY USAGE FOR LEGAL CULTIVATION (MWh)



PERCENTAGE OF OVERALL LEGAL ELECTRICITY CONSUMPTION BY GROW TYPE (2017 AND 2022)



TOTAL ELECTRICITY CONSUMPTION FORECAST: LEGAL STATES 2017-2022 (MEGAWATT-HOURS IN THOUSANDS)

STATE	2017	2018	2019	2020	2021	2022
California	221.8	189.1	248.5	305.3	351.5	389.8
Colorado	201.0	217.6	227.3	237.0	247.0	257.4
Washington	157.9	182.3	196.3	209.7	223.9	239.2
Michigan	146.9	159.6	167.2	174.7	182.1	189.4
Arizona	75.1	84.4	89.4	94.3	99.0	103.7
Oregon	63.5	72.0	83.7	95.9	101.7	106.0
Nevada	38.6	52.7	58.2	62.7	67.6	70.3
Massachusetts	28.5	76.6	161.4	205.2	237.4	272.3
Illinois	22.5	37.0	50.1	62.2	73.6	84.3
New Mexico	20.0	23.4	25.6	27.9	30.0	31.1
Connecticut	14.8	22.0	28.5	33.1	37.4	41.6
Montana	13.5	18.3	19.7	20.8	21.8	22.9
New Jersey	12.8	16.4	19.3	22.1	24.7	27.2
Rhode Island	6.6	7.8	8.5	9.3	10.0	10.8
New York	6.5	20.8	41.1	65.4	87.1	105.4
Maine	5.8	25.5	38.7	45.3	52.7	57.6
District of Columbia	5.3	7.6	9.4	10.6	11.6	22.7
Florida	4.4	56.1	112.7	173.6	234.8	291.4
Vermont	3.9	5.4	6.4	15.8	21.7	24.4
Minnesota	3.0	5.5	8.3	11.1	13.1	15.0
Hawaii	2.8	7.9	10.0	12.1	14.2	15.9
Delaware	2.5	4.3	6.3	8.0	9.4	10.6
Alaska	2.3	14.5	21.1	24.5	28.5	30.2
New Hampshire	1.9	3.6	5.6	7.9	9.9	11.3
Alabama	0.0	0.0	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	1.6	3.9	5.9	8.1
Georgia	0.0	0.0	0.0	0.0	0.0	0.0
Idaho	0.0	0.0	0.0	0.0	0.0	0.0
Indiana	0.0	0.0	0.0	0.0	0.0	0.0
Iowa	0.0	0.0	0.0	0.0	0.0	0.0
Kansas	0.0	0.0	0.0	0.0	0.0	0.0
Kentucky	0.0	0.0	0.0	0.0	0.0	0.0
Louisiana	0.0	0.0	1.2	2.3	3.6	5.2
Maryland	0.0	12.4	21.9	34.9	50.8	67.1
Mississippi	0.0	0.0	0.0	0.0	0.0	0.0
Missouri	0.0	0.0	0.0	0.0	0.0	0.0
Nebraska	0.0	0.0	0.0	0.0	0.0	0.0
North Carolina	0.0	0.0	0.0	0.0	0.0	0.0
North Dakota	0.0	0.0	0.4	0.8	1.5	2.3
Ohio	0.0	0.0	32.6	48.2	76.6	123.1
Oklahoma	0.0	0.0	1.6	3.7	5.1	6.5
Pennsylvania	0.0	17.0	47.9	63.5	99.0	143.0
South Carolina	0.0	0.0	0.0	0.0	0.0	0.0
South Dakota	0.0	0.0	0.0	0.0	0.0	0.0
Tennessee	0.0	0.0	0.0	0.0	0.0	0.0
Texas	0.0	0.0	0.0	0.0	0.0	0.0
Utah	0.0	0.0	0.0	0.0	0.0	0.0
Virginia	0.0	0.0	0.0	0.0	0.0	0.0
West Virginia	0.0	0.0	0.0	0.0	0.0	0.0
Wisconsin	0.0	0.0	0.0	0.0	0.0	0.0
Wyoming	0.0	0.0	0.0	0.0	0.0	0.0
US Total	**1,062.1**	**1,340.0**	**1,750.7**	**2,091.8**	**2,433.2**	**2,786.0**

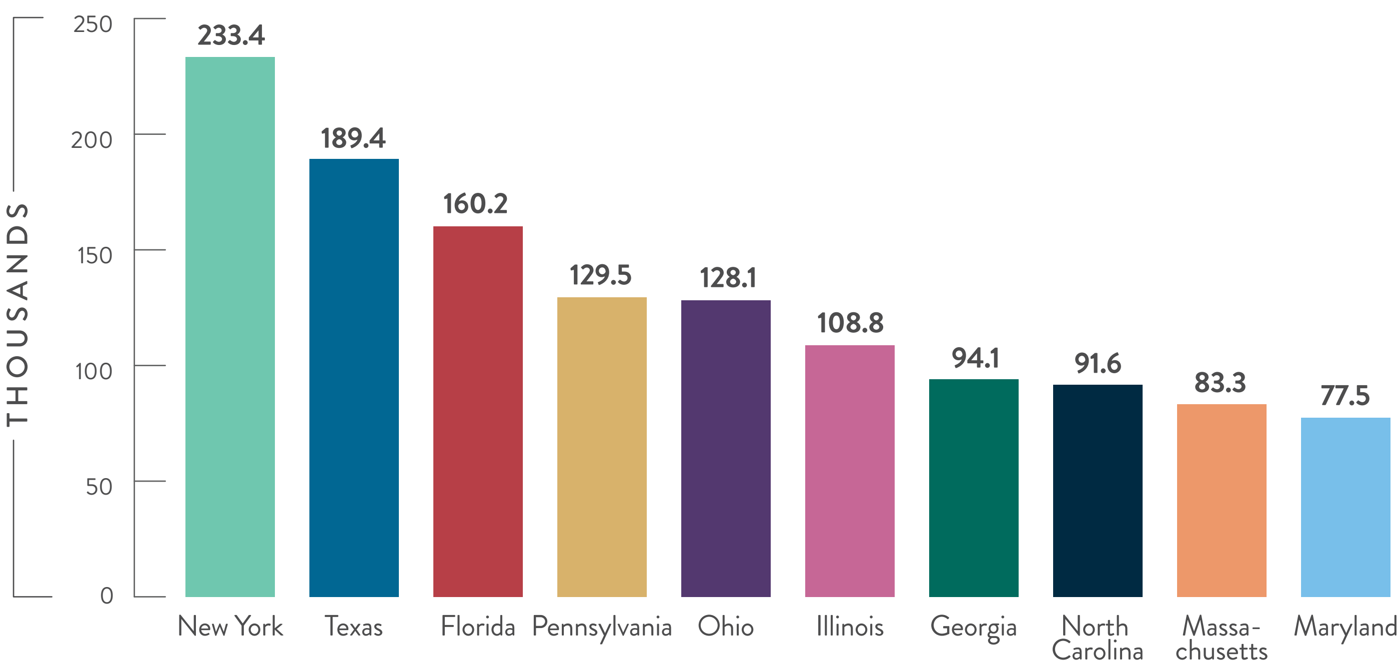
imported from other states. Largely populated states and those without legal access tend to have the highest rates of importation from other states, while states that have mature legal access have the smallest amount of electrical consumption associated with importation.

The top five importing states in 2017 included New York, Texas, Florida, Pennsylvania, and Ohio. Each of them imported supply that represented in excess of 125,000 MWh worth of product. Overall electricity consumption associated with illicit cannabis exported to other states represented 2.3 million MWh in 2017.

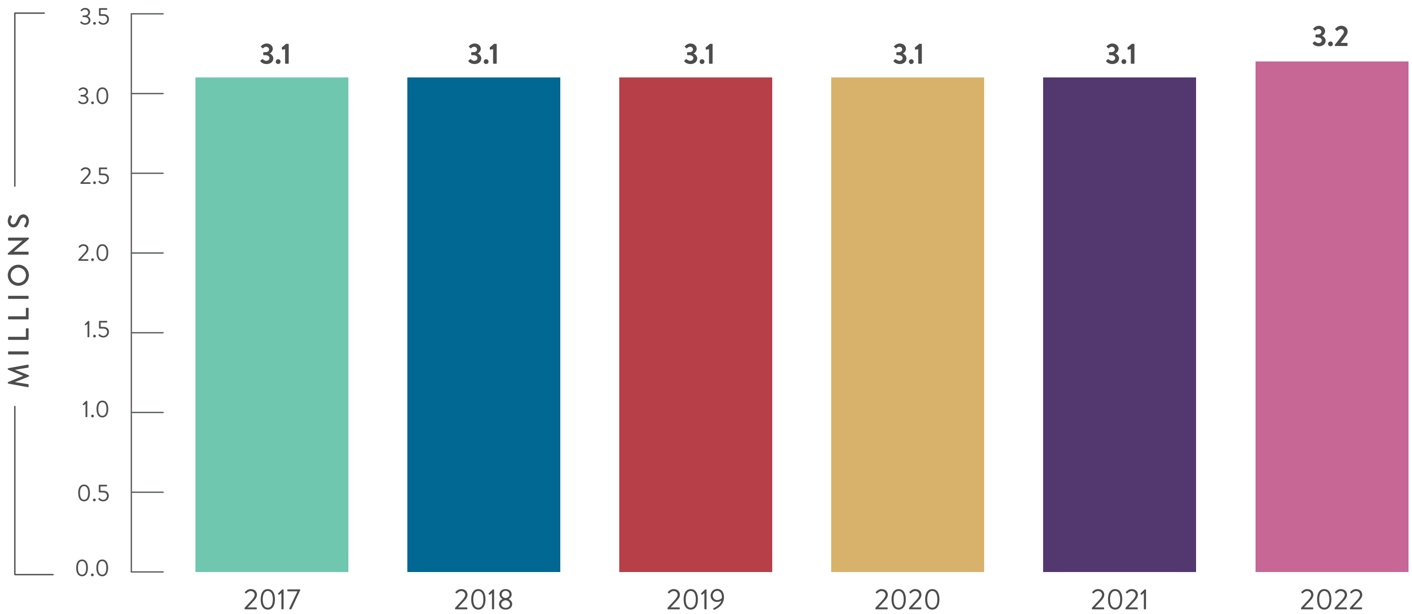
While there is exportation from states that are adjacent or near in proximity to legal states, a majority of the exports come from California, Oregon, Washington, Colorado, and within New England. By accounting for these exports, one can calculate a closer approximation of electricity consumption for cannabis cultivation across the U.S. This is calculated by taking the energy consumption from legal cultivation, adding in illicit production within that state, and adjusting for exports. This will approximate the total electricity consumption requirements for each state.

In 2017, the top 10 electricity consuming states represented over 92% of all electricity consumption associated with cannabis cultivation. As other more recently legal states ramp up their adult-use and medical programs, this percentage by 2022 will decrease to 83% of total electricity consumption.

TOP TEN IMPORTERS BASED ON ELECTRICITY CONSUMPTION 2017 (MWh)



TOTAL ELECTRICITY OF ILLICIT CONSUMPTION (MWh)



TOTAL ELECTRICITY CONSUMPTION BY STATE - ADJUSTED FOR EXPORTS - TOP TEN (MWh IN THOUSANDS)

STATE	2017	2018	2019	2020	2021	2022
California	2,249.7	2,308.8	2,357.2	2,432.0	2,510.0	2,589.0
Colorado	345.4	357.0	367.0	379.0	391.4	404.1
Oregon	328.5	337.1	344.0	354.2	364.2	374.0
Washington	304.0	319.0	333.0	349.0	366.0	384.0
Michigan	156.3	169.2	177.2	185.2	193.1	201.0
Maine	102.5	110.0	115.4	120.0	125.0	129.0
Florida	89.8	136.0	186.3	240.4	295.1	346.4
Vermont	86.0	88.0	89.0	91.4	94.0	96.0
Arizona	85.4	93.5	98.2	102.9	107.4	112.0
Massachusetts	51.0	95.4	173.0	214.0	244.0	277.0
U.S. Total	**4,143.3**	**4,465.0**	**4,834.3**	**5,178.3**	**5,545.4**	**5,942.0**
Top Ten percentage of Total	**91.7%**	**89.9%**	**87.7%**	**86.3%**	**84.6%**	**82.7%**

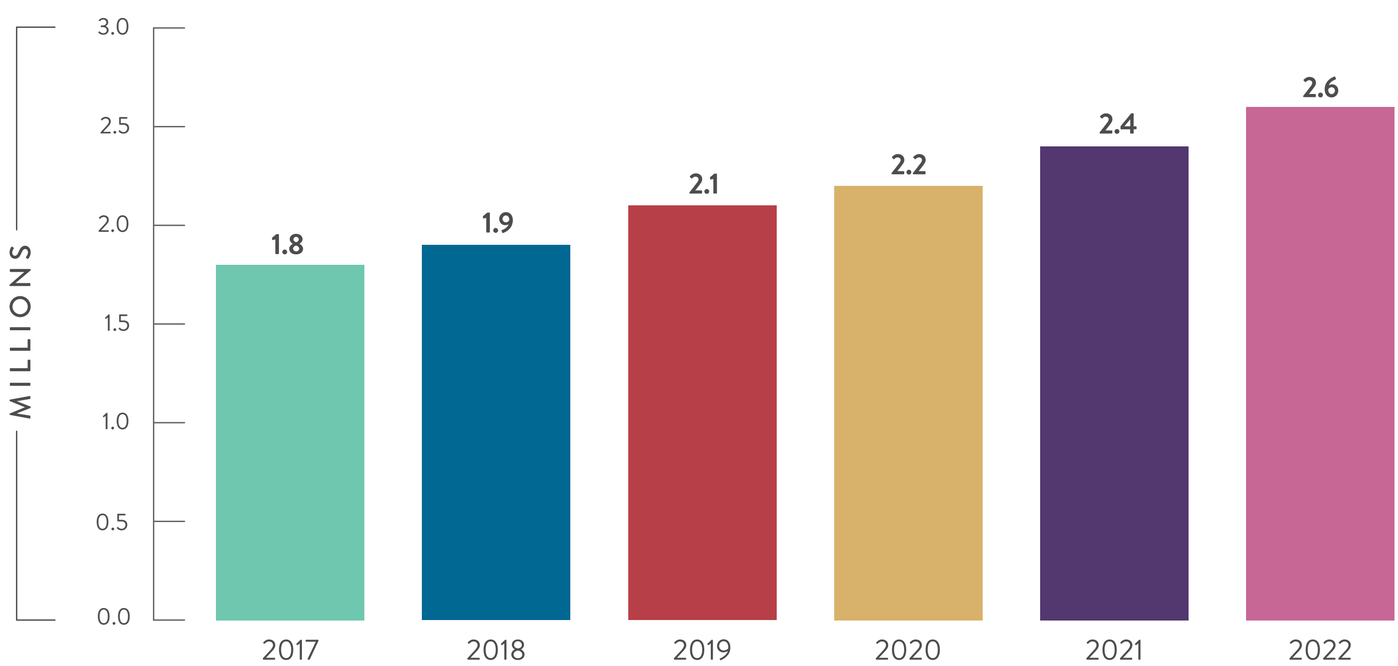
SUMMARY

While legal cultivation accounts for roughly 25% of all electricity used to produce cannabis, trends in the legal market are also influencing production in illicit markets. Illicit growers are not generally as sophisticated as legal commercial growers, and until recently have lacked incentives to improve. However, as more legal operations enter the market, and more cannabis is sold and produced, falling prices for legal products will put pressures on illicit growers. Growers will be forced to decrease their costs of production, increasingly forcing illicit suppliers to lower their costs to remain competitive. Regulators will play a crucial role not only in transitioning illicit suppliers to the legal market, but also facilitating the extent and time in which the efficiencies will take hold. If policymakers establish rules that make it difficult for cultivators to operate legally, energy consumption will remain high; however, if policymakers incentivize participation, then the amount of energy consumed will naturally be reduced due to natural competitive market forces.

Carbon Footprint

While energy consumption and forecasting are foremost in the minds of utility providers and regulators, understanding where the opportunities are for driving efficiencies and sustainability is also important, not only for individual operators but for the entire industry. Using data from the Cannabis PowerScore tool, this section will examine electricity-based carbon intensity of the cannabis cultivation industry in the U.S.

TOTAL ELECTRICITY-BASED CARBON EMISSIONS U.S. COMBINED 2017 - 2022 (TONS CO_2e)



Based on data from the Cannabis PowerScore tool, covering other amount of electricity-based CO_2 emissions varies by cultivation type.

Based on the 16.4 million pounds of cannabis cultivated in 2017, the resulting electricity-based carbon emissions associated with that level of production was 3.6 billion pounds (or 1.8 million tons) of carbon released into the atmosphere.

CARBON INTENSITY BY GROW TYPE

Grow Type	Carbon Intensity (lbs.-CO_2e/gram)
Indoor Production	1.24
Greenhouse Production	0.72
Outdoor Production	0.05

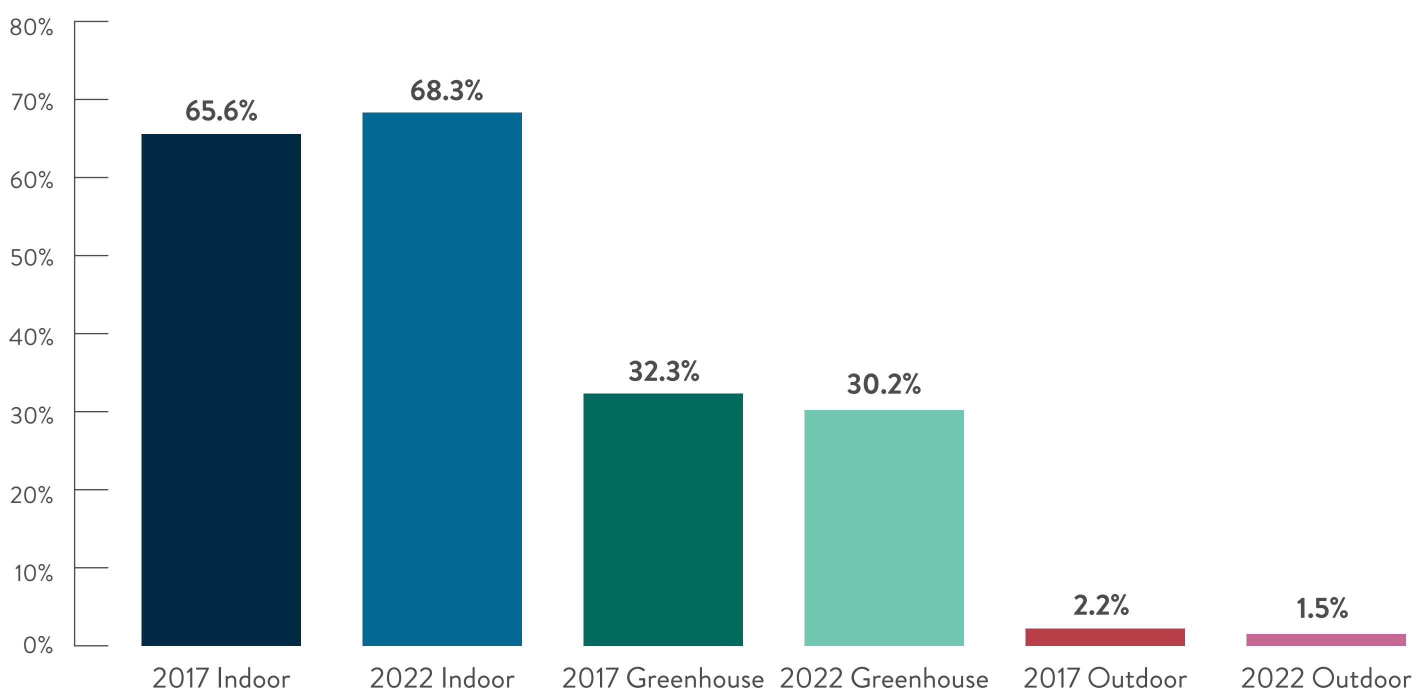
The legal market makes up roughly 25% of this amount of carbon emission. Not surprisingly, indoor production has the greatest impact, while outdoor production is more efficient.

While the carbon intensity of each state's power grid is different, there is a significant carbon footprint associated with the industry as a whole.

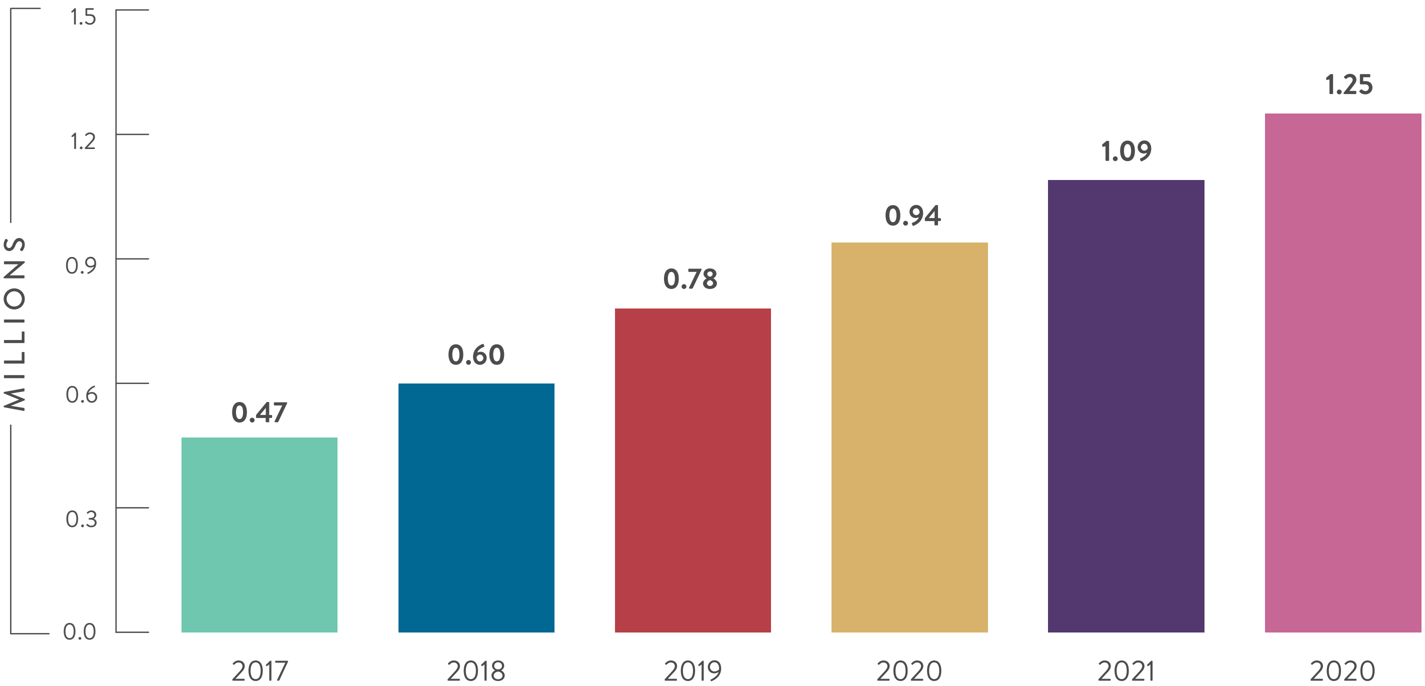
If left unchecked, growth in the area of carbon intensity will increase significantly over the next five years in the legal market alone.

By 2020, legal and illicit cannabis production will produce more than 2.6 million tons of CO_2e emissions.

PERCENTAGE OF OVERALL ELECTRICITY-BASED CO_2e EMISSIONS BY GROW TYPE (2017 AND 2022)



TOTAL ELECTRICITY-BASED CO_2 EMISSIONS FROM LEGAL CULTIVATION (TONS)



SUMMARY

As the growth of the cannabis cultivation increases, so does the amount of electricity and electricity-based carbon emissions associated with the production of the crop. This section reviewed the amount of carbon intensity estimated to support legal cultivation and the level of impact that illicit activity has on carbon emissions. The data highlights the need for innovations and the utilization of new technologies to reduce carbon emissions. The interaction between the industry, policymakers, and key stakeholders will play a key role in determining how well efficiency can be introduced to the market.

> **By 2020, legal and illicit cannabis production will produce more than 2.6 million tons of electricity-based CO_2e emissions.**

BEST PRACTICES, RESEARCH AND REGULATIONS

Recommendations for Investors and Operators

GLOBAL DEMAND FOR CLEAN POWER AND ENERGY EFFICIENCY IS FUELING TRANSFORMATIVE CHANGE

Many industry observers believe that the rapidly expanding global cannabis market, including the advent of legal cannabis exports, will shift production to locations where production costs (including labor, energy, and property management) are low; this will result in putting further cost pressures on producers in locations with high production costs. Regions with favorable climate conditions, inexpensive land, low energy prices, progressive energy policies and incentives, and an efficiency and quality-minded cultivation community will likely be in a winning position.

Further, as the cannabis marketplace continues to mature, and companies transform into global (even publicly held) brands, shareholders and consumers will expect to know more about the environmental impacts of the businesses they support. Likewise, climate-related investments and reporting will be legally required by some governments. For these reasons, it is critical for investors and executives to scrutinize their vendors and partners to ensure that energy does not play an oversized role in their operations.

MORE ENERGY REGULATION IS ON THE HORIZON AS LAWMAKERS TRY TO CONTAIN SURGING DEMAND

In early 2018, Massachusetts placed the first energy restrictions on the cannabis industry by announcing, among other requirements, a maximum "36 watts per square foot" in lighting power density for recreational grow operations with more than 10,000 square foot of canopy. By comparison, lighting power densities of approaches that appear to be industry practice are 33-50% more energy-intensive. The environmentally ambitious plan which establishes a clear preference for LED lighting has been met with resistance by investors and operators who claim that it negatively impacts their business models and economic returns. While the early implementation of the law will unquestionably be disruptive, the impact should diminish as key regulatory and environmental issues are resolved and solutions are created including availability of utility incentives, emergence of cultivation best practices, and independent verification of manufacturer's claims.

In contrast to Massachusetts, California's draft rules governing the industry emphasize low-carbon sources of fuel. In essence, the language requires that the average greenhouse gas intensity of all fuel sources used in cultivation match the state's increasingly clean electricity grid. This means that carbon impacts associated with the use of generators, propane, natural gas, and other sources of fuel may need to be offset.

It should be noted that California and Massachusetts are often leading states on energy policy, as ranked by the American Council for an Energy Efficient Economy. The progressive policies they enact are frequently adopted by other states.

In addition to state actions, local jurisdiction policies also impact the industry's energy and carbon future. Under their authority to determine "time, place, and manner," cities and counties determine whether and how cultivation can occur in their jurisdictions. Many elected officials to date have banned outdoor and greenhouse cannabis cultivation due to concerns about odor, visibility, and security.

These decisions dictate business models and drive higher energy expenses, even in climate zones where lower-cost, lower-carbon outdoor and mixed light cultivation would be feasible. Ironically, such decisions may result in increased grid pressure and higher electricity rates for all utility customers in a given area, and ultimately may lead to lower tax revenues as local cultivation operations cease to exist because of uncompetitive cost structures.

> **It is critical for investors and executives to scrutinize their vendors and partners to ensure that energy does not play an oversized role in their operations.**

EXAMPLES OF LOCALIZED IMPACTS AND POLICIES

Boulder County

The Boulder County Energy Impact Offset Fund has:

- Established a steering committee to direct the spending of the roughly $240,000 it currently has in its accounts. That committee includes representatives from the regulated grower community;
- Helped local growers subscribe to Xcel Energy's Renewable*Connect community solar program as an alternative method to offset part of their electricity emissions; and
- Published phase 1 of the Energy Impact Offset Fund's Demand Side Management Study (the report and supporting interval data are publicly available via the program's website.

Sonoma County

Preoperational energy requirements stipulate either that sources "must be 100% renewable (via power company or on site) or carbon offsets purchased (generators are prohibited)."

Desert Hot Springs

The Southern California desert town (one of the few California markets to open for cultivation) is served by a constrained electricity grid, yet established no energy efficiency regulations as it welcomed one of the largest concentrations of indoor canopy in the country.

British Columbia

For the first time in Canadian history, outdoor cultivation was made legal as of October 2018.

Despite a slew of regulatory considerations, it is clearly in the industry's interest to engage more proactively and collaboratively in public policy relating to natural resource impacts.

BEST PRACTICES ARE EMERGING

Generally, every industry reaches a time in its growth when its leaders come together to develop and communicate best practices with the goal of elevating standards in efficiency, quality, and public image. For example, the Beverage Industry Environmental Roundtable (BIER) is a technical coalition of leading global beverage companies working together to advance environmental sustainability in the beverage sector.

The City of Denver has held a Cannabis Sustainability Work Group for a number of years to address issues including energy consumption. The group has produced a peer- reviewed Cannabis Environmental Best Management Practices Guide. This multidisciplinary, collaborative approach is a good model for other jurisdictions to follow, and offers a template for larger valuable efforts such as multijurisdictional exchanges.

To fully embrace an industry wide interest in resource-efficient cultivation, the cannabis community may need to work through its historically secretive past and understand the collective value of commonly known, accepted, and executed best practices. The more efficient the regulated, tax-paying market becomes, the better positioned it will be to outperform the illicit market.

The cannabis industry also has an opportunity to exchange best practices with the traditional agricultural sectors, as well as the emerging controlled-environment agricultural community, and existing horticultural greenhouse industry.

CASE STUDY: ECO FIRMA FARMS

LOCATION

Canby, Oregon

SIZE OF FLOWERING CANOPY

4,800 sq. ft.

CULTIVATION ENVIRONMENT

Indoor

ENERGY EFFICIENT TECHNIQUES AND TECHNOLOGIES CURRENTLY EMPLOYED:

- LED lights
- Efficient HVAC - "Our HVAC system is specifically designed to be large enough to not run at 100% capacity. By running at 10% less than capacity increases efficiency 90%. We are currently running at 50% capacity."
- Multi-tiered grow environment – "By using a two-tiered growing environment, we have greatly reduced unutilized space and the need for additional heating and cooling."
- Automation system – "Provides us with a controlled, precise method for water and nutrients."
- Bioswale – "We utilize our own bioswale for processing water runoff. Many grow sites within a city have to send their runoff to a processing plant which runs off electricity."
- Trained and engaged staff – "This isn't a technique or technology, but there is an advantage to having a staff committed to the mission of environmental sustainability. Everyone chips in on the efficiency efforts."

RESULTS MOST PROUD OF:

- Cost per pound for production optimization;
- Grant from Energy Trust to support purchases of efficient technology;
- Wind power – "By buying wind power credits, we have come closer to achieving our goal of carbon neutrality and our mission of environmental stewardship. In 2018, we will become a Portland General Electric gold- level-certified wind power user – adding only 1.5% of expense to our power bill. So far in 2018 we've purchased 236,340 kWh of renewable power, which equates to:
- 373,197 lbs. of CO_2 avoided;
- 416,450 miles not driven; and
- 44 trees planted."

WHAT'S NEXT IN ITS EFFICIENCY JOURNEY?

- Solar panel installation;
- HVAC revamp to increase efficiency and dehumidification ability; and
- Nutrient mix – inclusion of agricultural byproducts from various industries that would normally go to landfill.

WHAT ARE SOME TIPS FOR SUCCESSFULLY CULTIVATING UNDER LED LIGHTS?

Why did you make the decision to convert to LEDs?

"There are many reasons why we made the decision to go to LED; the technology has advanced to the point that they are a great option now, they bring our production cost down, and they are substantially better on the environment (i.e., we are not changing bulbs every 6-12 months that go to the landfill, we do not have the heat load, and the drivers are lasting longer, etc.). To be able to keep on the cutting edge of a more and more competitive market, we need to be willing to take calculated risks on new tech for cultivation as it becomes available to us. LED was a forgone conclusion based on this core principle."

Do you use LEDs in veg or flower, or both?

"We use LED in both veg and flower, keeping a consistent spectrum was needed to truly evaluate the lights and make decisions regarding LED going forward."

What would you recommend when converting from HID to LED?

"Have a facility where you can keep tight environmental controls. The success and failure of many LED lights in facilities revolves heavily around the full triangle of cultivation (e.g., environment, nutrition, light). Also keep in mind: You are making a change that will affect phenotypical expression over time [so] this needs to be tracked, and cultivation techniques will need to be adjusted to maximize each plant's potential."

How should growers who switch make adjustments on water, nutrients, HVAC, cultivator training, other?

"This is a big question. As stated earlier, each strain will show a change in phenotypical expression; thus, adjustments to everything need to be made based on the plant's needs. Some basic guidelines: The plants may take less water as the radiant heat load is gone, [and] room temps and CO_2 may need to be increased to handle the plants' new metabolic rates, which in turn will most likely lead to a need to raise EC. Think of it like a weight lifter on steroids: a faster metabolism means more calories are needed to build more muscle, but not just calories; [also] proteins, carbohydrates, complex sugars at the right time. Cultivators need to be very in tune with their plants, and use empirical methodology to track actual plant changes and adjust to them accordingly."

Since you made the switch, what results are you seeing?

"We have seen a significant reduction in cost per lb. with no loss in quality. We are capable of cultivating for as low as $189/lb. indoor; with improvements and expansion we will be able to reduce that even more. The reality of the switch is that it allows us to cultivate in a different manner and be more efficient with our time and space."

Name some things that happened unexpectedly when you made the switch.

"Many of our design choices for efficiency began compounding, which is what helped us drive the price of production down so drastically. For example, a reduced load on HVAC led to less demand for heavy cooling when the lights turned on; this leads to less fluctuation in temperature on a compressed timeline, thus happier plants."

If you did it over again today, how would you do it differently?

"Ha-ha, I'd open a brewery...."

Recommendations for Government and Utilities

Governments and utilities should consider the rare opportunity presented by the cannabis industry to drive efficient infrastructure decisions at the outset of a market, while inspiring rapid innovation toward zero carbon and zero net energy solutions.

MORE RESEARCH AND TECHNOLOGY DEMONSTRATIONS ARE NEEDED TO DETERMINE THE MOST EFFICIENT TECHNOLOGIES AND TECHNIQUES

The U.S. Department of Energy released a report identifying terawatts of energy savings from indoor horticulture LED lighting, demonstrating a 40% savings alone at current technically attainable efficacies. The report's estimate did not include the additional savings (in the range of 10-25%) associated with HVAC efficiencies, according to Energy Trust of Oregon data.

Yet, how to effectively "tune" different grow environments in varying climates is not yet known. For example, in controlled environment cultivation operations, there are no clear "right combinations" of HVAC and lighting systems that drive the highest yield and most consistent quality at the lowest energy input.

In addition, several emerging technologies and service offerings - such as tubular daylighting devices (e.g., Solatubes), water-cooled LED fixtures and off-balance sheet renewable energy finance offerings - appear to offer significant energy and carbon savings opportunities, though require further exploration and third-party testing to validate outcomes.

Additional areas that are largely unstudied but which could have important implications for cultivation facility buildout strategies and regulatory policies include:

- How are land-use policies driving energy and climate impacts, and how can they be adjusted to minimize impacts (e.g., allow for greenhouse and outdoor cultivation while productively solving for nuisance issues such as odor and light pollution)?
- What are best practices in efficient lighting?
- What can the cannabis industry learn from other agricultural sectors?
- Which emerging technologies warrant further research?
- What is the true energy-saving impact of stacking plants vertically in indoor grow environments?
- How permanent and persistent are the energy savings that are estimated based on the incorporation of a variety of technologies and techniques?
- What policy options can support greater efficiency in indoor agriculture?
- Which non-electricity fuel sources are used, at what rate and in which cultivation settings?
- How much of an opportunity is there for waste-to-energy and biomass-to-energy processes to be employed, and what regulatory barriers must be addressed to enable them?
- What policies and offerings can best drive renewable energy adoption?
- What is the potential for demand response and grid integration programs?
- Beyond cultivation, how much energy is used in extraction and other industry processes?

- How should building codes be modified to address the indoor agriculture building sector?
- How can voluntary certification standards and programs drive energy and carbon reductions?
- How can solutions to cannabis banking reform be optimized to ensure financing for clean energy solutions?
- How would facility design standards drive conservation? Examples include the development of an empirical method for determining evapotranspiration rates and their subsequent effect on HVAC/dehumidification loads.

> **“ Most importantly, baseline studies of resource use should be performed by governments and utilities, in partnership with the industry.**

FUNDING FOR BASELINE STUDIES IS CRITICAL

Perhaps most importantly, to drive effective policies and incentives, baseline studies of resource use should be performed by governments and utilities, in partnership with the industry (as is done in other sectors).

As the California Energy Commission states in its revised 2018-2030 Electric and Natural Gas Demand Forecast report:[1] “Cannabis production methods at existing indoor facilities are highly energy-intensive... Besides this simple and well-known fact, there is a great deal of uncertainty about almost every aspect of marijuana production and consumption... Given the potential importance of cannabis production for energy demand and system reliability as well as its impact on carbon emissions, a careful study is warranted once better data on production methods and consumer demand become available.” The time is nearing as California draws to its first full year of adult-use regulation. Therefore, funding should be committed now.[2 3]

In tandem, governments should advance data collection by placing greater emphasis on required reporting of natural resource usage by recreational and medical grow operations. In addition to research and data, governments should consider tax policies that direct investment toward the development and deployment of efficient technologies and practices.

1. *California Energy Demand 2018-2030 Revised Forecasts, California Energy Commission, April 19, 2018*
2. *A Budding Opportunity for Energy Efficiency, Jennfer Thorne Amann, American Council for an Energy Efficient Economy, April 19, 2018*
3. *Utilities Grapple with Growth in Cannabis Legalization, Peter Maloney, American Public Power Association, January 17, 2018*

CURRENT BUILDING CODES ARE INSUFFICIENT TO ADDRESS THE UNIQUE ENERGY CHALLENGES OF CONTROLLED-ENVIRONMENT AGRICULTURE

Existing building codes are based on human occupancy, and require equipment that is not suited for growing environments. For example, air economizers are required by code, yet introduce fresh air, risking the exposure to mold, mildew, and other contaminants (e.g., pesticides sprayed on nearby farms or emissions from industrial facilities).

While economizers can reduce carbon emissions in human-occupied buildings, they can actually work against climate objectives in an indoor horticulture environment where CO_2 is added to pump plant growth and then vented directly into the atmosphere. In reality, growers often install economizers to pass inspection, and then remove the equipment.

Code officials should consider designating controlled environment agriculture structures as their own building class with associated codes and standards.

RESIDENTIAL ENERGY USE ALSO NEEDS TO BE ADDRESSED

In states with regulated medical cannabis, permitted growers are using residential structures to operate small-scale grow operations. In states with regulated recreational cannabis and permitted self-cultivation, residential structures are also deployed for small amounts of production.

Generally, the home grow market poses a significant challenge for utilities in that home operators can trigger power outages while running the building at maximum amperage over long periods of time. One Oregon utility noted seven outages in the first three months of regulated home growing in 2015, caused by intense power use by growers overloading local power grid equipment.

An Energy Trust of Oregon study of home grower and lighting characterization shows that home growers are most likely to live in single-family detached homes. The study also found that a majority of home growers use more than one lighting technology, with 61% using HID lighting, 56% fluorescent, and 49% LED. The study found that those home growers who select LEDs are making their purchases online versus at local retailers.[4]

By conducting targeted outreach to operators in residential buildings, utilities can reduce stress on residential transformers and promote energy-efficient lighting, cooling, and dehumidification options for growers.

4. *Energy Trust of Oregon Residential Grow Light Research Project, Evergreen Economics, May 11, 2018*

CONCLUSION

Despite the nascence of the legal cannabis industry, data from the Cannabis PowerScore tool has helped identify the amount of electricity and electricity-based carbon emissions required to support the market, and how quickly the energy needs will grow as the industry expands. Having a better understanding of how much energy is consumed and how much carbon intensity exists, will help industry stakeholders develop strategies to help drive efficiencies and reduce the environmental impact of the industry in the years ahead.

By sharing best practices, operators will be able to drive greater efficiencies, lower costs, and increase product quality and consistency. Investors will have the data they need to assess who is following best practices; and policymakers will be able to establish regulations that achieve their regulatory priorities on energy use while minimizing the negative externalities on the industry. Other key stakeholders will also use data to help plan the supply chain, size future energy consumption, and identify opportunities to introduce new technologies to energy providers and operators to evolve the industry as it matures. This analysis is intended to be a starting point by providing a benchmark on the current state of the industry's energy use, and serving as a foundation upon which future research can be framed. Based on the total estimated amounts of electricity consumed and the resulting electricity-based carbon emissions from both the legal markets and illicit operations, this report is bound to generate more questions than were answered. However, this analysis has highlighted the tremendous amount of energy required to support the U.S. cannabis demand, and a surging amount of carbon intensity as the industry grows. There are many opportunities for further research and development in energy consumption reduction and the minimization of the cannabis industry's carbon footprint. However, for operators, investors, regulators, and lawmakers, this research has made one thing abundantly clear: It is imperative to carefully consider energy use in all industry-related decisions. Failure to do so will have critical operational, competitive, and environmental implications that will be compounded as the market continues to grow.

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How are you staying competitive in this fast paced industry?
Are you capitalizing on cannabis market opportunities?

MARKET OPPORTUNITY

- **Customer Segmentation Study**
  Which customer segments will see the greatest growth in the next five years?
- **Market Strategy Assessment**
  How should you market yourself to businesses in the cannabis industry?
- **Consumer Market Assessment**
  What is the total addressable market of cannabis consumers?

CONSUMER BEHAVIOR

- **Product/Consumer Segmentation**
  How do consumers engage and become aware of a cannabis company's products?
- **Customer Segment Prioritization**
  What demographic most resonates with your products?
- **Cannabis Consumer Survey**
  How has legal cannabis impacted alcohol consumption?

RISK MANAGEMENT

- **Operation Planning Assessment**
  How can you save costs on supply chain?
- **Scenario Analysis**
  How can you plan for changing regulations?
- **Impact Assessment**
  What are the legislative and regulatory risks across different state markets?

DEMAND PLANNING

- **Product Inventory Analysis**
  What trending products should you add to your portfolio?
- **Market Prioritization**
  What is the best location to establish your business?
- **Price Benchmarking Analysis**
  What is the optimal price point to sell your products?

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ACKNOWLEDGMENTS

Acknowledgments for the Peer Review Committee:

- Jen Amann, *American Council for an Energy-Efficient Economy*
- Emily Backus, *Denver Department of Public Health & Environment*
- Damon Bosetti, *DesignLights Consortium*
- Dr. Jonathan Cachat, *Sungrown Zero*
- Nick Collins, *ERS*
- Keith Coursin, *Desert Aire*
- Mark Crowdis, *AgCurrent*
- Ron Flax, *Boulder County*
- Matt Gaboury, *Calyx King Consulting*
- Bob Gunn, *Seinergy*
- Jesce Horton, *Saints Cannabis*
- Bryan Jungers, *E Source*
- Brandy Keen, *Surna*
- Dr. Rebecca Knight, *BIOS Lighting*
- Alexi Miller, *New Buildings Institute*
- John Morris, *D+R International*
- Jesse Peters, *C21 Investments*
- Brad Queen, *Cube Resources*
- Kelson Redding, *Energy 350, working with Energy Trust of Oregon*
- Blake Shelide, *Oregon Department of Energy*
- Joe Sullivan, *CultivateEO*
- Michael Wheeler, *Flow Kana*
- Corinne Wilder, *Fluence Bioengineering*
- Neil Yorio, *BIOS Lighting*

GLOSSARY

Definitions of types of cultivation can vary from state to state. In addition, there are many different types and styles of cultivation techniques. In general, the Cannabis PowerScore analysis is primarily related to use of artificial lighting and HVAC, but other energy consumption sources are analyzed when data is available. Definitions of types of cultivation can vary from state to state. The analysis contained herein generally categorizes operations as outdoor, indoor or mixed light based on use of artificial lighting in the flowering stage. With very few exceptions, definitions used generally align with those issued by the State of California:

Canopy

- "Canopy" refers to the designated area(s) at licensed premises, except nurseries and processors, that will contain mature plants at any point in time, as follows:
- Canopy shall be calculated in square feet and measured using clearly identifiable boundaries of all area(s) that will contain mature plants at any point in time, including all of the space(s) within the boundaries;
- Canopy may be noncontiguous but each unique area included in the total canopy calculation shall be separated by an identifiable boundary that includes, but is not limited to, interior walls, shelves, greenhouse walls, hoop house walls, garden benches, hedgerows, fencing, garden beds, or garden plots; and
- If mature plants are being cultivated using a shelving system, the surface area of each level shall be included in the total canopy calculation.

Greenhouse / Mixed Light Cultivation

- "Mixed-light cultivation" means the cultivation of mature cannabis in a greenhouse, hoop-house, glasshouse, conservatory, hothouse, or other similar structure using a combination of:
- Natural light and light deprivation and one of the artificial lighting models listed below:
  - "Mixed-light Tier 1" without the use of artificial light or the use of artificial light at more than six watts per square foot;
  - "Mixed-light Tier 2" the use of artificial light at a rate above six and below or equal to twenty-five watts per square foot; or
- Natural light and one of the artificial lighting models listed below:
  - "Mixed-light Tier 1" the use of artificial light at a rate above zero, but no more than six watts per square foot;
  - "Mixed-light Tier 2" the use of artificial light at a rate above six and below or equal to twenty-five watts per square foot.

Indoor Cultivation

- "Indoor cultivation" means the cultivation of cannabis within a permanent structure using exclusively artificial light or within any type of structure using artificial light at a rate above 25 watts per square foot.

Lighting

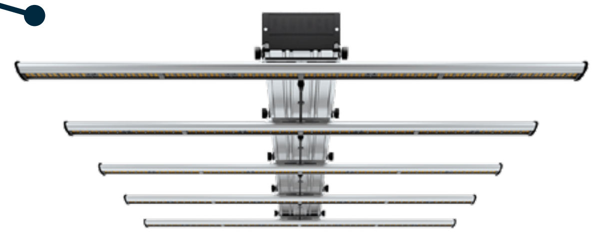
Abbreviations and images of lighting technologies used throughout the document include the following:

- HID (High Intensity Discharge): A class of high-watt, high-heat light fixtures that includes HPS, MH and CMH. These are the most common types across the total square footage of grow area, throughout the industry.

- HPS (High-Pressure Sodium)

- MH (Metal Halide)
- CMH (Ceramic Metal Halide)
- LEC (Light Emitting Ceramic) - a brand name for CMH
- Fluorescent: A class of low-watt, low-heat light fixtures that includes T5 lamps and compact fluorescent lamps (CFLs). These types are typically used in the vegetative and clone stages.

- LED (Light Emitting Diode) - A class of lower-watt, low-heat light fixtures that includes solutions with fixed or adjustable spectrum. These types are most prominently used in the vegetative stage, though they appear to be gaining market share in clone and flowering stages.



Mature Plant

- “Mature plant” or “mature” refers to a cannabis plant that is in the flowering stage.

Outdoor Cultivation

- “Outdoor cultivation” refers to the cultivation of mature cannabis without the use of artificial lighting or light deprivation in the canopy area at any point in time. Artificial lighting is permissible only to maintain immature plants outside the canopy area.

Square Footage

- Any metrics using square footage (e.g., kWh/square foot) in this report refer to square footage of flowering canopy.

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