Market Assessment of Energy Efficiency Opportunities in Laboratories

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EXECUTIVE SUMMARY

Laboratories are one of the next major frontiers in energy efficiency. After data centers, laboratories are widely recognized as consuming more energy per square foot than any other sector due to their energy-intensive equipment, around-the-clock operations, 100% outside air requirements, and high airflow rates. Although California houses the highest density of laboratories in the country, its total number of laboratories has never been estimated, nor has their geographic distribution, size, type, energy consumption, plug loads, and other key attributes. An estimated inventory of laboratory equipment in California also does not exist, although narrow studies have been conducted for a few equipment types. This report, prepared by the Center for Energy Efficient Laboratories (CEEL), constitutes a significant step forward in addressing these unknowns and demonstrates that the size of energy savings opportunities in labs warrants further study and investment.

A combination of market research, online surveys, in-person interviews, and a broad literature review of previous industry reports was used to estimate the potential for energy efficiency in laboratory facilities, with particular focus on the equipment plug loads. The scope of this market assessment study was limited to the laboratories contained in academic, life science research (LSR), hospital, and non-profit research facilities, and for the purposes of this study, a laboratory was defined as any space equipped to conduct experiments, tests, and investigations, or to manufacture chemicals, medicines, or the like. Total net lab square footage in California was estimated for these market segments, and this information was used to estimate the density of 32 different types of lab equipment across 7 product categories. Scientists surveyed across California and the wider United States contributed valuable information about the type and usage of their equipment to help estimate laboratory plug loads. Key statistics from the 3-month study include:

- Laboratory square footage was calculated for 171 academic institutions, 1,351 LSR organizations, and 532 hospitals in California.
- 1,199 scientists throughout the US were surveyed online, including 269 from California. An additional 366 US scientists were surveyed in person; 39 were from California.
- 78 facility and energy managers were surveyed online, of which 19 were from California.
- An additional 14 facility managers in California were interviewed in person.

Simply put, there are a significant number of laboratories in California and they consume a significant amount of energy. Over 116 million square feet of lab space was identified in just the four market segments studied. Moreover, the market is growing. Federal funding for academic research increased by 2.5% in 2014, and academic enrollment is projected to climb 15% annually through 2021. California's LSR industry has been growing steadily at 5% for the past 5 years, and this rate is expected to rise. Private funding for hospital research continues to increase, and new construction of healthcare facilities grew by nearly 5% in 2014. The survey results corroborated these trends: 25% of respondents indicated that their lab space would increase in the next 3 years.

Plug loads were estimated based on survey responses detailing the use of 32 types of laboratory equipment; a summary of 14 of these is shown in the below table. For each category of equipment studied, data gathered about equipment density were used to extrapolate the number of installed pieces of equipment across California. Coupled with manufacturer data and survey

Market Segment	Est. Lab Space in CA (M sq ft)
Academia	37
LSR	68
Hospitals	8
Non-Profits	3
Total	**116**

results pertaining to usage, these calculations were employed to estimate the annual energy consumption for each equipment type. The total electrical consumption by lab equipment in California is estimated to be at least 800 GWh/yr.

Some of the consumption ranges shown in the table are quite broad, as they are sourced from manufacturer estimates and uncoordinated field testing of a variety of equipment from different manufacturers. There is a clear need for objective, third-party data on laboratory plug loads to narrow these estimates. With the exception of ultra-low temperature freezers (ULT, -80°C), very few pieces of lab equipment have been evaluated for energy efficiency. Field studies of ULT freezers have suggested potential energy savings starting at 37 GWh/yr in California. In fact, if the plug loads studied were reduced by even 5%, the results would be equivalent to replacing approximately 2.5 million incandescent lamps with LED lamps.

Laboratory end-users and equipment manufacturers have overwhelmingly acknowledged the need for baseline studies, third-party testing to objectively measure equipment performance against that baseline, financial incentives, and technical support to motivate a paradigm shift to greater energy efficiency in labs. Over 70% of scientists and facility managers surveyed view energy efficiency as 'important' or 'very important', but cited a lack of objective information and economic drivers as obstacles to change. Both of these issues must be addressed in order to take advantage of the significant opportunities for savings.

California Lab Equipment Estimates	Equipment Density (units/lab)	Approx. Number (thousand units)	Est. Energy Consumption (GWh/yr)
-80 Freezer	2.9	58	228 – 648
-20 Freezer	3.7	74	126 – 363
Refrigerator	3.7	95	19 – 254
Fume Hood*	3.0	60	661 – 1322
Fluo Micro	1.7	34	6 – 12
Centrifuge	3.8	76	12 – 227
Water Bath	2.6	52	115 – 201
Heat Block	3.0	60	15
PCR Machine	2.2	44	35
Incubator	3.0	60	41 – 524
Shaker	1.2	24	53
Autoclave	0.8	16	26 – 527
Vac Pump	2.1	42	1 – 115
TC Hood	1.7	34	106 – 235

* HVAC electricity consumption due to fume hoods

Of the 13 pieces of equipment for which energy data existed, laboratory refrigeration and fume hoods, which have been studied extensively, emerged as clear opportunities for energy savings. However, of the 32 pieces of equipment included in this study, 18 equipment types still require further study into their energy consumption—both at the lab level and in California as a whole. Further study of these units will allow for a more accurate quantification of the energy impacts of individual lab equipment, and ultimately lead to a better estimate of the energy intensity of laboratories in California. This effort has already begun; as a direct result of this study, several ULT freezer manufacturers have agreed to provide freezers for baseline testing by the CEEL using the EPA's ENERGY STAR® test method published in early 2015. The goal of this testing is ultimately to establish ENERGY STAR standards by January 1, 2016.

The work done in this study supports the need for a fully-integrated approach to energy efficiency in laboratories, incorporating not only equipment testing but also laboratory facility audits, outreach, financial incentives, metrics to measure program performance, and stakeholder engagement and feedback on the program. The interplay of lab equipment selection, HVAC operations, exposure control systems, and occupant behavior must also be addressed to create safe and energy-efficient labs.

INTRODUCTION

Although recent years have seen the emergence of energy reduction plans for laboratory buildings, the conversation about laboratory operations and equipment has stalled due to a lack of information on market size, energy consumption, and the relationship between facility managers, manufacturers, procurement departments and end-users. To address the need for comprehensive market research, this study sought to characterize the size and composition of the research laboratory market in California. Information about laboratory facilities, equipment, and occupants was collected from over 1500 scientists and over 150 facility managers across the US (of which more than 350 responses were from California) through an online survey and in-person interviews. Data were collected not only on the type of equipment found in the labs, but also on the hours of operation, attitudes about energy and water efficiency, and motivation behind purchasing decisions. The findings and recommendations presented in this report provide the evidence required to move forward with a more holistic approach to energy conservation in labs.

CHAPTER 1: BACKGROUND

This project constitutes Phase 1 of a larger effort to establish a state-wide Center for Energy Efficient Laboratories (CEEL) to benefit the Investor-Owned Utilities (IOUs), their customers with laboratories, laboratory equipment manufacturers, and those industry stakeholders involved with laboratory efficiency projects and programs. The Center for Energy Efficient Laboratories (CEEL) is a partnership between Fisher-Nickel, Inc. (FNI), the Western Cooling Efficiency Center (WCEC) at UC Davis, My Green Lab, and kW Engineering.

The $96 billion biomedical industry is the second-largest industry in California, directly employing 267,000 people, and indirectly affecting the employment of over 497,000 more [1]. This industry is supported by an extensive network of top-tier academic research institutions, which collectively received more than $3.3 billion in NIH funding last year [2]. Hospital research conducted in over 200 hospitals in California also contributes substantially to the state's economic development.

The strength of the bioscience market is seen outside of California as well. Nationwide, the bioscience industry directly employed 1.62 million people in 2012, and accounted for an additional 5 million jobs. It has grown at a rate seven times faster than the total US private sector since 2001, and its growth continues to outpace most industries [3]. One sector of the US biosciences industry, biopharmaceuticals, generated $789 billion alone in 2011, or 2.9% of total US output [4].

Behind these market statistics are scientists working in laboratories. California is home to the largest number of academic research laboratories in the country [5], and San Diego and San Francisco have the highest density of biotech companies outside of Boston [6]. It is known that laboratories can consume 3-5 times more energy per square foot than a typical office space [7] due to their use of energy intensive equipment and their requirement for high airflow rates using 100% outside air. The lack of measured data for equipment energy use means that design estimates for plug loads tend to be overestimated. Thus space conditioning systems are oversized, resulting in inefficient operation under normal operating conditions.

A complete analysis and understanding of the size, scope, and equipment load contribution in laboratories is fundamentally important in identifying energy efficiency opportunities. While recent years have seen the emergence of energy reduction plans for laboratory buildings, the conversation about laboratory operations and equipment has stalled due to a lack of information on market size, energy consumption, and the relationship between facility managers, manufacturers, procurement departments and end-users. As a result, laboratories represent an untapped potential for energy savings opportunities.

Although it is known that California has the highest density of laboratories in the country, the actual number of laboratories, their distribution, size, type, energy consumption, plug loads, and other key attributes have not been estimated. And while a few case studies have been conducted for some types of equipment [8], a comprehensive review of laboratory equipment in California does not exist. From the perspective of the CEEL and its supporting utilities, not knowing the market size, equipment loads and density, and other related information makes it difficult to quantify potential energy efficiency impacts, determine which lab equipment to test, and prioritize (and budget for) initiatives.

This study includes an empirical assessment of existing laboratories, as well as aggregation, analysis, and correlation of previous studies of laboratory plug loads. Results of the empirical study were compiled from surveys issued to laboratories across California in the public, private, and commercial sectors, interviews with key stakeholders, and a compilation of available local and nation-wide data about the number of laboratories and their energy consumption.

The primary objective of this study is to identify the market opportunity around energy efficiency in laboratories in California, and to classify and quantify the type of equipment used in these laboratories. Where available, measured energy use data will be integrated into the results in order to provide a more complete picture of plug loads and energy savings opportunities.

Gathering in-depth information about the number of laboratories and the amount and types of laboratory equipment will help direct the focus of the CEEL, its supporting utilities, equipment vendors, and laboratory end-users alike. Vendors can benefit from accurate knowledge about the size and composition of their market. Utilities can also benefit from learning about the laboratory population, and can use this information to inform and guide future programs and incentives for lab energy efficiency under the auspices of the CEEL. The CEEL will also use this information to determine which types of equipment to focus on first, allowing for the greatest impact as test protocols are developed, training is provided, and laboratory incentive programs are designed.

This report analyzes laboratory equipment and operations in the academic, life science research, and hospital sectors.

The scope of the research is as follows:

- Gather available market data on the types, number, and square footage of laboratories in California and the United States
- Gather available market data on the types and usage of equipment commonly found in laboratories
- Gather available data on energy use per square foot in laboratories

- Develop and administer a comprehensive market survey for laboratory market stakeholders in both the public and private sectors
- Identify current and predicted market landscape and trends

As a result of this research, the most significant savings opportunities for laboratory plug loads will be identified, and the scope and priorities for the CEEL and the IOUs will be defined.

CHAPTER 2: METHODS

Estimating key attributes about research laboratories such as square footage, distribution, size, type, energy consumption, and plug loads required extensive research and outreach. Publicly available resources, including company profiles, manufacturer and industry reports, and NIH funding data were consulted, but they provided little of the information required to properly assess the market. A detailed online market survey was developed in order to gather data about laboratory equipment. Conversations with facilities managers, scientist end-users, and manufacturers yielded previously unpublished information about laboratory operations and equipment. Taken together, these three approaches gave a comprehensive portrait of the life sciences market, and have allowed for conclusions to be drawn about energy efficiency opportunities in laboratories.

2.1 DEFINITIONS

The word '**laboratory**' can be used to refer to a diversity of spaces. For the purposes of this study, a laboratory is any space equipped to conduct experiments, tests, investigations, etc., or to manufacture chemicals, medicines, or the like. This definition includes not only public and private research labs, but also clinical labs in hospitals and diagnostic labs. The standard facilities definition of 'laboratory', a space with 100% outside air requirements, was not used because it does not capture all spaces that might contain the type of equipment that is of interest in this study. In addition, scientists do not understand the ventilation requirements of the spaces in which they work, and therefore it would be difficult for them to respond to questions about their lab space using the canonical facilities definition.

An additional layer of complexity in understanding the word 'laboratory' exists beyond the simple definition. From a scientist's perspective, a laboratory is considered to be all space assigned to a single principal investigator (PI). A lab might contain one room, or it might be comprised of several different rooms on different floors in the same building. From a facility manager's perspective, one laboratory occupies one room. And from an auditor's perspective, a lab refers to the entire building in which laboratories reside. This discrepancy in understanding the term 'laboratory' can lead to misleading information about the number of laboratories in a particular building. To avoid this confusion, the study focused on square footage of laboratory space in a building or at an organization, not the number of laboratories.

One way to differentiate labs is according to the type of **facility**: academic, biotech, pharmaceutical, hospital, industrial, clinical, and testing are all categories of laboratories, and each of these different types of labs represents opportunities for energy efficiency. The categorization of labs by facility type is convenient as it clearly delineates the market sectors, which, taken together, result in a very large total addressable market. Although the CEEL aims to address this total market in the future, this study pertains only to research laboratories found in academia, life science research (LSR) companies, and hospitals.

The term '**research lab**' captures the first part of the broad definition cited above. These three market segments were chosen because together they were thought to represent a sizable portion of the overall market. They also all have an emphasis on biology and therefore would be expected to have a relatively similar composition. The composition of a lab at Chevron is not the same as a lab at Monsanto, which is not the same as a lab at UCSC, for example. Given the complexity of the market, sample homogeneity is critical to deriving meaningful conclusions from the data.

For the purposes of this report, **academic laboratories** are defined as those laboratories residing in higher-education facilities. Both **research and teaching labs** found in universities and colleges qualify under this definition. **Life science research (LSR) labs** are classified as those laboratories located in a biotech, pharmaceutical, or medical device company in which research is conducted; manufacturing facilities are excluded from this definition. The definition of **hospital laboratories** for the study includes both pure research spaces as well as diagnostic areas within a hospital or a facility owned by a hospital. The spaces designed to gather the data for the diagnostic tests (phlebotomy labs, for example), are excluded from this study. In all cases, research support areas, such as animal and core facilities, have been included in the market assessment.

Just as there are many different types of facilities that contain laboratories, there are also many different types of laboratories within those facilities. This study focused primarily on those that would fall under the classifications of Life Sciences and Physical Sciences, with an emphasis on the Life Sciences in all market segments outside of academia. Not every category within these classifications was addressed; Life Sciences alone is comprised of over 30 different categories. The categories studied in this report were: **Biology, Biochemistry, Biomedical Engineering, Cell Biology, Chemistry, Chemical Engineering, Computational Sciences, Engineering, Forensics, Genetics, Geothermal studies, Marine Biology, Materials Science, Microbiology, Molecular Biology, Immunology, Neuroscience, Oncology, Pathology, Plant Biology, Physics, Stem Cell Research, Systems Biology, Translational Medicine, and Virology**. Of these, Chemistry, Engineering, Computational Sciences, Engineering, and Physics all fall into the **Physical Sciences** classification; the rest are classified as **Life Sciences**.

The classification of laboratories was used to better understand laboratory equipment distribution and use. These classifications were not used to further refine the laboratory facility analysis as this level of detail would have been incredibly difficult to resolve for an entire organization.

This work was supported by the California IOUs: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). Data were segmented according to IOU service territory counties [9]; however, local municipal providers within those counties were not accounted for. In general, Northern California was assigned to

PG&E; the Central region and Los Angeles, Orange, and Riverside Counties to SCE; and the Imperial Valley and San Diego regions to SDG&E.

2.2 ESTIMATING THE OVERALL MARKET SIZE

The addressable laboratory market is large and complex. There are no available data on total square footage of laboratory space for most organizations, and few scientists are aware of the square footage of their laboratories. Moreover, while there are reports on the estimated total number of academic, LSR, and hospital organizations nationwide and in the state of California, these reports do not include information about whether these organizations have research labs.

Online research was conducted to gather lists of research facilities in California. These lists were cross-referenced with multiple different sources in order to compile an accurate accounting of the three main facility types being studied.

Academic Institutions: The scope of academic institutions studied included only those that were classified as 'higher education'. This included post-secondary education institutions such as colleges, universities, and specialized trade schools. A list of higher-education academic institutions in the state was compiled using NIH and NSF funding information as well as lists from the California Postsecondary Education Commission, The Princeton Review, and US News and World Report. The California Public Education Commission (CPEC) identifies eight categories for degree-granting institutions in California: University of California, California State University, California Community Colleges, Other Public Colleges and Universities, Western Association of Schools and Colleges (WASC)-Accredited Non-Public 4-Year Institutions, WASC-Accredited Non-Public 2-year Institutions, State-Approved Institutions, and Institutions Exempt from State Approval. Investigation was done into 171 of the 401 degree-granting higher education institutions in the state. These 171 schools were assessed for potential research and/or teaching laboratory space. If applicable, the total square footage of laboratory space on campus was calculated using information available on the school's website and public information about new and existing construction. If laboratory square footage data could not be found, an estimate was made based on the academic curriculum and the total number of students enrolled in the institution. This estimate was based on trends observed from similar-sized institutions for which data were available. In the study, all 10 University of California (UC) schools were accounted for, as were all 23 of the California State Universities. The remaining 127 schools studied were a combination of community colleges, private universities, and specialized trade schools.

Life Science Research Companies: The classification of life science research (LSR) companies includes those companies that are traditionally classified as biotech, pharmaceutical, and medical device companies. Also included in this definition are contract research organizations (CROs) – companies to whom biotech and pharmaceutical companies outsource their basic research. The operational definition of a biotech company is a company that combines biology and technology to develop products and services. A pharmaceutical company is a company that develops and sells pharmaceuticals. The working definition for this report does not require the company to manufacture the product in order for it to be considered a pharmaceutical company. Note, Life Sciences, the term used to describe categories of research, is not to be confused with the Life Science Research

(LSR) market, the term described above that refers to a specific commercial market segment.

A list of LSR companies in the state was compiled using existing information from Bloomberg reports, SoCal Bio, BayBio, Indeed, and Monster. Other smaller websites, such as BioPharm Guy, and theLabRat, provided names of additional biotech companies in the state, and attendance at the Biotech Showcase conference in San Francisco yielded information about biotech start-ups. Each company on the list was further investigated for evidence of conducting research at their facility in California. Not all of the LSR companies in the state do R&D in California; many of them have administrative offices in the state and conduct their R&D elsewhere.

For those companies who are engaged in R&D in California, the total square footage of laboratory space was often determined by looking at the company website, where it was listed. If the total square footage of laboratory space was not evident from the website, it was derived based on the number of employees. In the case of the latter, the number of employees was determined either from information on the company website or through LinkedIn. The average percentage of employees 'linked' to their company of employment on LinkedIn has been shown to be approximately 70 percent [10]. Based on conversations with real estate developers and trends in the data that had been collected, it was determined that approximately 70 percent of the people in a LSR company are engaged in research. This number will vary depending on the size of the organization, with smaller organizations typically having a higher percentage of their staff engaged in research activities, and larger organizations typically exhibiting a lower percentage of their staff engaged in research. Nevertheless, the number of employees linked to a company on LinkedIn was deemed to be a good predictor of employees engaged in research, so it was used as the basis for determining square footage of laboratory space. Real estate developers in the state use an estimate of 3 people per 1000 sq ft of lab space, and this figure was used to estimate square footage based on the number of employees. For example, if a company had 300 employees linked on LinkedIn, it was said that this number represented 70% of all employees (390 employees total), and that 70% of the total employees were engaged in research (300). If 300 employees were involved in research, the total square footage of laboratory space would be calculated as 300/3*1000, or 10,000 sq ft.

Published information about the total square footage of LSR facility space – including labs, administrative offices, and communal spaces – across the state was used to verify the assumptions and calculations above.

Hospitals: The hospitals of interest for this study are those that are classified as teaching, training, and research. While it is possible that the other types of hospitals – admitted acute care, sub-acute and non-acute care, non-admitted care, mental health care, and emergency care – have spaces that would be classified as laboratories, the scope of this report does not include hospitals that are strictly speaking classified as one of these other types.

A list of hospitals in California was gathered from NIH funding data and Healthcare Atlas, an online database of hospitals in the state. All 532 hospitals on the list were further investigated for evidence of laboratory research activity. For those that were found to be engaged in research, a determination of laboratory square footage was made either based on information found on the hospital website, or derived based on the number of researchers in the hospital, using the methodology described above.

California state and nationwide data on trends in academic, LSR, and hospital research organizations were gathered as well. These data were used to verify the assumptions and calculations made above, and they were used as a point of comparison for California.

2.3 Survey of Laboratory Equipment

This report marks the first comprehensive study of the number, type, and usage of equipment in laboratories. Because so little information was available, an inventory of laboratory equipment was conducted using a multi-faceted approach.

In the broadest approach, scientists working in a research facility were identified through scientific organizations and vendor lists. The use of these types of lists was critical in surveying scientists who work in private industry, as gaining access to LSR laboratories was more challenging than reaching those in academia. Potential respondents were contacted via email, which included a link to an online survey. This approach had several benefits, including the ability to reach hundreds of people in a relatively short amount of time, and allowing people to complete the survey anonymously. The online survey was created using SurveyMonkey, and it was distributed nationwide through the following channels: Green Labs Google Group, I^2SL mailing list, Priorclave customer list, Eppendorf customer list, Leica customer list, Sigma Xi (research honor society) posts, Facebook, Twitter, and the My Green Lab website. All CEEL partners distributed the survey to their contact lists as well. At least 20,000 potential respondents were contacted via email.

In a more targeted approach, department heads, sustainability officers, and facility managers in organizations across the state were asked to distribute the survey to scientists in their respective institutions, leveraging strong existing relationships with these stakeholders to gain access to the target audience.

In order to ensure that the data collected adequately represented laboratories across California, a large sample size was needed. If the number of laboratories were infinite, surveying a random sample of 67 would be enough to give a confidence interval of 90% with relative precision of 10%. Over 250 responses were collected in California alone, more than were needed to be statistically significant.

A copy of the complete assessment can be found in Appendix I. In brief, two different assessments were distributed. The first was directed towards laboratory occupants, and the second was directed towards facility managers. Facility managers are ideally suited to respond to questions about building operations and laboratory square footage – they usually oversee many laboratory buildings and are thus in the best position to comment on the overall inventory of laboratory space at a particular institution.

The survey directed towards laboratory occupants asked questions about the type of equipment found in their labs. The equipment assessed included those items known to be commonly found in laboratories and routinely used by occupants (see Table 1 below). Included in the assessment was an opportunity for respondents to identify other pieces of equipment that they viewed as being particularly important or abundant in their lab. The information gathered included not only the quantity of a particular piece of equipment in the lab, but also the hours of its operation.

TABLE 1: EQUIPMENT INVENTORY LIST

CATEGORY	TYPE
Refrigeration	-80°C Freezer -20°C Freezer Refrigerator
Fume Hoods	All Fume Hoods Variable Air Volume
Microscopes	Fluorescence Microscopes Confocal Microscopes Electron Microscopes
Benchtop Equipment	Heating Block Water Bath Centrifuge PCR Machine Magnetic Stir Plate Vacuum Pump Water Distiller
Large Laboratory Equipment	Shaker Table Autoclave Gas Laser qPCR Machine NMR Mass Spectrometer Gas Chromatograph HPLC FACS Incubator Tissue Culture Hood Sonicator Vacuum Chamber Air Table
Hospital Equipment	MRI CT Scanner X-Ray Machine
Environmental Room	Warm Room Cold Room

While it was important that the details about the types and number of laboratory equipment found in labs in California were uncovered, it was equally important that occupants' attitudes regarding energy and water efficiency were assessed. Therefore, several questions were included about the importance of energy and water efficiency in the context of the laboratory space.

The survey was also used to facilitate calculating the density of laboratory equipment. Information about total square footage of lab space via the market survey, and the various pieces of equipment found in lab spaces via the online survey, allowed for an estimate of equipment density in labs to be calculated. Any existing data on the energy consumption of the equipment surveyed were collected, and in conjunction with the equipment density information, estimations were made about the plug loads in labs. The survey also queried whether the size of occupants' lab space was increasing or decreasing over time.

The second survey (designed for facility managers) asked more generic questions about the type of equipment found in labs in an effort to understand the general landscape of a facility. These questions were focused on ascertaining the square footage of labs as a function of the entire facility space, and on understanding facility HVAC system specifications. For example, the survey asked whether a particular facility had fume hoods or freezers, but not the hours of operation of a PCR machine. As in the occupant survey, facility mangers' attitudes about energy and water efficiency were also assessed.

In all cases, results that are labeled 'California' were derived solely from the data set of respondents who work in California. Results that are labeled 'US' or 'United States' include data gathered from all states except California.

Interviews and conversations with over 500 scientists from across the country were conducted at the Society for Neuroscience (SfN) annual meeting in November 2014. Scientists who passed by the booth were offered chocolate in exchange for filling out a shorter, paper survey (Appendix II). They were not informed about the topic of the survey so as to avoid bias in the sample – they were simply handed a survey and asked to complete it.

Fourteen in-depth interviews with facilities managers were also conducted across the state of California. These interviews asked more specific questions regarding overall energy consumption, current and planned energy efficiency projects in laboratories, and more detailed information about the questions in the assessment. In-person interviews revealed several accounts of laboratory space square footage. These numbers were used to validate the method employed for determining laboratory square footage as a function of employment (i.e. 3 people per 1000 sq ft).

2.4 EVALUATING ENERGY CONSUMPTION

Energy consumption in laboratories was determined based on the estimated square footage of laboratory space and the estimated numbers and usage of laboratory equipment determined from the study.

CHAPTER 3: INTRODUCTION TO LABORATORY EQUIPMENT

The laboratory equipment market for the Physical and Life Sciences is large and complex. Laboratories contain many pieces of highly specialized equipment, some of which may be considered ‘typical’ for a particular category of laboratory, and some of which may be so specialized as to only be found in a few institutions across the state. Complicating matters, even manufacturers do not have insight into the size of their market as a function of number of units sold. The Life Sciences industry in particular is known to report market size as a function of dollars spent, making it difficult to correlate those dollars with an exact count of pieces of equipment. And while some types of laboratory equipment are required to be inspected and catalogued every year (e.g. fume hoods and diagnostic equipment), the majority of laboratory equipment is not tracked in a database after it has been installed and registered at an institution. For example, a microscope purchased by a lab at UCI in 2003 may have moved with that lab to Yale in 2010, or it may have been given to the lab down the hall. Even most LSR companies do not have an easily accessible, searchable database of laboratory equipment. The information may exist in these companies, but it is not a data set that can be easily generated, and therefore it is not used to inform future purchasing decisions [11].

Laboratory equipment is usually purchased by a laboratory or department; very few pieces of laboratory equipment are purchased by people who do not work in a lab. Some pieces of equipment are owned and operated by a particular lab, and others are owned and operated by more than one lab. The latter is known as ‘shared equipment’. Shared equipment may be owned by one lab, but operated by many. It may also belong to the department, or it may be housed in ‘core facilities’, which are centers that have a high concentration of a particular type of equipment. For example: a freezer may be shared by two labs, thus making it shared equipment; a department might own one large centrifuge, which is then shared among all labs in the department; and a core facility might have seven different microscopes in three rooms, all of which can be used by anyone in the organization. All of these are examples of shared equipment. This report will make the distinction between shared and privately owned equipment whenever possible. The importance of this is in estimating the density of laboratory equipment – a chemistry department with one shared fume hood has a very different energy profile than several chemistry labs with one fume hood each.

3.1 Description of Laboratory Equipment Surveyed

This study surveyed the number and usage of 30 different pieces of laboratory equipment and two different types of environmental rooms. Below is a brief description of each type of equipment surveyed and its common use in the laboratory. Note that these pieces of equipment were chosen not only because they are commonly found in laboratories, but also because they have properties that would make them good candidates for being high energy consumers. Any instrument that uses vacuums, requires high pressure, has heating/cooling requirements, or uses magnets is likely to consume a substantial amount of energy, and have the potential for larger savings. All product categories are supplied by multiple vendors.

A. Refrigeration

- *-80°C Freezer:* Also known as an ultra-low temperature (ULT) freezer, these are large freezers that are used to store samples at temperatures below -65°C. They are often referred to as '-80s' because -80°C is the standard temperature to which these are set. These freezers are typically used for long-term storage of samples and reagents. The majority of these freezers employ a cascade compressor system, however new technologies, such as the use of a Stirling engine, have recently emerged. Although the upright model of ULT freezers is more common, it is generally recognized that the chest model is more energy efficient.

- *-20°C Freezer:* These freezers are set to -20°C and are used for storing samples and reagents that do not need to be stored at lower temperatures. The compressor-based upright and under-counter models are most frequently found in laboratories.

- *Refrigerator*: The term refrigerator is used here to capture any other cold storage mechanism that is not a freezer. Dorm room refrigerators, residential kitchen-sized refrigerators, and sliding glass door refrigerators are all found in laboratories. Sometimes these refrigerators are carefully temperature controlled (4°C is a common set point). Refrigerators are often used to store reagents and for short-term sample storage.

B. Fume Hoods

- *All Fume Hoods:* A fume hood is a ventilation device used to limit exposure while working with harmful chemicals and toxins. One side of the hood is open to the laboratory, and this side has a glass sash that can be raised in order to work inside the hood. The sash can also be lowered when the fume hood is not in use. Because fume hoods are intended to keep noxious chemicals contained inside the hood and away from the researcher, they are designed to be used with an exhaust fan that continuously draws air from the room through the hood and expels it outside of the building. Fume hoods can generally be classified as either constant air volume or variable air volume. Constant air volume (CAV) fume hoods exhaust a constant volume of air; variable air volume (VAV) fume hoods exhaust only the amount of air required to maintain a certain face velocity through the opening. Fume hoods are considered off-the-shelf products, although some accessories, including any associated exhaust air valves, are not supplied with the hood. Note, fume hoods are NOT considered plug loads in labs; they are not plugged in, and they themselves do not consume any energy. All energy consumption associated with fume hoods is a result of ventilation. In new buildings, labs are often set up with 6 air changes per hour (ACH) minimum occupied ventilation rate and 4 ACH for an unoccupied space, though they may be set higher or lower. Ventilation rates are usually set according to safety requirements for the space, and sometimes they are also set to accommodate equipment loads.

- *Variable Air Volume Fume Hood:* This particular type of fume hood is of interest because of its ability to reduce the volume of air exhausted in response to lowering the sash position on the hood. This can lead to a significant reduction in energy consumption when compared with a CAV fume hood or a VAV fume hood with the sash left open.

C. Microscopes

- *Fluorescence Microscope:* A fluorescence microscope is a specialized type of light microscope that is designed to enable the visualization of fluorescently-labeled samples. Samples are illuminated with a special type of light source, one that emits light with peaks in the visual spectrum at specified wavelengths. Traditionally this light source has been a mercury or metal halide bulb; more recently these light sources are LEDs. Mercury and metal halide bulbs for microscopes are usually between 100W and 250W. Their LED replacements are 30W – 150W. The power supplies that accompany the microscope bulbs also differ substantially in their energy consumption, with those that power the mercury and metal halide consuming more energy than those that power the LEDs.

- *Confocal Microscope:* Confocal microscopes are light microscopes that are used to visualize fluorescently-labeled samples with high resolution. Like fluorescence microscopes, they also use specialized light sources. Traditional mercury or metal halide light sources are used to see samples through the eyepieces of the microscope, and high powered lasers are used to take images of the samples in high resolution.

- *Electron Microscope:* The category of 'electron microscope' contains both scanning electron microscopes (SEM) and transmission electron microscopes (TEM). Both types use a high voltage electron beam instead of light to create images of samples at a level of resolution nearly 1000x that of a light microscope. Samples must be viewed in a vacuum because even air molecules can scatter the electron beam. High voltage and high pressure are characteristics of these types of microscopes

D. Benchtop Equipment

- *Heating Block:* Heating blocks are technically called 'dry bath incubators', but they are more commonly referred to by the interchangeable tube holders that are used in the incubators, known has 'heating blocks'. These units are used in labs to uniformly heat samples to a particular temperature, usually between 37°C and 100°C. Dry bath incubators tend to be less than 12 inches long and 9 inches wide.

- *Water Bath:* Water baths are a mechanism to uniformly heat samples for long periods of time. The working temperature range for water baths is usually between 5°C and 99°C. The capacity of water bath reservoirs tends to range between approximately 1.5L and 43L.

- *Centrifuge:* There are several different types of benchtop centrifuges. All use an electric motor to rotate objects in order to separate samples by density, and some are refrigerated (usually to 4°C). Microcentrifuges are used for the smallest volume samples (usually 0.5mL – 1.5mL), and general purpose tabletop centrifuges are generally used for samples ranging from 5mL to 400mL. Ultracentrifuges are a separate classification of centrifuges that are optimized for high speed rotation.

- *PCR Machine:* PCR machines are more formally known as thermal cyclers. They are used to amplify DNA through a process known as polymerase chain reaction (PCR). This is accomplished through several cycles of sample heating and cooling. PCR machines typically have a small footprint in the lab, measuring less than 15 x 15 inches.

- *Magnetic Stir Plate:* Also known as a magnetic stirrer, this device uses a rotating magnetic field to cause a magnetic stir bar located in a liquid sample to spin around, stirring it. Most magnetic stir bars range from 0.5 inch to just over 6 inches; this piece of equipment is used to stir relatively small sample volumes (under 4L).

- *Vacuum Pump:* Vacuum pumps have many different uses in laboratories, including filtration, distillation, and air displacement.

- *Water Distiller:* Distilled water is primarily used in laboratories as a solvent to prepare reagents or as a calibration standard. It is also used to sterilize equipment and to make ultra-pure or high purity water. Distilled water is often available throughout a building; it is usually hooked up to one of the faucets in the lab. There are still some labs that make their own distilled water, although there are fewer and fewer of these over time as more facilities provide distilled water to the building from a large central plant.

E. Large Laboratory Equipment

- *Shaker Table:* Shaker tables, also known as rockers or shakers, are used to agitate samples. Shakers usually have a table board that oscillates horizontally, and rockers have the ability to tilt and rotate. Shaker tables come in a variety of sizes.

- *Autoclave:* Autoclaves are pressure chambers used to sterilize equipment, reagents, and hazardous waste. They subject the contents to high pressure steam (121°C) for 15-20 minutes, depending on what needs to be sterilized. Autoclaves come in a variety of sizes, from relatively small research-grade autoclaves that will fit on a benchtop, to medical grade autoclaves that occupy half of a room.

- *Gas Laser:* Gas lasers produce a beam via the discharge of an electric current through a gas medium. They often require some form of air or water cooling. Gas lasers are used for imaging, spectroscopy, gas sensing, environmental monitoring, and testing night vision among other applications.

- *qPCR Machine:* Quantitative PCR machines both amplify and detect DNA (unlike PCR machines, which just amplify DNA). The detection of DNA is accomplished through the use of a fluorimeter, an instrument that measures fluorescence. Temperature uniformity and detection sensitivity are key attributes to qPCR machines. These systems are larger than PCR machines, though they can often still fit on a lab bench.

- *NMR:* The principle behind nuclear magnetic resonance (NMR) is as follows: atomic nuclei placed in a magnetic field will absorb and re-emit electromagnetic radiation. The resonance frequency of the energy emitted will depend on the properties of the atoms in the sample and is proportional to the strength of the applied magnetic field. NMR is used to probe biomolecular structures, study protein folding, quantify molecular dynamics, analyze chemicals, study polymer chemistry and physics, and screen for drugs, among many other applications.

- *Mass Spectrometer:* Mass spectrometry measures the mass-to-charge ratio of ions in a mixture. An ion source ionizes the sample, and the ions are accelerated through electrical and/or magnetic fields. The deflection of the ions in these fields is based on the ratio of their mass to their charge. An ion detector is used to detect ions that have been deflected, and the signal is amplified by electron multipliers and read out by a computer program. Historically, mass spectrometry has been used to identify and quantify proteins, although recent years have seen mass spectrometers used for other applications such as testing water quality, carbon dating, and determining the structures of drugs during the drug discovery process.

- *Gas Chromatograph:* Gas chromatography is used to separate and analyze components in a mixture, often to test for purity or to separate out components from a mixture. Samples are separated according to vapor pressure differences, thus requiring precise temperature controls in order to heat the liquid sample to a gaseous phase.

- *HPLC:* High performance liquid chromatography (HPLC) is another technique that is used to separate and analyze components in a mixture. A mixture of highly pressurized liquid and the sample are pumped through a column filled with an adsorbent material, with which the sample interacts. The flow rate of the sample will depend on its interaction with the column, and it is from this flow rate that characteristics about the components in the sample can be ascertained.

- *FACS:* Fluorescence-activated cell sorting (FACS) is a method for sorting cells from a heterogeneous mixture based on the light scattering and fluorescent properties of the cells. Like microscopes, FACS machines employ mercury lamps and lasers to visualize the sample. It is not uncommon for FACS systems to have ten or more lasers.

- *Incubator:* Incubators are used to maintain constant temperature and humidity. Levels of CO_2 and O_2 may also be regulated in an incubator. Temperature ranges for incubators are typically between 25°C and 60°C. They range in size from slightly bigger than a microwave to the size of an ultra-low temperature freezer. Incubators are most commonly used in academic research to grow cell cultures, but they are also widely used for storing samples. Incubators tend to be off-the-shelf products.

- *Tissue Culture Hood:* Tissue culture hoods are formally known as laminar flow hoods, or biosafety cabinets. They can provide a sterile work environment for sensitive research, and, like fume hoods, they are designed to protect the researcher from potentially hazardous materials. Sterility in the area is maintained through the unidirectional flow of HEPA-filtered air over the work area. Class II biosafety cabinets are commonly known as tissue culture hoods because they are often used for cell culture work. Other types of biosafety cabinets include Class I, which do not have HEPA-filters, and Class III, which are more widely known as glove boxes. Tissue culture hoods are often purchased are built-up units rather than custom-built.

- *Sonicator:* A sonicator is a tool that uses sound to agitate a sample. Ultrasonic frequencies are often used in this process, and they are applied to the sample either in a bath or directly via a probe. Sonicators can be used to homogenize tissue samples, stir NMR samples, and produce nanoparticles.

- *Vacuum Chamber:* A vacuum chamber is a low-pressure environment in which air and all other gases have been removed using a vacuum pump. Vacuum chambers are used to conduct experiments in particle physics, as well as to simulate conditions in outer space, and for vacuum drying/vacuum coating.

- *Air Table:* Air tables are also known as vibration isolation tables. They are required for use in microelectronics fabrication, and in laser/optical systems. Most air tables operate on a constant supply of compressed air.

F. Hospital Equipment

- *MRI:* Magnetic Resonance Imaging (MRI) is an imaging technique that employs strong magnetic fields and radio waves. It is used to investigate physiology. Although there are many different types of MRI machines, the most commonly used in research are fMRI (functional MRI) to measure neural activity, and multinuclear imaging to detect chemical bonds.

- *CT Scanner:* CT Scanners use multiple x-ray beams and detectors to create a more complete image than what can be achieved by a conventional x-ray.

- *X-Ray Machine:* In an x-ray machine, an electron beam is generated by heating a filament to high temperatures on one side of an electrode pair (cathode), and that beam is directed across a glass vacuum tube to the other side of the pair, the anode, which is made of tungsten. When the electron beam hits the tungsten, it causes an electron to move to a lower energy state, thus releasing a high-energy photon (the x-ray). A thick lead shield is used to prevent the x-rays from scattering in all directions. X-rays are most useful for imaging hard materials, such as bones.

G. Environmental Rooms

- *Cold Room:* A cold room is a single room that is maintained at a constant (cold) temperature, usually 4°C, but other temperatures, such as -20°C, are not uncommon. These rooms are operated at this temperature 24/7, regardless of whether they are actively being used.

- *Warm Room:* A warm room is a single room that is maintained at a constant (warm) temperature, usually 37°C, but other temperatures are not uncommon. These rooms are operated at this temperature 24/7, regardless of whether they are actively being used.

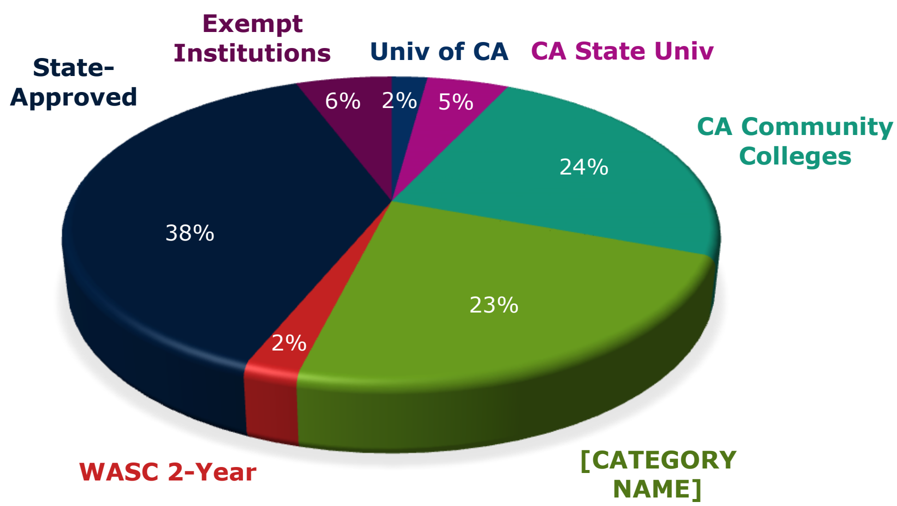
CHAPTER 4: RESULTS, FACILITY STUDIES

4.1 ACADEMIC FACILITIES

It is natural to start the conversation about laboratory facilities with academic institutions – academic facilities are where most basic research is done and future scientists are trained. Academic facilities are also known to have many energy-intensive laboratories, often accounting for nearly 50% of energy consumption on campus while representing only 20-30% of total campus facility space.

There are a total of 401 degree-granting institutions in California [12]. Figure 1 shows the relative number of institutions in each category.

FIGURE 1: SEGMENTATION OF DEGREE-GRANTING HIGHER-EDUCATION INSTITUTIONS IN CALIFORNIA



One-hundred seventy-one of the 401 institutions were analyzed for this study. Table 2 below shows the percentage analyzed in each category.

TABLE 2: NUMBER OF ACADEMIC INSTITUTIONS IN CALIFORNIA ANALYZED FOR THE STUDY

Category	Total Count in CA	Total Number Analyzed	Statistical Significance
University of CA	10	10	Confidence Level: 99%
CA State University	23	23	Confidence Level: 99%
CA Community Colleges	112	52	Confidence Level: 95% Confidence Interval:10
Other Public Colleges & Univ.	2		
WASC 4-Year	108	51	Confidence Level: 95% Confidence Interval:10
WASC 2-Year	11		
State-Approved	180	35	Confidence Level: 95% Confidence Interval:15
Exempt Institutions	27		

Laboratories in these different institutions fall into one of two general categories: teaching laboratories and research laboratories.

4.1.1 ACADEMIC INSTITUTIONS – TEACHING LABORATORIES

Teaching laboratories are a subset of class laboratories. A class laboratory is defined by the US Department of Education's National Center for Education Statistics (NCES) as 'a room used primarily for formally or regularly scheduled classes that require special purpose equipment or a specific room configuration for student participation, experimentation, observation, or practice in an academic discipline'. For the purposes of this study, not all class laboratories can be considered – some of these spaces are used for architecture, or drama, or woodworking. Therefore, the term 'teaching laboratory' will be used to denote that subset of class laboratories that specifically focus on instruction in the Physical and Life Sciences.

Information about the number of teaching laboratories nationwide and in California is not available; the estimated number of teaching laboratories was derived based on available information. An institution was deemed to have teaching labs if the building plans, website, and/or course material referenced teaching labs. Students at these institutions were considered to have access to teaching labs. A series of studies into teaching laboratories from 1999 -2011 conducted by Paulien & Associates, Inc [13] found that the average square footage (ASF) per full time student (FTE) for teaching labs was 11 ASF/FTE for research institutions with enrollment greater than 10,000 students. Because this was the most conservative estimate that was found (the national average seems to be somewhere between 15 and 20 ASF/FTE for research institutions), this is what was used in the calculation. Whenever possible, this study erred on the side of conservative estimates.

The California Postsecondary Education Commission's (CPEC) most recent complete set of student data comes from 2008. In this report it was found that there were a total of 2,820,000 students enrolled in post-secondary education in California.

Students had access to Physical and/or Life Science teaching laboratories in five of the eight academic institution categories studied. Three of the eight categories represented less than 1% of the enrolled student population and were therefore not investigated further. Access to teaching laboratories, and percentage of institutions with teaching laboratories, for the different categories is summarized below in Table 3.

TABLE 3: A SUMMARY OF TEACHING LABORATORIES IN CALIFORNIA

CATEGORY	TOTAL COUNT IN CA	PERCENT WITH TEACHING LABS	STUDENT ENROLLMENT (PERCENT OF CA TOTAL STUDENT ENROLLMENT)
University of CA	10	100	9.7
CA State University	23	100	15.8
CA Community Colleges	112	98	61.2
Other Public Colleges & Univ.	2	N/A	0.15
WASC 4-Year	108	46	10.4
WASC 2-Year	11	N/A	Combined with above
State-Approved	180	73	2.6
Exempt Institutions	27	N/A	0.15

To estimate the square footage of teaching laboratory space, the total number of students studying at an institution that has teaching lab facilities (FTE) was multiplied by the average ASF per FTE taken from Paulien & Associates, Inc. These values were then multiplied by the percentage of institutions with teaching labs.

FTE per category * ASF / FTE = ASF per category

ASF * % of institutions in category with teaching labs = estimated teaching lab space

The results are presented in Table 4 below.

TABLE 4: ESTIMATED TEACHING LAB SPACE IN CALIFORNIA

CATEGORY	ESTIMATED TEACHING LAB SPACE (SQ FT)
University of CA	276,000
CA State University	744,000
CA Community Colleges	11,393,000
Other Public Colleges and Universities	N/A
WASC 4-Year	12,000
WASC 2-Year	combined with above
State-Approved	150,000
Exempt Institutions	N/A
Total	**12,600,000**

Thus the total square footage of teaching laboratory space in California is estimated to be 12.6 million sq ft.

A recent document released by the California Community College Chancellor's Office points to the sum total of laboratory square footage in the California community colleges as just over 11 million sq ft [14], thus corroborating this method of analysis for the community colleges at a minimum. However, given that the most recent available data for student enrollment and for class laboratory space are over six years old, it is likely that some of the estimates presented in Table 4 are lower than the actual values.

4.1.2 Academic Institutions – Research Laboratories

At research institutions [15], research laboratories occupy a substantially larger percentage of space than teaching laboratories. It is not uncommon for an academic research institution to have over 1,000,000 sq ft of laboratory space. This is not the case with non-research institutions, such as community colleges; these higher-education facilities tend to have more teaching labs than research facilities.

Information about the total square footage of research laboratories on a given campus was more readily available than information about teaching laboratory spaces. The majority of research facilities had some information on their website related to the size of laboratory spaces, even if it was just an announcement for the opening of a new building on campus. As before, if the total square footage of laboratory space was not listed, the most conservative estimate possible was made. Table 5 summarizes the findings from an extensive investigation into research laboratories in academic institutions.

Table 5: Estimated Research Lab Space in Academic Institutions in California

Category	Total Count in CA	Percent with Research Labs	Estimated Research Lab Space (sq ft)
University of CA	10	100	15,300,000*
CA State University	23	100	3,900,000
CA Community Colleges	112	**	
Other Public Colleges & Univ.	2	N/A	
WASC 4-Year	108	**	
WASC 2-Year	11	N/A	
State-Approved	180	13	5,500,000
Exempt Institutions	27	N/A	
Total			**24,700,000**

* This total number was provided by the University of California Office of the President

**Note that while some WASC 4-Year institutions and community colleges do have research programs, they often utilize the same space as the teaching labs.

There is an estimated total of 24.7 million sq ft of laboratory space being utilized in California's higher education institutions for research purposes.

Taken together, academic laboratories account for a minimum of 37.3 million sq ft of space in California. Keeping in mind the alternative teaching lab ASF/FTE ratio of up to 20, the teaching lab square footage could be up to 22 million sq ft in addition to the total shown in Table 5 above.

California's academic research institutions account for 10% of NIH funding. When doing calculations on laboratory markets in the US it is common practice to assume that a state's share of the market is roughly equivalent to its NIH funding. This is largely due to the fact that NIH funding is the single largest funding source for academic laboratories. Therefore it is possible to use the total square footage derived for academic institutions in California to extrapolate the nationwide square footage of academic teaching and research laboratory space: 373 million sq ft.

4.2 LIFE SCIENCE RESEARCH FACILITIES

One of the challenges in understanding the life science research (LSR) market is that there is no consensus on the definition of this market. Battelle/BIO, who publish a well-respected industry report every two years, call the market 'bioscience' and include in this term: agriculture; bioscience-related distribution (which includes facilities that would have laboratories); medical devices; research, testing, and medical laboratories; and drug and pharmaceutical companies [16]. By contrast, PricewaterhouseCoopers (PWC) and the California Healthcare Institute use the term 'biomedical' to mean ostensibly the same market as Battelle/BIO (less the agricultural sector), yet the industry numbers they arrive at are dramatically different from each other. Other non-profits in California, such as BayBio, SoCal Bio, and the San Diego Biotechnology network among others, speak of only the biotech industry, but include in their lists of biotech companies many companies that classify themselves as something other than a biotech company (i.e. pharmaceutical, medical device company).

These discrepancies in definitions are important when trying to quantify the overall market space irrespective of laboratories. Therefore, in this section, as each piece of information is presented, the terms used by the authors of the original reports to describe the market will be used. It is not possible to make comparisons between different reports, but it is possible to identify trends.

According to a report published in 2014 by PWC and the California Healthcare Institute, employment in California's biomedical industry is second only to the computer and other peripheral manufacturing sector [17]. In fact, nearly twice as many people are employed in California's biomedical industry than in the tech industry. In 2012 they found that there were a total of 2,490 biomedical companies located in California, representing $96 billion in revenue.

The most recent estimate of the overall bioscience market in California from Battelle/BIO indicates that over 7,900 establishments in the state were classified as bioscience companies in 2012 [18]. By comparison, there were 71,316 bioscience establishments nationwide. The total number of establishments and total employment in this sector in California account for 14% and 11% respectively of the total US market. Figures 2 and 3 depict the relative sizes of the four sub-categories that comprise the bioscience market.

FIGURE 2: SEGMENTATION OF THE BIOSCIENCE MARKET IN CALIFORNIA

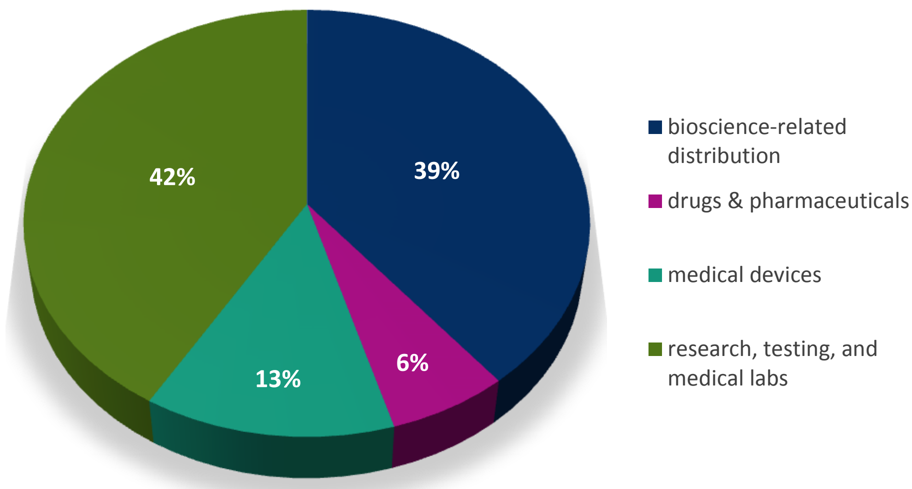
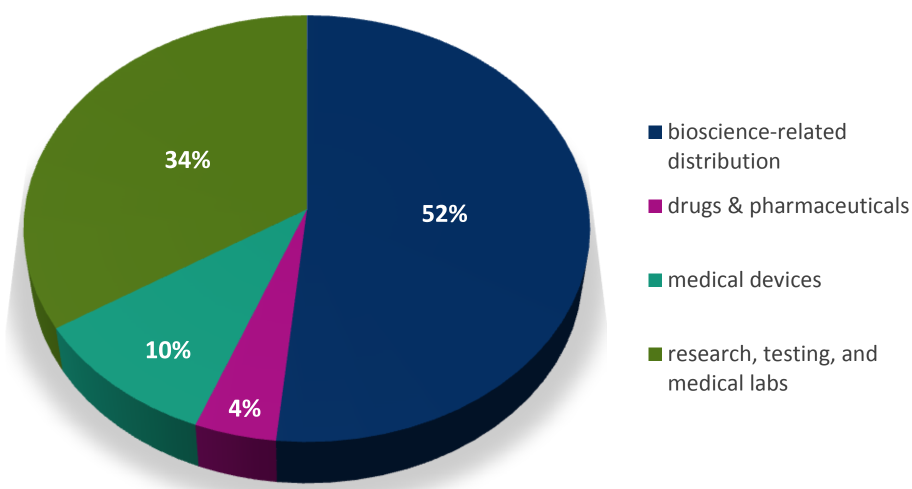


FIGURE 3: SEGMENTATION OF THE BIOSCIENCE MARKET IN THE UNITED STATES



Further segmentation of the biomedical market by region indicates that the Bay Area, Northern California, and Sacramento County employ 29% of the people in the biomedical industry; LA County employs 19.5%; Orange, Riverside, San Bernardino, Ventura and Santa

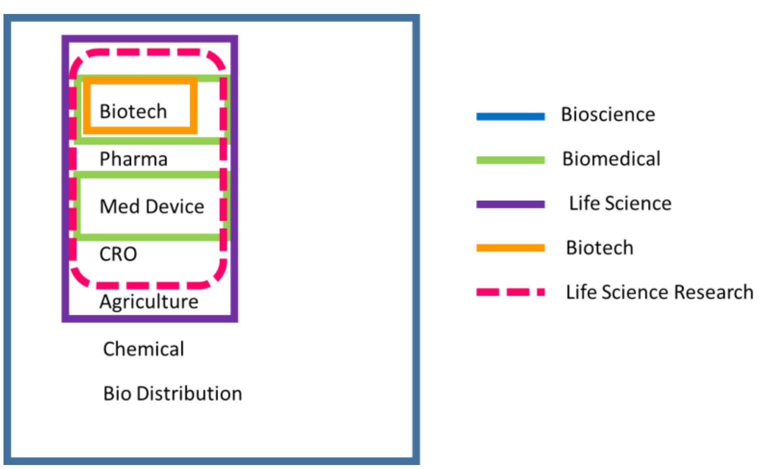
Barbara Counties employ 25%; and San Diego County employs 14%. The remaining biomedical employees are scattered throughout the state.

A 2010 report on the biotechnology industry in California found that 21% of biotechnology firms were in Los Angeles County (1085 firms), 30% were in the Bay Area and Silicon Valley (1545 firms), 14% were located in San Diego County (723 firms), and 13% were in Orange County (670 firms) [19]. The remaining biotech companies were found in the Inland Empire (6%), the Central Valley (5%), South Central (5%), Sacramento (5%), and in the Far North (1%).

The same report found that biotech revenue was correlated with concentration of biotech firms, with the Bay Area and Silicon Valley accounting for more than $20 billion in revenue in 2010, followed by Los Angeles County generating between $6.3 and $9.0 billion, and finally San Diego County generating between $2.4 and $6.2 billion. Of note is that the correlation of revenue was with the number of firms, and not the number of employees, which appear to be most highly concentrated in the central part of the state.

Local estimates on the number of biotech companies in Northern and Southern California are more conservative, and are also quite varied. According to BioSpace the six-county region of Greater Los Angeles has nearly 900 life science companies [20]. BayBIO estimates that there are over 2000 life sciences companies in Northern California [21], and the San Diego Biotechnology Network identifies over 430 biotech companies located in San Diego County [22]. The San Diego Regional EDC cites over 700 biotech companies and more than 80 research institutions in the region [23], and Biocom claims 1,116 life science establishments in San Diego alone, with another 1,409 companies located in Imperial, Orange, and Riverside Counties. It is possible that these varied estimates are the result of differences in market segment definition. It may also be the case that the criteria by which these companies are being evaluated are different. For example, a company office that is occasionally used by outside sales people may 'count' in one type of study, such as an economic impact study, but may be discounted in a study that is focused on the number of establishments with manufacturing capabilities.

FIGURE 4: SUMMARY OF MARKET DEFINITIONS



The semantic challenges outlined above and summarized in Figure 4 were carefully considered when analyzing the total laboratory space in the state. In spite of their lack of consensus on a total number of establishments, taken together these reports indicate that the biomedical/bioscience/biotech market in California is large. The extent of laboratory space in this market has not been studied in previous reports, and will be explored in the next section.

4.2.1 Life Science Research Companies – Laboratory Spaces

Lists of life science research companies were compiled for each of the investor-owned utility sectors in California. Companies were classified according to the following categories: pharmaceutical, biotech, contract research organization (CROs), and medical device.

A total of 1,351 companies were evaluated, of which 679 were located in Northern California, 242 in Los Angeles, Orange, and Riverside Counties, and 430 in San Diego County and the Imperial Valley. Companies were classified based on information available on their websites and/or LinkedIn profiles. Companies that considered themselves to be therapeutic or diagnostic companies were classified as pharmaceutical companies, provided they were not medical device companies.

Table 6 shows the composition of the life science research market studied as a function of market segment in California. The LSR market in California can be further subdivided by utility service territory, also shown in Table 6. Note that the percentages for each utility service territory are correlated with the total number of companies studied.

Table 6: Number of LSR Companies Individually Studied for this Report

	Total Number of Companies Studied	% in SDG&E's Territory	% in SCE's Territory	% in PG&E's Territory
Pharmaceutical	569	38%	38%	46%
Biotech	423	35%	33%	29%
CRO	145	15%	7%	9%
Medical Device	214	12%	22%	16%

In Southern California, the percentage of medical device companies was more heavily weighted toward SCE's territory, although the relative percentage of pharmaceutical and biotech companies were nearly the same in SCE's and SDG&E's territories. Northern California has a slight shift towards the pharmaceutical industry.

An analysis of just the Southern California market [24] reveals similar trends. Biocom also found that the number of medical device companies was greater in Orange and Riverside Counties than in San Diego County (using employment data as a proxy for the number of companies).

Most reports of the LSR market in California focus on the number of employees in a particular region. Therefore, in an effort to corroborate the findings from this study with the findings from other reports, employee data were also analyzed for the more than 1300 companies studied in this report [25].

TABLE 7: EMPLOYMENT FIGURES FOR COMPANIES INDIVIDUALLY STUDIED FOR THIS REPORT

EMPLOYEES BY SEGMENT	SDG&E		SCE		PG&E		ALL TERRITORIES	
Pharmaceutical	9,020	52%	15,135	63%	11,475	54%	35,630	57%
Biotech	4,619	27%	5,537	23%	6,218	30%	16,374	26%
CRO	1,264	7%	209	1%	1,957	9%	3,430	6%
Medical Device	2,182	13%	3,212	13%	1,519	7%	6,913	11%
Total	**17,085**		**24,093**		**21,169**		**62,347**	

A closer look by PWC at biomedical employment in California revealed that the largest number of employees were in SCE's territory, followed by PGE&E's and finally SDG&E's territories [26]. These are the same trends revealed by the data set above.

Taking together the company number and employment data, it was confirmed that the data set to be analyzed for this study was in agreement with the trends identified in previously published findings.

All 1,351 companies were subsequently evaluated as to whether they conducted research at their facilities. Only companies that were deemed to conduct research were further investigated for square footage of laboratory space. Most companies that conduct research list their R&D sites on their websites, and those that do not usually only list administrative facilities. If it was not immediately obvious whether research was done at a particular site, the organization was either contacted to confirm the existence of laboratories, or it was deemed to do no research in an effort to err on the side of underestimating the market size rather than over-estimating it.

As seen in Table 8, on average, 80% of the LSR companies and 58% of the medical device companies studied perform research in California. In other words, this study includes laboratory information from 909 LSR companies and 124 medical device companies.

TABLE 8: PERCENTAGE OF LSR COMPANIES CONDUCTING RESEARCH IN THEIR CALIFORNIA FACILITIES

MARKET SEGMENT	SDG&E	SCE	PGE&E	ALL TERRITORIES
Pharmaceutical	72%	74%	80%	77%
Biotech	87%	84%	75%	81%
CRO	84%	89%	95%	91%
Medical Device	60%	55%	60%	58%

A summary of square footage of laboratory space in the LSR market is shown in Table 9. These values represent the sum of all laboratory square footages either found or derived for the 1351 companies studied. The data below represent a statistically significant population of the total addressable market of LSR companies.

TABLE 9: ESTIMATED LABORATORY SPACE IN CALIFORNIA IN THE LSR MARKET (OF THOSE COMPANIES STUDIED)

MARKET SEGMENT	SDG&E SQ FT (M) %TOTAL		SCE SQ FT (M) %TOTAL		PG&E SQ FT (M) %TOTAL		ALL TERRITORIES SQ FT (M) %TOTAL	
Pharmaceutical	5.3	45%	5.9	60%	5.8	38%	17.0	46%
Biotech	4.7	39%	2.6	26%	3.4	23%	10.6	29%
CRO	0.7	6%	0.3	3%	2.2	15%	3.2	9%
Medical Device	1.3	10%	1.0	11%	3.6	24%	5.9	16%
Total	**12.0**		**9.8**		**15.0**		**36.7**	

But Table 9 does not reflect the market in its entirety. Extrapolating these data to include the total addressable market is necessary in order to estimate the total square footage of laboratory space in the life science research sector in California.

As explained above, different reports classify the life science research market in different ways, making it difficult to compare among the various studies or to draw conclusions about the overall market. Battelle/BIO appears to present the most comprehensive research, so their data were used as the estimation of total market size. The report from Biocom appears to be least comprehensive, and the PWC report only segregated out medical device companies, and this number was higher than the number assumed by Battelle/BIO.

The 2014 Battelle/BIO report estimates a total of 500 pharmaceutical, 3217 biotech, and 1039 medical device companies in California [27]. They do not make a separate distinction for CROs; these are included in the biotech sector. Because it is not clear from their report whether their pharmaceutical and biotech definitions were in complete alignment with the definitions used in this study, all pharmaceutical and biotech companies identified by Battelle/BIO were combined for a total of 3717. Although the Battelle/BIO study was published in 2014, the data reflected in the report are from 2012. This study identified 1137 companies in the LSR market. The total list of companies that comprise the data set used for this study likely did not have 100% overlap with the companies studied by Battelle/BIO, especially considering that their data is already more than 2 years old. It was not possible to compare the lists of companies between the two studies because the complete list of companies used for the Battelle/BIO report was not published. However, as a function of number of companies, the present study captures at least 31% of the market identified by Battelle/BIO. Considering that an average of 83% of companies in the pharmaceutical/biotech/CRO market segment conduct research at their facilities (see Table 8), that leaves 2064 companies with laboratory space identified by Battelle/BIO unaccounted for in this study.

A similar analysis was done for the medical device companies identified by Battelle/BIO. Of the 1039 medical device companies in California, 214 were analyzed in this study. In the 214 sample size it was found that, on average, only 58% of medical device companies conducted research. Thus, 481 of the total number of potential medical device companies with laboratories were not accounted for.

This same logic can be used to understand the square footage of laboratory space in California, as shown in Table 10. The total square footage accounted for in the study was increased by the percentage of unaccounted-for space in order to give an estimate of the total space.

TABLE 10: ESTIMATED LABORATORY SPACE IN THE CALIFORNIA LSR MARKET, BY NUMBER OF COMPANIES

MARKET SEGMENT	IDENTIFIED IN THE STUDY (SQ FT, M)	ADDITIONAL IMPLIED BY BATTELLE/BIO STUDY (SQ FT, M)	TOTAL (SQ FT, M)
Pharma./Biotech/CRO (Battelle/BIO)	30.8	68.6	99.4
Medical Device	5.9	22.3	28.2
Total	**36.7**	**90.9**	**127.7**

Thus the total addressable market for LSR appears to be approximately 127.7 million sq ft of laboratory space.

It was noted, however, that while the LSR data set appeared to capture only 31% of the total market when viewed through the lens of the number of companies, the data set seemed to capture 77% of employees in the LSR market when viewed from the perspective of employment data. Employees are likely a better predictor of square footage than number of companies simply because the addition of employees to a LSR company is more likely to yield more space and/or more equipment dedicated to research activities. By contrast, adding a new company to the roster does not necessitate an increase in lab space. Furthermore, utilizing employment data leads to the most conservative estimate of square footage.

Analysis of the companies comprising the data set by employment is shown below in Table 11. Employment figures were taken from the Battelle/BIO study, and multiplied by the percentages that are thought to be engaged in research in that market segment (based on Table 8). This meant that 83% of the employees reported to be working in the pharmaceutical/biotech/CRO sector are employed at a facility that conducts research, and 58% of the employees reported to be working the medical device sector are employed in a facility that conducts research. Seventy percent of each of these values was then taken to represent the number of employees actively engaged in research (see Section 2), and requiring laboratory space for their work. The employee numbers for the current study are already assumed to be engaged in research operations.

TABLE 11: EMPLOYMENT INFORMATION FOR THE LSR MARKET

MARKET SEGMENT	EMPLOYMENT FIGURES FROM CURRENT STUDY	EMPLOYMENT FIGURES FROM BATTELLE/BIO	PERCENT ADDRESSED WITH CURRENT STUDY
Pharmaceutical/Biotech/CRO	55,434	71,768	77%
Medical Device	6,913	25,227	27%
Total	62,347	96,995	

Looking at the market from the perspective of employment gives a very different picture than looking at it from the perspective of the number of companies. Extrapolating the data above to square footage (using the same methods as described in Section 2) results in a different set of conclusions (Table 12).

TABLE 12: ESTIMATED LABORATORY SPACE IN THE CALIFORNIA LSR MARKET, BY NUMBER OF EMPLOYEES

MARKET SEGMENT	IDENTIFIED IN THE STUDY (SQ FT, M)	UNACCOUNTED FOR (SQ FT, M)	TOTAL (SQ FT, M)
Pharma./Biotech/CRO (Battelle/BIO)	30.8	9.2	40.0
Medical Device	5.9	16.0	22.0
Total	**36.7**	**25.2**	**62.0**

It is interesting to note that both forms of analysis yield similar results for the medical device sector. These data shown in Table 12 suggest that the total addressable market of life science research (LSR) laboratory space in California is approximately 62 million sq ft, or nearly half that predicted by looking at the number of companies alone. The data in the Battelle/BIO study was from 2012. Using published growth rates for the life science research sector from 2010-2012 (5% per year), the 62 million sq ft calculated above for 2012 becomes 68 million sq ft in 2015. It should be noted that the total is likely even higher than this as a result of new businesses.

The square footage values for the life science research sector were checked against published data. According to a 2009 publication, there were 30 million sq ft of LSR space in the Bay Area in 2009, including laboratories and office spaces [28]. Assuming 70% of that space is laboratory space, in 2009 there were approximately 21 million sq ft of LSR lab space in the Bay. At the industry standard growth rate of 5% annually, the 21 million sq ft of LSR space in 2009 is approximately 28 million sq ft in 2015. Conversations with real estate developers put the estimated square footage of laboratory space in Bay Area at approximately 25 million in 2015, which is only 3 million less than the predicted laboratory square footage when assuming a 5% annual growth rate in this sector. Data obtained for this study revealed PG&E's market share for LSR to be approximately 50% of the laboratory square footage in the state, or nearly 34 million sq ft. If 28 million sq ft of that are accounted for in the Bay, that would leave an additional 6 million sq ft of laboratory space in Northern California between Sacramento and Northern California. This value seems reasonable. Employment statistics from a 2012 PWC report show that Northern California (excluding the Bay) employs roughly 14,000 people in just one of the market segments studied, which, translated to laboratory space, is approximately 3.3 million sq ft for just a subset of biotech alone. Therefore, the estimation in this report of 34 million sq ft of laboratory space in PG&E's territory seems reasonable.

Because the values obtained for the life science research market in PG&E's territory were corroborated by outside sources, it is assumed that this method of estimating laboratory square footage is sound, and can be used in other regions across the state.

Assuming California accounts for 11% of all LSR companies [29], the total square footage of lab space across the US in the LSR market segment is approximately 665.7 million square feet.

4.3 Hospital Research Facilities

The American Hospital Association (AHA) recognizes 5,724 hospitals in the United States, approximately half of which are non-profits, and a quarter of which are operated by either the state or local government. The AHA makes a distinction between hospitals and academic medical centers (AMCs), which are hospitals and health systems that have a close affiliation with a medical school. They have identified 400 AMCs in the US as of 2013. For the purposes of this study no distinction will be made between a hospital and an AMC – both will fall under the categorization of 'hospital'. Thus there are 6,124 hospitals nationwide. The California Office of Statewide Health Planning and Development has identified 532 hospitals in the state of California [30]. California's hospitals account for 8.7% of the total US hospital market.

Reports on trends in hospitals focus on the health care side of the business, making it difficult to identify pertinent market information on research in hospitals. In the absence of specific analysis of the research hospital market, publication data can be used to shed light on the state of this industry. A recent paper published in the Journal of Hospital Medicine demonstrated that peer-reviewed publications from hospital research laboratories have increased nearly five-fold since 2006 [31]. The authors also found that of 645 members of the Society of Hospital Medicine surveyed, 33% were actively engaged in research. Assuming that California follows this national trend, it is likely that research activities in hospitals in the state are increasing.

4.3.1 Hospital Research Facilities – Laboratories

For the purposes of this report, any hospital that is found to engage in research will be deemed a research hospital, regardless of whether the institution refers to itself as such. By definition, all research hospitals will have laboratories.

The word 'laboratory' has many different meanings in the context of a hospital. If asked, most hospitals will confirm that they have a lab – meaning that they have a place to perform patient tests. This understanding of the word 'laboratory' does not meet the operational definition of this study, however. Hospitals with clearly identifiable spaces for research will be deemed to have laboratories. In addition, hospitals with spaces and equipment that are used for clinical diagnostic testing will also be considered to have laboratories. The latter meets the 'testing' requirement of the definition. These clinical diagnostic testing spaces are often referred to as clinical laboratories, but that term can be misleading as it is also used to refer to spaces in which human research is done, and it can be used to describe places where samples are taken from patients but no testing is done (e.g. phlebotomy labs).

Of the 532 hospitals in California identified by the California Office of Statewide Health Planning and Development, 166 were found to contain laboratory spaces, as determined using the criteria above for research and testing. Of these, 142 had only clinical diagnostic testing laboratories, and the remaining 24 had both clinical testing laboratories as well as research laboratories. The laboratory space in the research hospitals far exceeded that of the hospitals that only had testing laboratories. Table 13 below summarizes the findings from the analysis of the hospital data.

TABLE 13: ESTIMATED HOSPITAL LABORATORY SPACE IN CALIFORNIA

HOSPITAL LAB CATEGORY	EST. NUMBER IN CA	EST. TOTAL LAB SPACE (SQ FT)	ESTIMATED PERCENTAGE OF HOSPITAL LAB SPACE
Clinical Diagnostic Testing	142	500,000	8%
Research	24	5,900,000	92%
Total	**166**	**6,400,000**	**100%**

Medical schools affiliated with the University of California schools accounted for 67% of research laboratory space in hospitals. The amount of space devoted to research in hospitals was determined from personal communications with the UC Office of the President and Stanford (which together comprise over 90% of the total), as well as from published documents containing information about research laboratory square footage. Ascertaining the square footage of clinical diagnostic testing space was more difficult. Only one of the 142 locations published the square footage of their space (3,890 sq ft), and Kaiser offered an estimation of theirs during a personal communication. The remaining laboratories were estimated to be between 1,000 and 3,000 sq ft, with 2,000 sq ft being the most common estimate. Two-thousand square feet is just below the average estimated square footage for an academic lab.

One important medical research facility not included in the table above is the VA (Veterans Affairs). There are three major VA networks in California that have research facilities: the VA San Diego Healthcare system, the VA Greater Los Angeles Healthcare System, and the VA Palo Alto Healthcare system. The VA San Diego Healthcare system has 193 researchers [32]. Using a conservative estimate of 1000 sq ft per researcher (assuming each 'lab' has one PI and 2-3 other scientists), the VA San Diego Healthcare system has an estimated 193,000 sq ft of laboratory space. The VA Greater Los Angeles Healthcare System has published the square footage dedicated to research in their facilities: 346,821 sq ft as of 2010 [33]. This space corresponds to 237 researchers. The VA Palo Alto Healthcare system has approximately 700 researchers in its network [34]. Using the same assumption of 1000 sq ft per researcher, the total square footage of laboratory space can be estimated at 700,000 sq ft. **Thus, the VA facilities in California account for an additional 1.2 million sq ft, bringing the total to 7.6 million sq ft for the state**.

California may be home to 8.7% of all hospitals in the country, but given that the funding for research in hospitals is similar to that of academia it is likely that California represents at least 10% of the US hospital lab market. Therefore, extrapolating these findings to the US reveals that US hospital labs occupy an estimated 76million sq ft.

4.4 Non-Profit Institutions

Although non-profit facilities fall outside of the scope of this report, it became apparent in researching hospital facilities that there are several non-profit research centers across the state that are loosely affiliated with a university, a hospital, or both. The John Wayne Cancer Institute in Santa Monica, for example, has an affiliation with UCLA; Scripps Research Institution has an affiliation with Scripps Hospital. Thirty-six of these affiliated, and some non-affiliated, non-profit institutions were analyzed with respect to laboratory space, and they were found to account for an additional 3.1 million sq ft.

4.5 Summary

A summary table of estimated lab space in academia, the biopharmaceutical industry, hospitals, and non-profits is below.

Table 14: Total Estimated Laboratory Space in California

Market Segment	Estimated Lab Space in California (sq ft, M)
Academia	37.3
Life Science Research (LSR)	68.3
Hospitals	7.7
Non-Profits	3.1
Total	**116.4**

It is evident from just these four market segments that the laboratory sector in California is large. By comparison, the food service industry represents approximately 160 million sq ft in California [35]. **Thus, the market segments studied represent a minimum of 73% of the food service industry space**. Considering this study did not take into account any agricultural, industrial or chemical companies, forensic labs, local and state testing facilities, or government labs, it is reasonable to expect that the laboratory market is comparable in size to that of the food service industry. As an example, the State Department of Health Services operates a 700,000 sq ft facility in Richmond, CA [36]. There are 48 forensic laboratories in the state [37] – even if each one only had 5,000 sq ft of laboratory space, they would comprise nearly 240,000 sq ft among them. Monsanto recently expanded their laboratory space by 90,000 sq ft, bringing the total laboratory space at just that one facility in Woodland to over 200,000 sq ft [38]. Monsanto is just one of over 117 companies in the state that conducts agricultural research. It is easy to see that the market for laboratory spaces is large.

Moreover, should the higher estimation for the LSR market be used, the total estimated square footage of laboratory space from just the four market segments studied in this report would be 175.6 million sq ft. If the higher estimate for academic teaching labs (20 ASF/FTE instead of 11 ASF/FTE) were also included, the total area of lab space would be 197.6 million sq ft in California alone.

4.6 ESTIMATION OF FACILITY SQUARE FOOTAGE FROM ONLINE SURVEYS

Facility managers were asked about the approximate square footage of their institution. Survey data gathered about facility square footage were used to check and verify the methods used to estimate the square footage of laboratories in the LSR market wherever possible. In addition, these values were also correlated with the estimated number of pieces of laboratory equipment at each facility (see Chapter 5).

4.7 ESTIMATION OF FACILITY SQUARE FOOTAGE FROM IN-PERSON INTERVIEWS

In-person interviews revealed several accounts of laboratory space square footage. These numbers were used to validate the method used for determining laboratory square footage as a function of employment. Although the sample size was small, the method correctly predicted the square footage of the space 80% of the time.

4.8 MARKET TRENDS

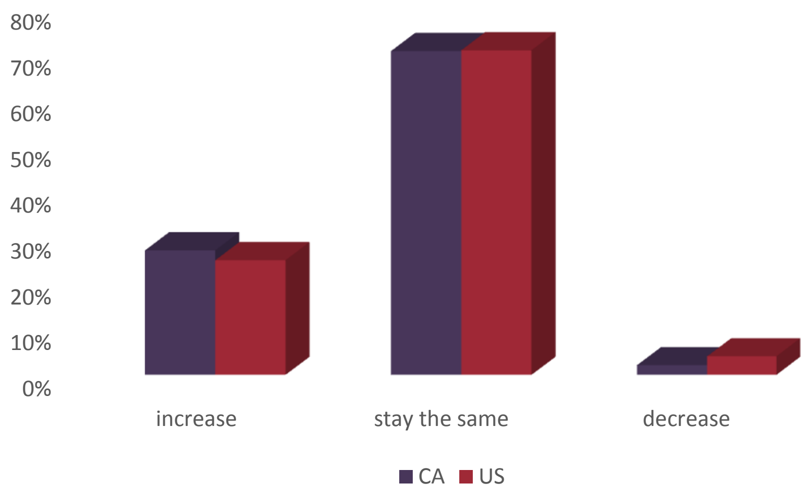
Not only is there a lot of laboratory space, but the market continues to grow. The projected growth for enrollment in academic institutions is 15% from 2012 to 2021 according to the Fortieth Edition of the National Center for Education Statistics report, and federal funding for academic research was projected to increase by 2.5% in 2014 [39].

Every two years Battelle and BIO publish an industry report entitled 'Battelle/BIO State Bioscience Jobs, Investments and Innovation', the latest of which was published in 2014. According to this report there are 73,088 bioscience establishments nationwide, and the sector grew at a rate of 11.4% from 2007-2012. Battelle/BIO have also demonstrated a growth rate of 5% per year for the past 5 years in the LSR market in California.

New construction of healthcare facilities was expected to increase by 4.8 percent in 2014 according to the American Institute of Architects, making it one of the fastest growing sectors [40]. The Journal of the American Medical Association has found that 1/20th of NIH funding goes to health services research, and that this amount has decreased slightly (0.8%) from 2004 to 2012. However, this decline was offset by private funding, which increased from 46% in 1994 to 58% in 2012.

Moreover, interviews with universities and companies have confirmed that lab space is increasing. Twenty-seven percent of survey respondents in California, and 25% in the United States, have confirmed that their lab space will increase in the next three years, shown in Figure 5. In both cases 70% of respondents have said that they do not expect their space to change, and less than 5% said that they expect it to decrease.

FIGURE 5: GROWTH OF LABORATORY SPACE IN THE NEXT THREE YEARS



Market trends in academia, LSR, and the hospital sectors reveal that laboratories are a large, growing market both in California and nationwide.

CHAPTER 5: RESULTS, PLUG LOAD STUDY

5.1 SURVEY DEMOGRAPHICS

A total of 308 laboratory scientists across California were surveyed about the number, type, and usage of their laboratory equipment. Of these, 269 completed an online survey created in SurveyMonkey, and 39 completed a shorter paper survey. An additional 930 survey responses were collected online from laboratories nationwide, and another 352 paper surveys were completed by scientists from labs outside of California. The number of responses in California gave results with a confidence level of 95% at a confidence interval of 5.6 [41]; the number of responses nationwide gave a confidence level of 95% with a confidence interval of 2.7. The sample populations in both cases were assumed to be random [42].

Scientists who completed the survey came from all three market sectors investigated in this report – academic, LSR, and hospital organizations. Figure 6 below shows the market segmentation of the respondents in California (a) and in the US (b). In both cases the majority of respondents were from academic institutions. This level of response from academic laboratories was not unexpected – they are the easiest to reach as their contact information is publicly available. The 'other' category contains responses from people who work in government or non-profit institutions.

FIGURE 6A: SURVEY RESPONDENTS FROM CALIFORNIA AS A FUNCTION OF MARKET SEGMENT

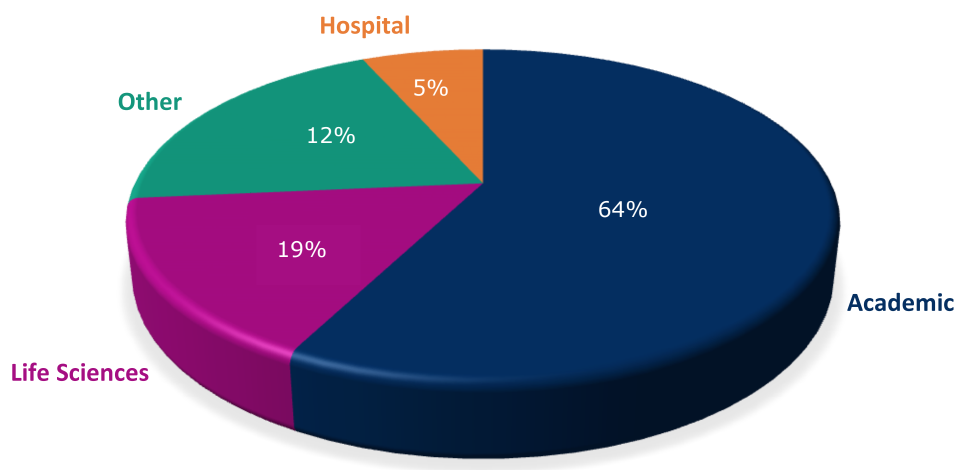
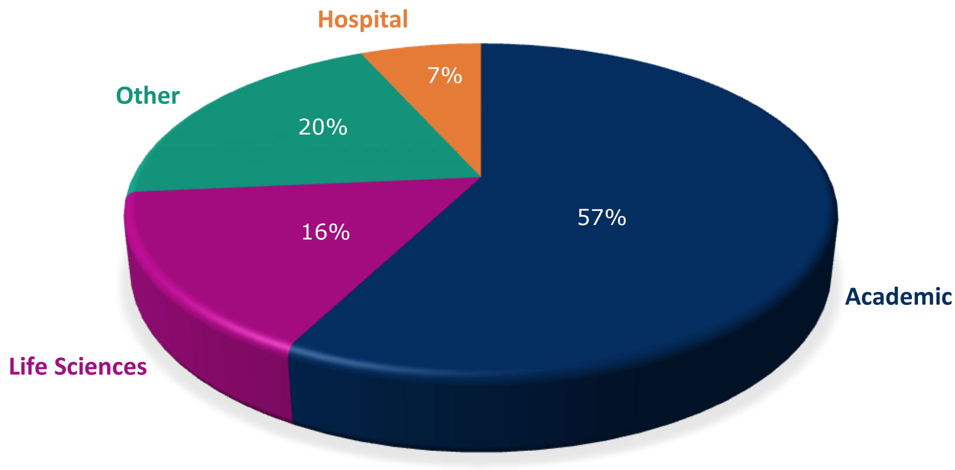


FIGURE 6B: SURVEY RESPONDENTS FROM THE UNITED STATES AS A FUNCTION OF MARKET SEGMENT



Within each of these market segments are a variety of different Physical and Life Science laboratory types. The diversity of the labs surveyed is shown in Figures 7a and 7b. Notably, the majority of respondents worked in the Life Sciences (82%), which is in alignment with the facility types studied in Chapter 4. No one discipline dominated the survey responses, and the distribution of responses from the various disciplines was relatively consistent between California and the rest of the US.

FIGURE 7A: CALIFORNIA SURVEY RESPONSES BY DISCIPLINE

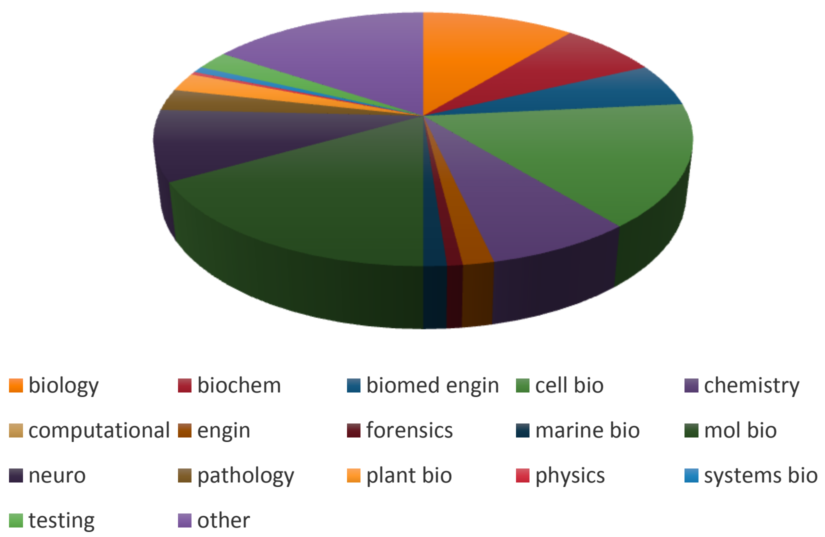
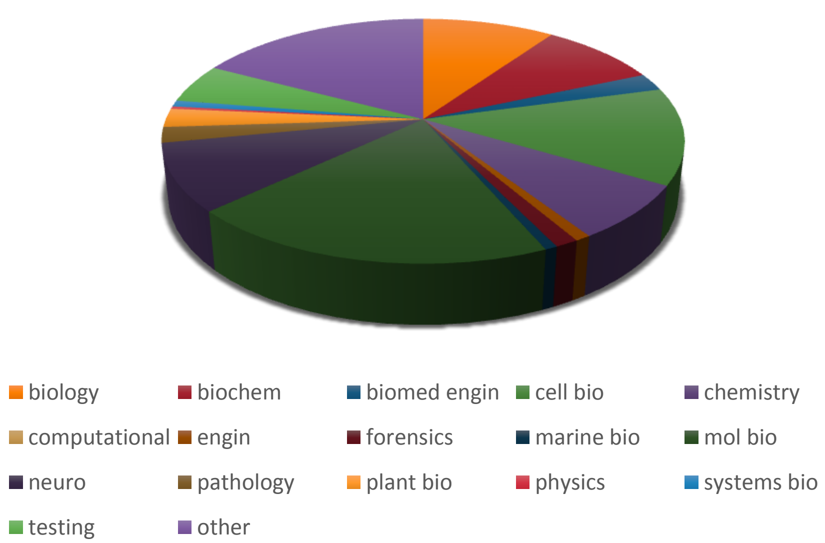


FIGURE 7B: UNITED STATES SURVEY RESPONSES BY DISCIPLINE



Scientists who responded to the survey were classified according to three categories: principal investigators (PI), lab managers, and all other scientists working in the lab, including staff scientists, postdocs, graduate students, and undergraduate students. PIs are the people who run the lab; they are the people responsible for determining the course of the research, and for securing funding for the lab. Lab managers are responsible for the day-to-day operations in the lab. Not all labs have lab managers; sometimes this function is performed by a postdoc or graduate student. PIs and lab managers were separated out from the rest of the people working in the lab because they have control over financial decisions. Figure 8 shows the distribution of respondents according to their role in the lab. Nationwide, 57% of respondents were either PIs or lab managers.

FIGURE 8A: CALIFORNIA SURVEY RESPONSES BY ROLE IN THE LAB

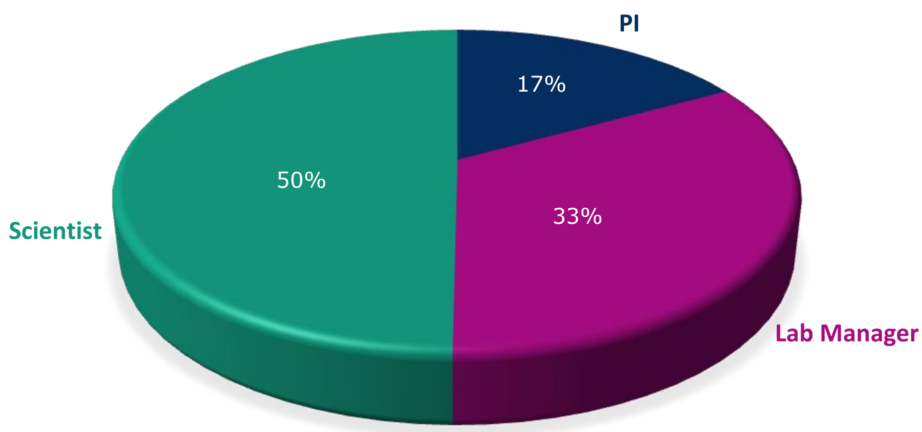
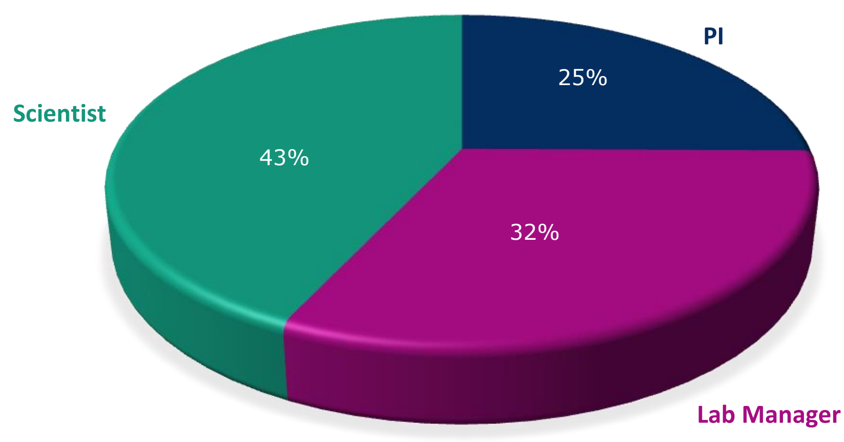
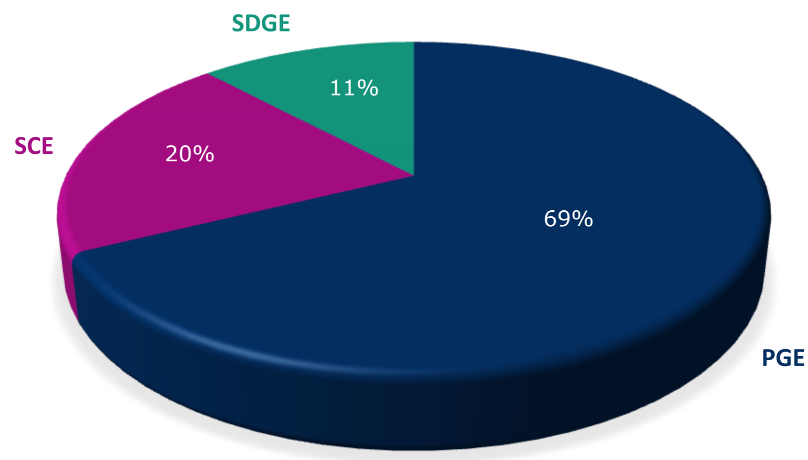


FIGURE 8B: UNITED STATES SURVEY RESPONSES BY ROLE IN THE LAB



The responses from California can be further subdivided by service territory.

FIGURE 9: CALIFORNIA SURVEY RESPONSES BY SERVICE TERRITORY



As seen in Figure 9 above, the majority of responses to the survey came from PG&E's territory (Northern California). Nearly as many respondents came from SCE and SDG&E's territories (Southern California) combined as from PG&E's territory (Northern California) alone. It was expected that there would be more responses in PG&E's territory owing to the fact that the many of the survey distribution channels were located primarily in Northern California. However, even when the survey was distributed through nationwide channels, more people in Northern California responded than in Southern California.

5.2 Online Equipment Survey Results

The types of laboratory equipment surveyed were consistent with the types of equipment commonly found in the laboratories being asked to complete the survey.

5.2.1 Refrigeration

Respondents were asked how many freezers were in operation in their lab. Ninety-eight percent of people responded to this question, shown in Table 15 below.

Table 15: Survey Responses in California – Number of Refrigeration Units per Lab

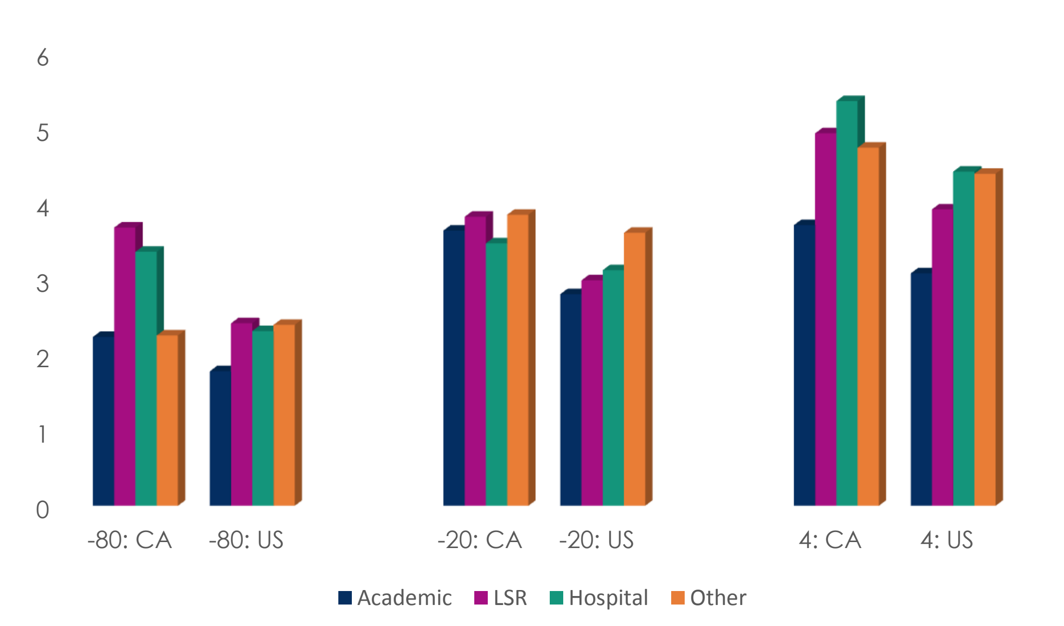
Freezer Type	0	1	2	3	4 - 9	>10
-80°C Freezer	15.3%	29.7%	23.8%	8.1%	15.7%	7.4%
-20°C Freezer	5.6%	21.7%	17.3%	13.3%	31.3%	10.8%
Refrigerator	3.6%	13.5%	18.2%	13.6%	38.3%	12.8%

Refrigeration equipment is clearly heavily utilized in laboratories. In the Life Science market segment, less than seven percent of respondents did not have an ultra-low temperature freezer (-80°C freezer), and less than three percent did not have a -20°C freezer. Nearly 54% of respondents had either one or two -80°C freezers; 39% had either one or two -20°C freezers. The distribution of refrigerators was broader, with 71% of respondents having 1 – 5 units. The distribution of cold storage units was slightly different in the Physical Science market: while 46% of respondents had either one or two -80°C freezers, 50% of respondents did not have any. Minus 20°C freezers were more common, with 40% of respondents having either one or two, and only 16.7% having none. Nearly every lab had a refrigerator, and the broad distribution seen in the Life Science market was also reflected in the Physical Science market.

Correlating the number of freezers to the size of the lab was difficult as 77% of scientists did not know the square footage of their lab space, but for the data that were available, there did not appear to be any correlation between the size of the space and the number of freezers. The reasons for this are likely to be a) people are not correctly estimating the square footage of their space and/or b) freezers are located outside of the space that people would refer to as their 'lab', and therefore respondents did not include that space in their calculation. The latter explanation will become important in Chapter 6.

Nationwide refrigeration data compared with California refrigeration data is shown below in Figure 10. The average number of freezers or refrigerators per lab was calculated and compared across market segments in California and the US.

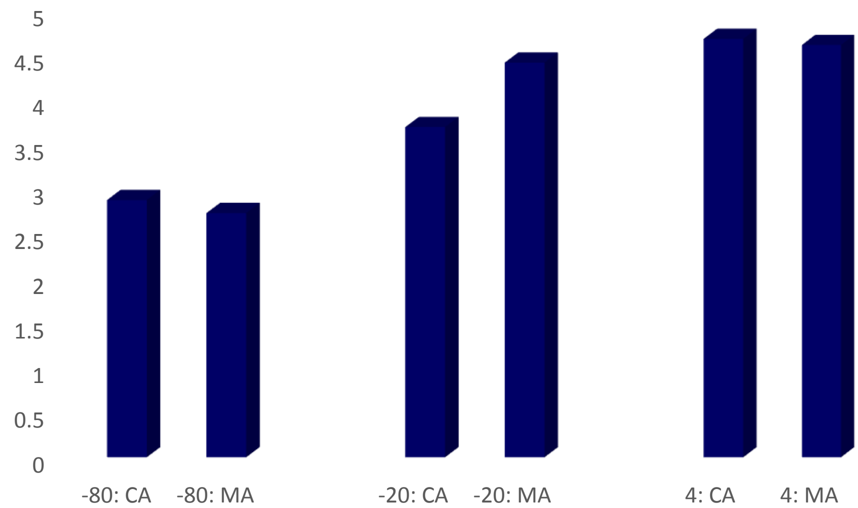
FIGURE 10: AVERAGE NUMBER OF REFRIGERATION UNITS PER LAB – CALIFORNIA AND THE UNITED STATES



On average, the number of refrigeration units per lab was found to be 20% higher in California than in the rest of the US. According to the data collected through the online survey, the average number of -80°C freezers per lab in California is 2.9, and the average number for the United States is 2.2. The average number of -20°C freezers per lab in California is 3.7; the average for the United States is 3.1. The average number of refrigerators per lab in California is 4.7, and the average for the United States is 4.0.

These discrepancies may be due to the fact that California's labs receive the most government and venture capital funding in the country. Examining refrigeration unit numbers between Massachusetts, which receives the most funding per capita in the country, and California reveals that funding may in fact have something to do with the higher average values of equipment seen in the state.

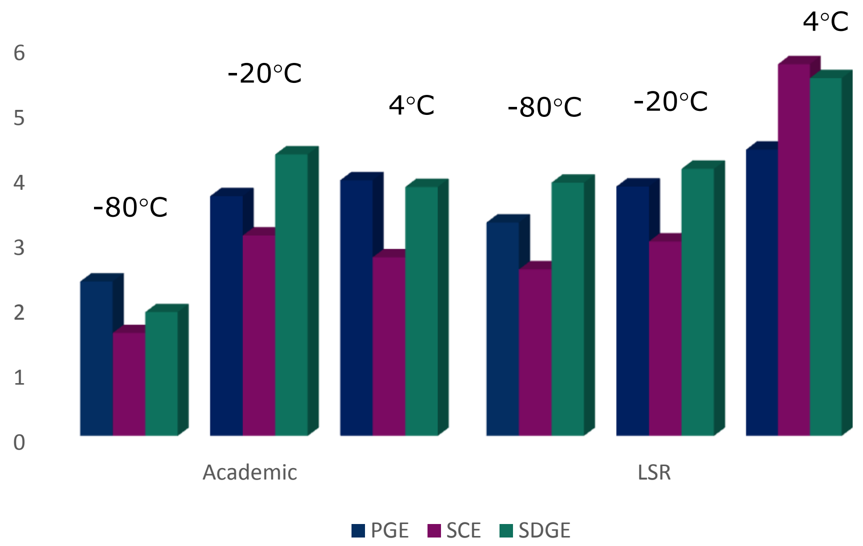
FIGURE 11: AVERAGE NUMBER OF REFRIGERATION UNITS PER LAB – CALIFORNIA AND MASSACHUSETTS



Massachusetts averages 2.7 -80°C freezers per lab, 4.4 -20°C freezers per lab, and 4.6 refrigerators per lab. All of these are not only higher than the national averages, but the average number of -20°C freezers per lab in Massachusetts appears to be higher than California. Given the similarity between the equipment densities in California and in Massachusetts, and how similarly Massachusetts and California deviate from the US refrigeration unit average, it seems clear that funding opportunities have an impact on how much equipment is found in a lab.

Further segmentation of the data into California investor-owned utility service territories revealed that there was agreement on refrigeration unit averages among the different service territories.

FIGURE 12: AVERAGE NUMBER OF REFRIGERATION UNITS PER LAB – SERVICE TERRITORIES



In alignment with the hypothesis that funding affects the average number of units found in a laboratory, refrigeration numbers reported in PG&E's and SDG&E's territory were slightly higher than those reported in SCE's territory. Because the data for refrigeration were so robust, this chart will be taken as evidence that the trends seen in California as a whole are also independently reflected in each service territory.

It is also notable that the data set shown in Figure 12 reflects a higher concentration of laboratory equipment in the LSR market segment when compared with academia.

5.2.2 FUME HOODS

Ninety-one percent of respondents responded to the question about fume hoods. While 93% of those who responded had at least one fume hood in their lab, less than half of those have a variable air volume (VAV) hood. The data for number of fume hoods are summarized below in Table 16.

TABLE 16: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF FUME HOODS PER LAB

TYPE OF FUME HOOD	0	1	2	3	4 -9	>10
Total Number of Fume Hoods	6.8%	32.3%	23.1%	14.7%	14.7%	8.4%
VAV Fume Hoods	56.1%	16.7%	12.7%	5%	5%	4.5%

The usage of the hoods is summarized below.

TABLE 17: SURVEY RESPONSES IN CALIFORNIA – FUME HOOD USAGE

TYPE OF FUME HOOD	0	1-3HRS	4-7HRS	9-10HRS	11-23HRS	24HRS
All	13.7%	43.7%	12.9%	2.8%	2.4%	24.5%
VAV Fume Hoods	3.3%	51.7%	19.8%	4.3%	4.3%	16.6%

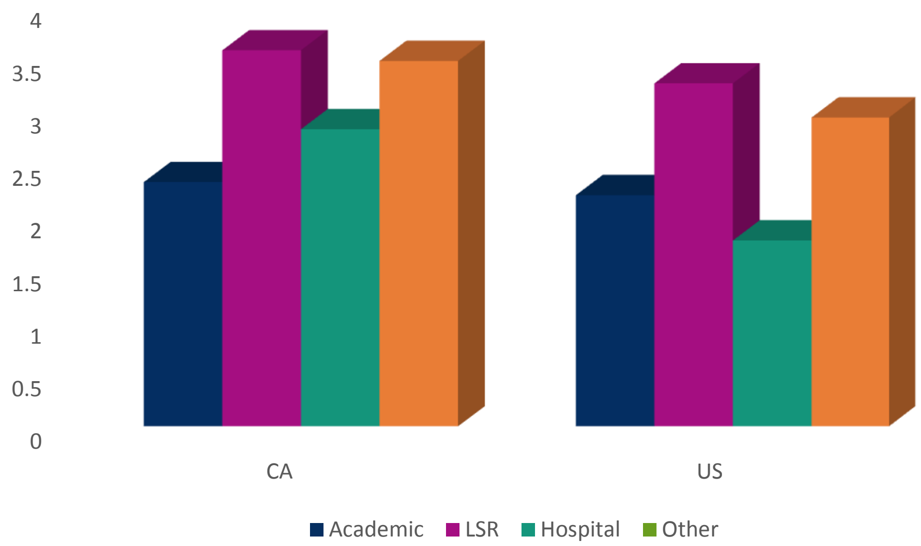
Respondents were asked how many hours per day they were actively using their fume hoods. It is interesting that of the 93% of respondents who have a fume hood in their lab, 14% of them do not use it at all. VAV fume hoods appear to be more heavily utilized than CAV fume hoods according to the data trend seen in Table 17.

Seventy-three percent of respondents who work in the Life Sciences [see Chapter 2] have 1-3 fume hoods in their lab (33.3% have one, 25.3% have 2 and 14.3% have 3). They tend to use their hoods from 1-3 hours per day (50%). Scientists who work in the Physical Sciences also typically have 1-3 fume hoods (22.3% have one, 16.7% have 2 and 16.7% have 3). However, unlike the life scientists, 27% have more than 10 fume hoods in their labs. Physical scientists also used their fume hoods for longer hours, with 24.1% using theirs from 1-3 hours, and the same number using theirs from 4-7 hours. Thirty-one percent of respondents use their fume hoods for 24 hours.

Fume hoods are not considered to be a part of plug loads in laboratories. However, both because they are known to consume a substantial amount of energy, and because they have been the most widely studied piece of equipment in laboratories to date, they were surveyed along with the other pieces of equipment.

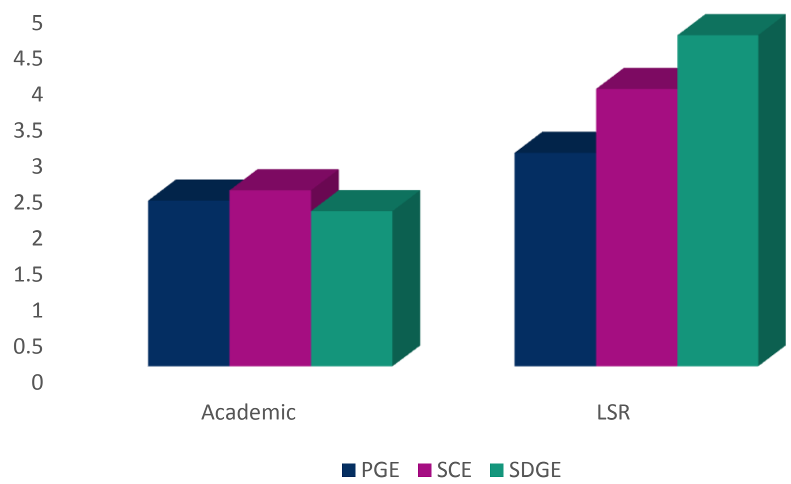
Comparing fume hood data across the country it was observed that the average number of fume hoods per lab in California was 3.0; across the country the average was found to be 2.5. Thus California's laboratories have an average of 20% more fume hoods than the average US lab.

FIGURE 13: AVERAGE NUMBER OF FUME HOODS PER LAB – MARKET SEGMENT COMPARISON



As seen in Figure 13, the average number of fume hoods per laboratory was consistent in academia, but differed in the life sciences, hospital, and other sectors.

FIGURE 14: AVERAGE NUMBER OF FUME HOODS PER LAB – MARKET SEGMENT COMPARISON BY SERVICE TERRITORY



There appear to be nearly 70% more fume hoods per lab in LSR in SDGE's territory than in PG&Es. These results are discussed further in Chapter 7.1.

5.2.3 MICROSCOPES

Questions about microscope quantity and use were answered by 91% of respondents. This question marked the first in a series of questions about highly specialized pieces of equipment. The results are below.

TABLE 18: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF MICROSCOPES PER LAB

MICROSCOPE TYPE	0	1	2	3	4 – 9	>10
Fluorescence Microscopes	33.2%	31.5%	16.8%	6.3%	9.7%	2.5%
Confocal Microscopes	57.5%	25.3%	9.4%	1.3%	5.2%	1.3%
Electron Microscopes	89.5%	7.5%	1.3%	0.4%	0.9%	0.4%

Fluorescence microscopes were by far the most prevalent, though this was expected as both confocal microscopes and electron microscopes are substantially more specialized and expensive. The usage data demonstrate that labs use these microscopes for 1-3 hours per day on average, with 18-25% of labs using their microscopes for 4-7 hours per day.

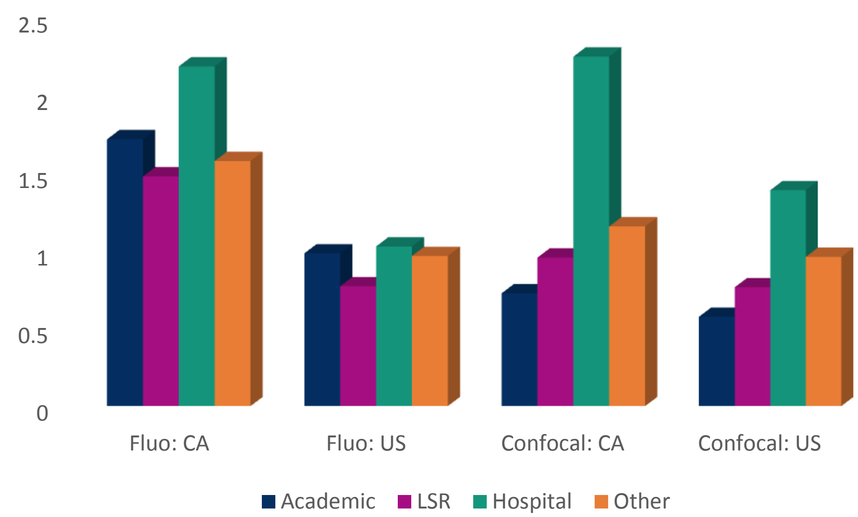
TABLE 19: SURVEY RESPONSES IN CALIFORNIA – MICROSCOPE USE

MICROSCOPE TYPE	1-3 HRS	4-7 HRS	8-10 HRS	11 -23 HRS	24 HRS
Fluorescence Microscopes	59.6%	25.2%	10.6%	4.6%	0%
Confocal Microscopes	55.7%	20.6%	10.3%	10.3%	3.1%
Electron Microscopes	59.1%	18.1%	18.1%	4.5%	0%

These types of microscopes are overwhelmingly found in the Life Science market segment; 69% of scientists whose work falls under the Physical Sciences category did not have a fluorescence microscope, and if they did have one, they were 8x more likely to have one than two. No one who responded had more than two. Confocal microscopes and electron microscopes followed a similar pattern for that market segment.

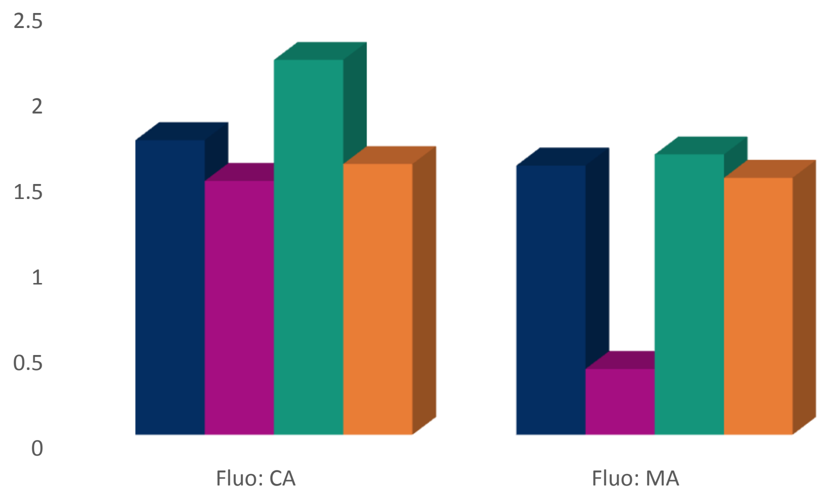
Comparing data between California and the rest of the United States reveals that although the trends are the same, there appear to be nearly twice as many fluorescence microscopes per lab in California as there are in the rest of the United States.

FIGURE 15: AVERAGE NUMBER OF MICROSCOPES PER LAB: MARKET SEGMENT



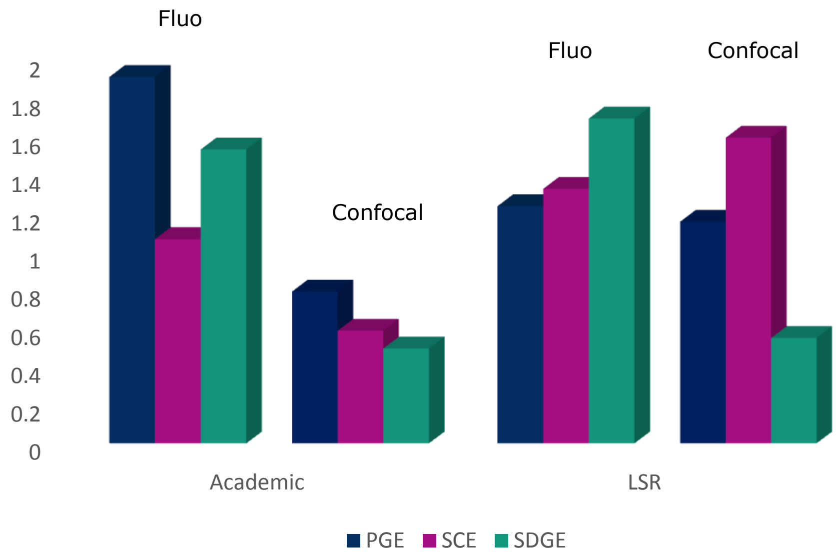
Again turning to Massachusetts as a point of comparison, with the exception of the large average number of fluorescence microscopes in the LSR sector, it appears that California and Massachusetts are in alignment with each other in terms of average number of fluorescence microscopes per lab. On average, California has 1.7 fluorescence microscopes per lab to Massachusetts' 1.3.

FIGURE 16: AVERAGE NUMBER OF MICROSCOPES PER LAB: COMPARISON BETWEEN CALIFORNIA AND MASSACHUSETTS



A comparison of microscope quantities across the California investor-owned utilities is shown in Figure 17.

FIGURE 17: AVERAGE NUMBER OF MICROSCOPES PER LAB: COMPARISON AMONG SERVICE TERRITORIES



The average number of confocal microscopes in SDG&E's territory was reported as being substantially lower in the LSR market than in PG&E's or SCE's territories. Because the sample size for this value was small, it is possible that this result is an anomaly due to sampling.

5.2.4 BENCHTOP EQUIPMENT

The benchtop equipment category refers to those pieces of laboratory equipment that typically reside on top of a lab bench. They tend to be smaller, more portable pieces of equipment. Ninety percent of respondents replied to survey questions about their benchtop equipment.

Table 20 presents a summary of the percentage of respondents in California who have one or more of the pieces of benchtop equipment studied. Because each piece is unique, each one will be considered separately in this section.

TABLE 20: SUMMARY OF BENCHTOP EQUIPMENT FOUND IN CALIFORNIA LABORATORIES – NUMBER PER LAB

	0	1	2	3	4-9	>10
Heating Block	13.5%	17.5%	22.3%	12.2%	26.5%	8%
Water Bath	10.5%	20.6%	27.3%	15.1%	22.3%	4.2%
Centrifuge	5.5%	12.2%	19.8%	15.1%	38.6%	8.8%
PCR Machine	27.4%	22.2%	18.4%	8.1%	19.2%	4.7%
Magnetic Stir Plate	10.5%	16.5%	20.3%	13.9%	30.8%	8%
Vacuum Pump	28.8%	35.1%	12.1%	5%	12.7%	6.3%
Water Distiller	37.1%	50.2%	8.9%	1.3%	1.7%	0.8%

A. Heating Block

TABLE 21: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF HEATING BLOCKS PER LAB

	0	1	2	3	4-9	>10
Heating Block	13.5%	17.5%	22.3%	12.2%	26.5%	8%

Heating blocks were found to be widely used in labs, with nearly 70% of labs having two or more. Importantly, more than 25% of those heating blocks are left on 24/7, as illustrated in Table 22.

TABLE 22: SURVEY RESPONSES IN CALIFORNIA – HEATING BLOCK USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Heating Block	3.9%	43.2%	16.5%	5.8%	3.9%	26.7%

While Life Science researchers were twice as likely to have a heating block, researchers in the Physical Sciences were twice as likely to have more than 10 of them if they had them in their lab. They were also more likely to have between four and nine units. In spite of Physical Science researchers possessing heating blocks in higher concentrations than Life Science researchers, they were less likely to leave them on for 24 hours; over 50% are used only between 1 and 7 hours per day.

B. Water Bath

TABLE 23: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF WATER BATHS PER LAB

	0	1	2	3	4-9	>10
Water Bath	10.5%	20.6%	27.3%	15.1%	22.3%	4.2%

Water baths are only slightly more common than heating blocks in the labs surveyed, but scientists tend to have fewer water baths than heating blocks, according to the results shown in Table 23.

Thirty-seven percent of respondents operate their water baths 24/7, as seen in Table 24.

TABLE 24: SURVEY RESPONSES IN CALIFORNIA – WATER BATH USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Water Bath	2.3%	29.7%	16%	10%	4.7%	37.3%

The trend in number of water baths is similar between the Life Sciences and the Physical Sciences. As was seen with heating blocks, scientists in the Physical Sciences primarily use the equipment for 1-7 hours; they are 66% less likely to leave their water baths on for 24 hours.

C. Centrifuge

TABLE 25: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF CENTRIFUGES PER LAB

	0	1	2	3	4-9	>10
Centrifuge	5.5%	12.2%	19.8%	15.1%	38.6%	8.8%

Nearly all laboratories surveyed had at least one centrifuge, with people being more likely to have two, three, or four centrifuges in their lab than one. Unlike heating blocks and water baths, centrifuges were not found to be in operation 24/7; they were more likely to be operated for 1-7 hours, as seen in Table 26.

TABLE 26: SURVEY RESPONSES IN CALIFORNIA – CENTRIFUGE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Centrifuge	3.1%	56.2%	24.3%	11.5%	2.7%	2.2%

Centrifuges were less common in Physical Sciences laboratories, but a majority (73%) of respondents had at least one. The operational data between the two groups was similar.

D. PCR Machine

PCR machines are often considered to be specialized pieces of equipment, but in fact they appear to be in widespread use according to the data collected in this survey. Forty percent of respondents had one or two, and nearly 20% had between four and nine machines.

TABLE 27: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF PCR MACHINES PER LAB

	0	1	2	3	4-9	>10
PCR Machine	27.4%	22.2%	18.4%	8.1%	19.2%	4.7%

Respondents indicated that they use PCR machines 1-7 hours per day, as seen in Table 28.

TABLE 28: SURVEY RESPONSES IN CALIFORNIA – PCR MACHINE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
PCR Machine	0%	37.7%	34.1%	18%	5.4%	4.8%

All laboratories that had PCR machines used them for at least one hour every day. The data suggest that PCR machines are primarily found in Life Science labs, as might be expected. Whereas 83.5% of Life Science respondents had a PCR machine, only 26% of Physical Scientists had one. And if a Physical Scientist did happen to have one, it was very likely that the person had only the one, and it was used for only 1-3 hours per day.

E. Magnetic Stir Plate

TABLE 29: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF MAGNETIC STIR PLATES PER LAB

	0	1	2	3	4-9	>10
Magnetic Stir Plate	10.5%	16.5%	20.3%	13.9%	30.8%	8%

Over 70% of respondents had between one and five magnetic stir plates in their lab. The vast majority of these are in use 1-3 hours per day.

TABLE 30: SURVEY RESPONSES IN CALIFORNIA – MAGNETIC STIR PLATE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Magnetic Stir Plate	7.5%	60%	23.1%	6.1%	2.4%	0.9%

In contrast to PCR machines, magnetic stir plates seem to reside in the realm of the Physical Sciences. Twenty-five percent of respondents in the Physical Sciences reported having >10 magnetic stir plates, compared with just 4.9% in the Life Sciences. Forty-six percent of Physical Science researchers had between four and nine magnetic stir plates in their labs; 31% of Life Scientists had the same number. These devices are also used for longer hours in Physical Science laboratories, with the majority being used for 4-7 hours, compared to the Life Sciences, where they were typically used 1-3 hours per day.

F. Vacuum Pump

TABLE 31: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF VACUUM PUMPS PER LAB

	0	1	2	3	4-9	>10
Vacuum Pump	28.8%	35.1%	12.1%	5%	12.7%	6.3%

Just over 70% of laboratories have at least one vacuum pump, making them about as common as PCR machines. There appear to be fewer vacuum pumps than PCR machines per lab, but they are twice as likely to be running 24/7.

TABLE 32: SURVEY RESPONSES IN CALIFORNIA – VACUUM PUMP USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Vacuum Pump	9.6%	54.2%	18.1%	1.8%	3.6%	12.7%

Vacuum pumps were reported to be slightly more prevalent in Physical Science laboratories. Notably, 14.3% of physical science laboratories reported having >10 vacuum pumps in their labs. This number is over three times as many as are found in this category for the Life Sciences. And while the data for vacuum pumps in Life Science laboratories tends to be clustered in the 1-3 hour range, in Physical Science laboratories it is more evenly distributed between 1-3 hours, 4-7 hours, and 24 hours (approximately 30% for each option).

G. Water Distiller

TABLE 33: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF WATER DISTILLERS PER LAB

	0	1	2	3	4-9	>10
Water Distiller	37.1%	50.2%	8.9%	1.3%	1.7%	0.8%

Over 60% of the labs surveyed reported having at least one water distiller. This was somewhat surprising given the distribution of Life Science laboratories in the survey sample size, as water distillers are often associated with the Physical Sciences.

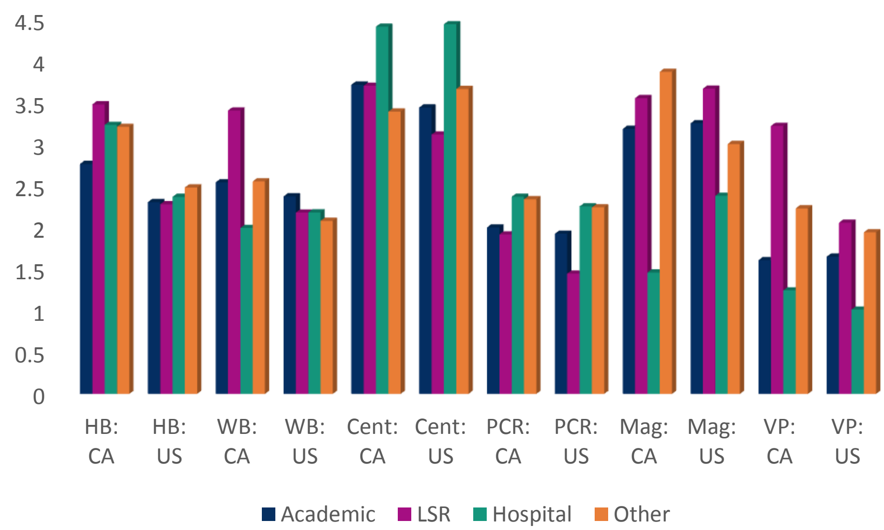
TABLE 34: SURVEY RESPONSES IN CALIFORNIA – WATER DISTILLER USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Water Distiller	0%	43.2%	13.5%	11.5%	3.4%	28.4%

Of the water distillers found in labs, almost 30% of them are running 24/7. The trend for number of water distillers is consistent across the market segments surveyed. However, Physical Science laboratories demonstrated a largely bimodal distribution in their response to the usage of their water distillers – they were either being used for 1-3 hours, or for 24 hours. In comparison, Life Science lab respondents reported using their water distillers for all time ranges noted above.

A selected subset of the data is presented in Figure 18. These pieces of equipment were deemed to be the most prevalent of those studied. A comparison between California and the rest of the United States reveals that once again California trends slightly higher in the number of units per laboratory. Figure 18 also shows that a comparison between the market segments identified in Chapter 4 shows increased numbers of equipment in the LSR market segment in several instances. This trend is most prominent in California, though it is observed with vacuum pumps in the rest of the US.

FIGURE 18: AVERAGE NUMBER OF UNITS PER LAB: BENCHTOP EQUIPMENT COMPARISON BETWEEN CALIFORNIA AND THE UNITED STATES



The average number of heating blocks was consistent across the market segments studied. Centrifuges tended to be found in higher quantities in hospital settings, likely owing to the sample analysis (e.g. blood, urine) that is routinely done in these laboratories. Magnetic stir plates are less likely to be found in hospital laboratories, averaging approximately 1.5 per lab in hospitals and more than 3 per lab in other market segments. Vacuum pumps appear to be consistently more likely to appear in the LSR market space.

The table below summarizes the average number of units per lab for the various pieces of equipment both in California and in the rest of the United States.

TABLE 35: SUMMARY OF AVERAGE NUMBER OF UNITS PER LAB – BENCHTOP EQUIPMENT IN CALIFORNIA AND THE UNITED STATES

HB:CA	HB:US	WB:CA	WB:US	CENT:CA	CENT:US	PCR:CA	PCR:US	MAG:CA	MAG:US
3.2	2.4	2.6	2.2	3.8	3.7	2.2	2.0	3.0	3.1

Note: HB = heating block; WB = water bath; Cent = centrifuge; PCR = PCR Machine; Mag = magnetic stir plate

A comparison among the California utility companies of the pieces of equipment shown above can be seen in Figures 19 – 23.

FIGURE 19: AVERAGE NUMBER OF HEATING BLOCKS PER LAB: COMPARISON AMONG SERVICE TERRITORIES

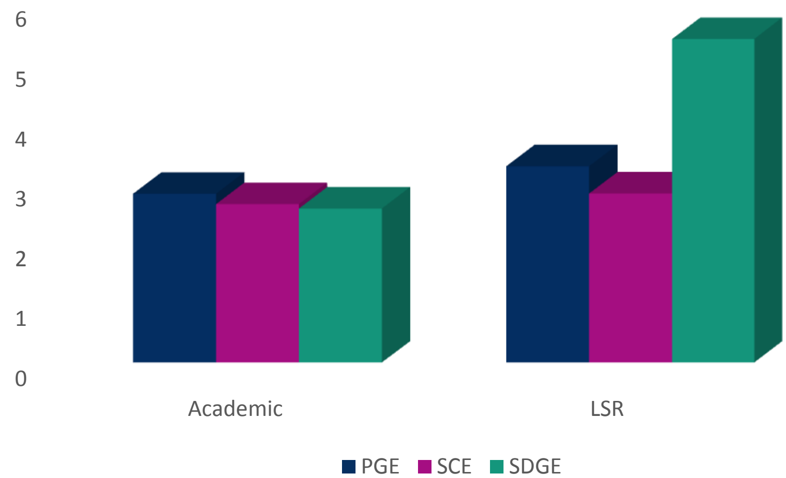


FIGURE 20: AVERAGE NUMBER OF WATER BATHS PER LAB: COMPARISON AMONG SERVICE TERRITORIES

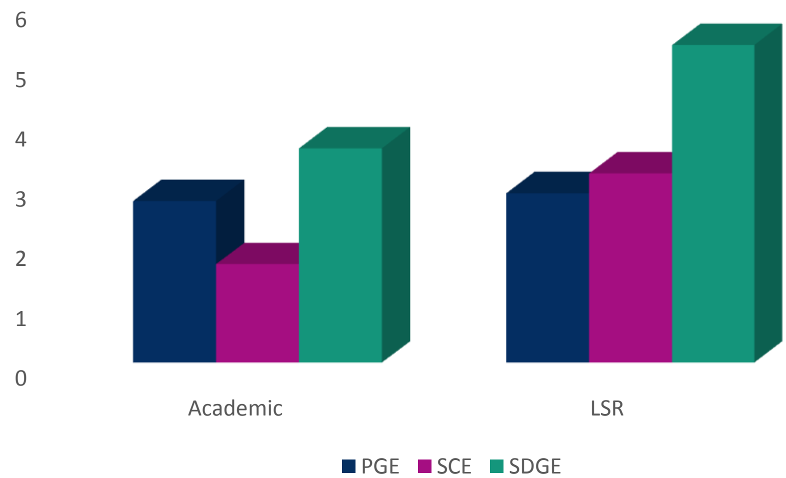


FIGURE 21: AVERAGE NUMBER OF CENTRIFUGES PER LAB: COMPARISON AMONG SERVICE TERRITORIES

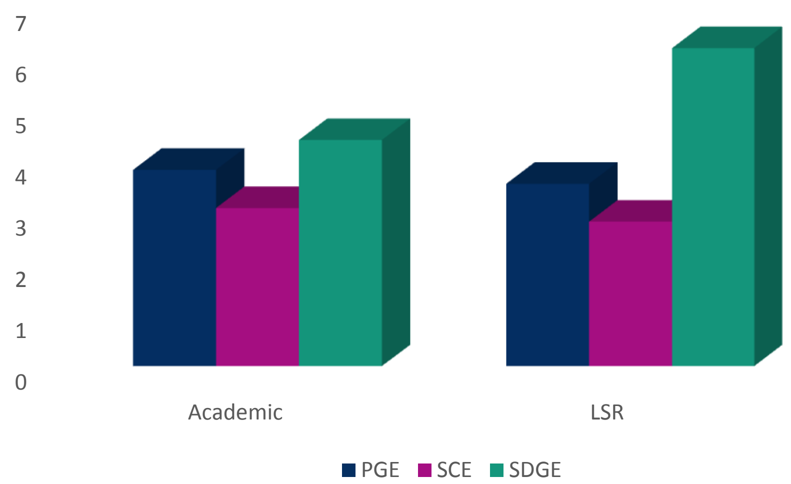


FIGURE 22: AVERAGE NUMBER OF PCR MACHINES PER LAB: COMPARISON AMONG SERVICE TERRITORIES

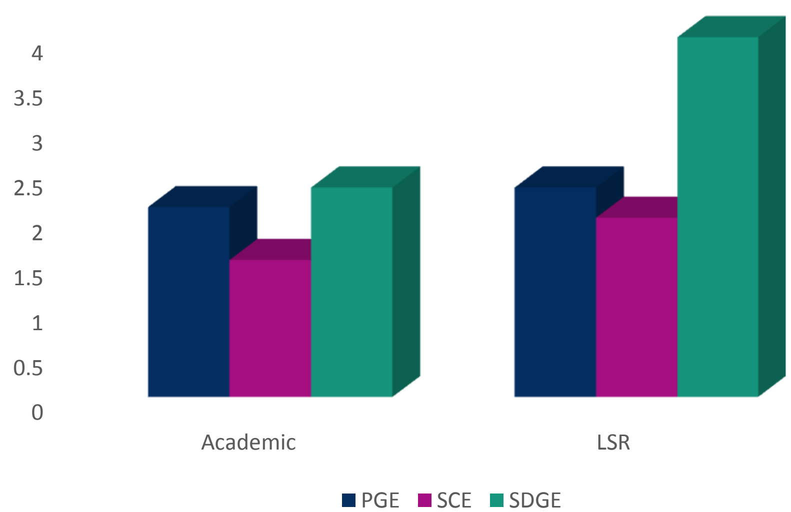
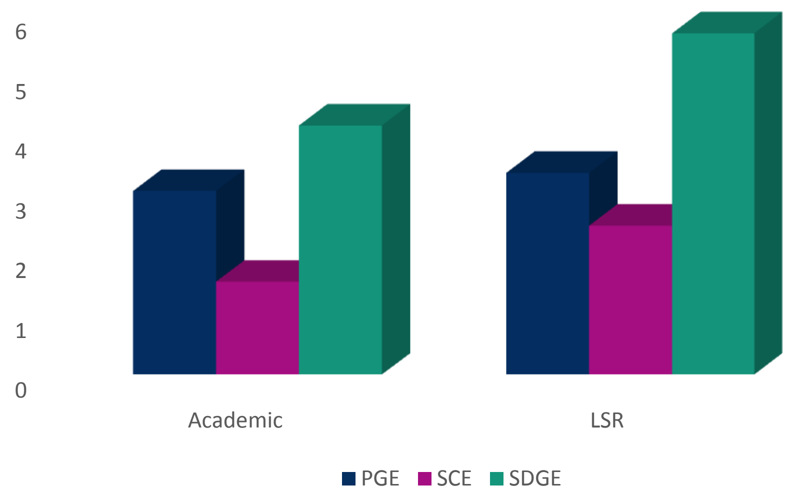


FIGURE 23: AVERAGE NUMBER OF MAGNETIC STIR PLATES PER LAB: COMPARISON AMONG SERVICE TERRITORIES



One of the most striking observations from these results is that SDG&E's territory consistently reported higher averages per lab than the other service territories in the LSR sector. Because SDG&E's sample size for this particular market segment was small, it is likely that these results can be explained by not having enough data. The other possibility is that these values are accurate and San Diego has a higher concentration of benchtop equipment than the other service territories due to the composition of the LSR market there. SDG&E's territory was found to have nearly twice the number of CROs than the other service territories (Figure 9). Not enough data for SDG&E's territory were collected in order to determine whether the increased density of equipment reported in that region is the result of the large number of CROs found there.

5.2.5 LARGE LABORATORY EQUIPMENT

The category of 'large laboratory equipment' refers to those pieces of equipment that are either positioned on the floor or are large enough to require their own bench space. Eighty-seven percent of respondents answered questions about their large laboratory equipment.

A summary of the percentage of respondents in California who have one or more of the large pieces of equipment studied is below in Table 36. Because each piece is unique, each one will be considered separately in this section.

TABLE 36: SUMMARY OF LARGE LABORATORY EQUIPMENT FOUND IN CALIFORNIA LABORATORIES

	0	1	2	3	4-9	>10
Shaker Table	43.9%	25.2%	16.1%	4.8%	8.7%	1.3%
Autoclave	54.3%	30.6%	8.6%	3.5%	3%	0%
Gas Laser	93.4%	3.1%	0.9%	0.4%	2.2%	0%
qPCR Machine	65.7%	23.8%	6.2%	1.3%	2.6%	0.4%
NMR	95.6%	1.8%	0.9%	1.3%	0.4%	0%
Mass Spectrometer	82.6%	9.8%	2.2%	0.9%	4%	0.5%
Gas Chromatograph	0%	25%	29.2%	20.8%	8.3%	16.7%
HPLC	75.1%	9.7%	4.8%	3.9%	5.6%	0.9%
FACS	0%	34.4%	37.5%	15.6%	12.5%	0%
Incubator	18.1%	15.6%	16%	14.3%	28.6%	7.4%
Tissue Culture Hood	33.2%	23.3%	20.7%	7.7%	12.1%	3%
Sonicator	33.2%	23.3%	20.7%	7.7%	12.1%	3%
Vacuum Chamber	0%	60%	18%	4%	4%	14%
Air Table	77.5%	8.4%	6.2%	2.2%	4.8%	0.9%

A. Shaker Table

TABLE 37: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF SHAKER TABLES PER LAB

	0	1	2	3	4-9	>10
Shaker Table	43.9%	25.2%	16.1%	4.8%	8.7%	1.3%

Shaker tables were found in 56% of laboratories surveyed, and the majority of them were only used for 1-3 hours per day. One hundred percent of respondents use their shaker tables every day, and it was found that shaker tables were more likely to be left on for 24 hours than for 8-10 or 11-23 hours per day.

TABLE 38: SURVEY RESPONSES IN CALIFORNIA – SHAKER TABLE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Shaker Table	0%	52.8%	16.8%	8.8%	8.8%	12.8%

Forty percent of Physical Science researchers reported having at least one shaker table, compared with 60% of life science researchers. The operational habits of the two groups were similar, with the majority using this instrument for 1-3 hours per day.

B. Autoclave

TABLE 39: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF AUTOCLAVES PER LAB

	0	1	2	3	4-9	>10
Autoclave	54.3%	30.6%	8.6%	3.5%	3%	0%

Autoclaves are the first piece of equipment surveyed that are typically not purchased by a laboratory. In academia, they are usually departmental pieces of equipment, or they belong to the building and are shared pieces of equipment. In a company they may either be shared or used by a single laboratory, similar to a hospital setting. Therefore it was surprising that 30% of respondents identified their lab as having its own autoclave.

TABLE 40: SURVEY RESPONSES IN CALIFORNIA – AUTOCLAVE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Autoclave	0%	50.5%	30%	15%	1.9%	2.8%

Eighty percent of respondents who have their own laboratory autoclave use it between 1-7 hours per day, with 50% of them using it 1-3 hours per day.

Just over 50% of Life and Physical Science researchers reported having an autoclave in their lab. The distribution of number of autoclaves as well as their usage was similar between the two groups.

C. Gas Laser

TABLE 41: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF GAS LASERS PER LAB

	0	1	2	3	4-9	>10
Gas Laser	93.4%	3.1%	0.9%	0.4%	2.2%	0%

Gas lasers were one of the least frequently found pieces of equipment in the laboratories that were studied, with just 7% of respondents having one or more.

TABLE 42: SURVEY RESPONSES IN CALIFORNIA – GAS LASER USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Gas Laser	0%	22.1%	38.9%	16.7%	16.7%	5.6%

Of those respondents that have gas lasers, the majority of them use their lasers 4-7 hours per day.

Somewhat surprisingly, only one Physical Scientist surveyed reported having a gas laser in his/her lab. The rest of the (sparse) data above comes from the Life Sciences. This means that the lasers being reported in this survey are most likely being used for imaging purposes.

D. qPCR Machine

TABLE 43: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF QPCR MACHINES PER LAB

	0	1	2	3	4-9	>10
qPCR Machine	65.7%	23.8%	6.2%	1.3%	2.6%	0.4%

qPCR machines are larger, more complex pieces of equipment than PCR machines. As such, they are less frequently found in laboratories. The survey revealed that the majority of laboratories in the study did not have a qPCR machine, and that of those that did, most of them had only one.

TABLE 44: SURVEY RESPONSES IN CALIFORNIA – QPCR MACHINE USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
qPCR Machine	0%	39.5%	42.1%	10.5%	5.3%	2.6%

Over 50% of respondents use their qPCR machine for 4-10 hours per day. Life Scientists were 1.5x more likely to have a qPCR machine in their lab than Physical Scientists, although both groups tended to have only one or two in their space. For the laboratories that had this equipment, the usage was similar between the two groups.

E. NMR

TABLE 45: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF NMRS PER LAB

	0	1	2	3	4-9	>10
NMR	95.6%	1.8%	0.9%	1.3%	0.4%	0%

NMR machines are another highly specialized piece of equipment, typically found in core facilities and not in individual laboratories. This is reflected in the data above.

TABLE 46: SURVEY RESPONSES IN CALIFORNIA – NMR USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
NMR	11.1%	33.3%	44.4%	0%	22.2%	0%

The sample size for the usage calculations was very small, so it is difficult to draw any conclusions from the data. Those labs that responded as having their own NMR were found to use it typically 1-7 hours per day.

Because of the small sample size, no further analysis into the breakdown of Physical and Life Scientist responses was done.

F. Mass Spectrometer

TABLE 47: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF MASS SPECTROMETERS PER LAB

	0	1	2	3	4-9	>10
Mass Spec	82.6%	9.8%	2.2%	0.9%	4%	0.5%

Mass spectrometers are yet another piece of highly specialized equipment not often found in individual laboratories. It was therefore surprising to find that 17% of labs surveyed had their own mass spectrometer.

TABLE 48: SURVEY RESPONSES IN CALIFORNIA – MASS SPECTROMETER USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Mass Spec	0%	24.3%	24.3%	24.3%	5.5%	21.6%

The usage of mass spectrometers appears to be evenly distributed among the options provided in the survey, with nearly equal numbers of people choosing 1-3 hours, 4-7 hours, 8-10 hours and 24 hours of use.

Due to the small sample size no further analysis was done into the number of mass spectrometers attributed to the Life Science versus Physical Science responses.

G. Gas Chromatograph

TABLE 49: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF GAS CHROMATOGRAPHS PER LAB

	0	1	2	3	4-9	>10
Gas Chromatograph	89.9%	4%	1.8%	1.3%	2.6%	0.4%

Just over 10% of scientists surveyed responded affirmatively to having a gas chromatograph in their laboratory.

TABLE 50: SURVEY RESPONSES IN CALIFORNIA – GAS CHROMATOGRAPH USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Gas Chromatograph	0%	25%	29.2%	20.8%	8.3%	16.7%

Like the usage for mass spectrometers, gas chromatograph use runs the gamut, from 1-24 hours. However, the sample size for this piece of equipment was quite low owing to its lack of prevalence in the community of laboratories surveyed. For this reason further analysis on the occurrence of gas chromatographs was not done.

H. HPLC

TABLE 51: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF HPLCS PER LAB

	0	1	2	3	4-9	>10
HPLC	75.1%	9.7%	4.8%	3.9%	5.6%	0.9%

HPLCs were found in 25% of laboratories surveyed. They were found to be used consistently throughout the day.

TABLE 52: SURVEY RESPONSES IN CALIFORNIA – HPLC USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
HPLC	0%	30%	18%	18%	18%	16%

Thirty-five percent of Physical Scientists reported having at least one HPLC in their laboratory, compared with only 22% of Life Scientists. The hours of use of HPLCs in physical laboratories were also slightly longer, with the mode being 8-10 hours for these labs as opposed to 1-3 hours for life science laboratories.

I. FACS

TABLE 53: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF FACS PER LAB

	0	1	2	3	4-9	>10
FACS	85.7%	8.9%	3.1%	0.5%	1.3%	0.5%

Fourteen percent of respondents reported having a FACS in their lab. The majority of those who have a FACS have only one in their lab.

TABLE 54: SURVEY RESPONSES IN CALIFORNIA – FACS USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
FACS	0%	34.4%	37.5%	15.6%	12.5%	0%

FACS were found to be most frequently used 1-7 hours per day. Because the sample size for this piece of equipment was so small, no analysis was done into the trends between Life Science and Physical Science researchers.

J. Incubator

TABLE 55: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF INCUBATORS PER LAB

	0	1	2	3	4-9	>10
Incubator	18.1%	15.6%	16%	14.3%	28.6%	7.4%

Over 80% of the labs surveyed had an incubator, and the majority had more than two in their labs. Incubators were found to operate 24/7 in most laboratories.

TABLE 56: SURVEY RESPONSES IN CALIFORNIA – INCUBATOR USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Incubator	0%	8.9%	7.8%	3.3%	2.3%	77.2%

Just over 50% of researchers in the Physical Sciences reported having an incubator, whereas over 88% of life science researchers reported having one. The majority of both groups report using theirs 24/7.

K. Tissue Culture Hood

TABLE 57: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF TISSUE CULTURE HOODS PER LAB

	0	1	2	3	4-9	>10
Tissue Culture Hood	33.2%	23.3%	20.7%	7.7%	12.1%	3%

Tissue culture hoods were found to be in operation in 67% of the laboratories surveyed.

TABLE 58: SURVEY RESPONSES IN CALIFORNIA – TISSUE CULTURE HOOD USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Tissue Culture Hood	0%	26.4%	39.9%	10.8%	7.4%	15.5%

The majority of respondents use their tissue culture hoods for 4-7 hours per day, followed by 1-3 hours per day.

Tissue culture hoods were found almost exclusively in Life Science laboratories, with only 25% of Physical Scientists reporting at least one tissue culture hood.

L. Sonicator

TABLE 59: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF SONICATORS PER LAB

	0	1	2	3	4-9	>10
Sonicator	40.3%	45.1%	9.9%	1.7%	2.6%	0.4%

The laboratories surveyed averaged approximately one sonicator per lab. As sonicators are typically used for just a few minutes at a time, it is not surprisingly that the majority of labs indicated that this piece of equipment is on for 1-3 hours per day.

TABLE 60: SURVEY RESPONSES IN CALIFORNIA – SONICATOR USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Sonicator	0%	87.2%	8.5%	3.4%	0.9%	0%

The prevalence and usage of sonicators were similar between Life Science and Physical Science researchers.

M. Vacuum Chamber

TABLE 61: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF VACUUM CHAMBERS PER LAB

	0	1	2	3	4-9	>10
Vacuum Chamber	75.1%	16.2%	3.5%	1.3%	3.5%	0.4%

Vacuum chambers were not among the more common pieces of equipment in the surveyed laboratories, being found in just 25% of labs on average. Most vacuum chambers were found to be in operation 1-3 hours per day.

TABLE 62: SURVEY RESPONSES IN CALIFORNIA – VACUUM CHAMBER USE

	0	1-3 HRS	4-7 HRS	8-10 HRS	11-23 HRS	24
Vacuum Chamber	0%	60%	18%	4%	4%	14%

While neither group reported having a large number of vacuum chambers, 25% of Life Science researchers responded that they had at least one. By comparison, only 15% of Physical Science researchers reported the same.

N. Air Table

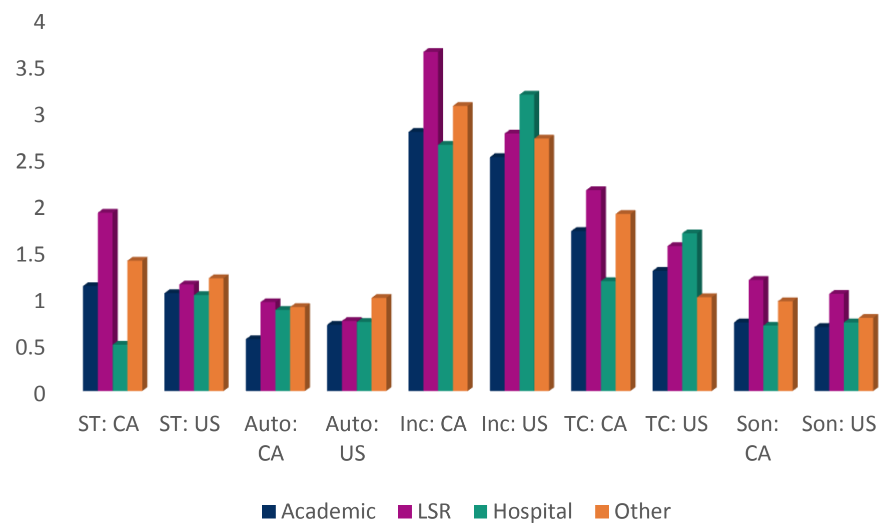
TABLE 63: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF AIR TABLES PER LAB

	0	1	2	3	4-9	>10
Air Table	77.5%	8.4%	6.2%	2.2%	4.8%	0.9%

Twenty-three percent of the respondents had at least one air table in their laboratory. Air tables were found to be almost exclusively located in Life Science laboratories. Air tables require a constant supply of air, and as such are considered to be on all of the time.

A selected subset of the data is presented in Figure 24. These pieces of equipment were deemed to be the most common of those studied. Figure 24 shows both a comparison between California and the rest of the United States, as well as a comparison among the different laboratory market segments identified in Chapter 4 (academic, LSR, and hospitals). A comparison between California and the rest of the United States demonstrates that again California trends slightly higher in the number of units per laboratory, with the notable exceptions of autoclaves in academic research settings and tissue culture hoods in hospital environments. In all instances but tissue culture hoods, California's average number of units per lab are within 20% of the national average.

FIGURE 24: AVERAGE NUMBER OF UNITS PER LAB: LARGE LAB EQUIPMENT COMPARISON BETWEEN CALIFORNIA AND THE UNITED STATES



Key: ST = shaker table; Auto = autoclave; Inc = incubator; TC = tissue culture hood; Son = sonicator

There was quite a bit of variation on the average number of shaker tables (ST) among the various market segments in California; this variation was not seen in the US market. It is possible that the larger sample size of the US resulted in a more reliable average for this particular piece of equipment. Autoclaves (Auto) appear to be uniformly distributed across the market segments studied, as are incubators (Inc), with the exception of a slight increase in the average number of incubators per lab seen in the LSR market. The tissue culture hood (TC) pattern seen in California is slightly different from that seen in the rest of the US in that there appears to be an average of 1 tissue culture hood per lab fewer in hospitals in California. The LSR market averages 0.5 more sonicators per lab than the rest of the market segments.

The average number of units per lab can be seen more clearly in Table 64.

TABLE 64: SUMMARY OF AVERAGE NUMBER OF UNITS PER LAB: LARGE LAB EQUIPMENT IN CALIFORNIA AND THE UNITED STATES

ST:CA	ST:US	AUTO:CA	AUTO:US	INC:CA	INC:US	TC:CA	TC:US	SON:CA	SON:US
1.2	1.1	0.8	0.8	3.0	2.8	1.7	1.4	0.9	0.8

A comparison of large laboratory equipment across the California investor owned utilities is below.

FIGURE 25: AVERAGE NUMBER OF SHAKER TABLES PER LAB: COMPARISON AMONG SERVICE TERRITORIES

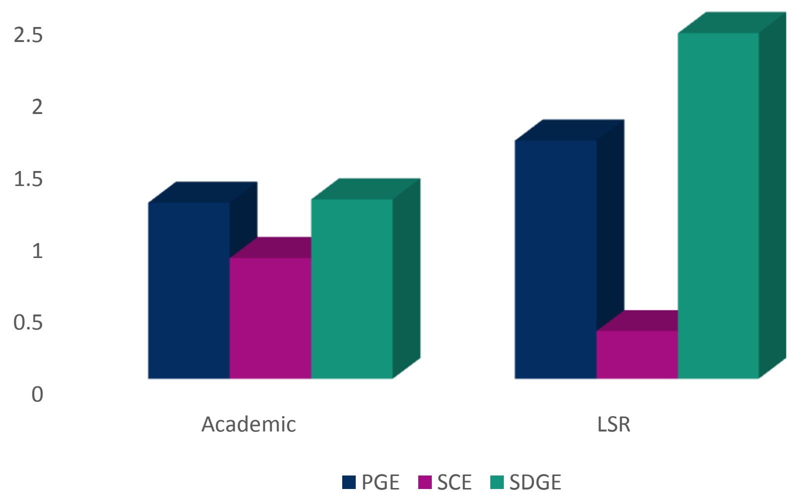


FIGURE 26: AVERAGE NUMBER OF AUTOCLAVES PER LAB: COMPARISON AMONG SERVICE TERRITORIES

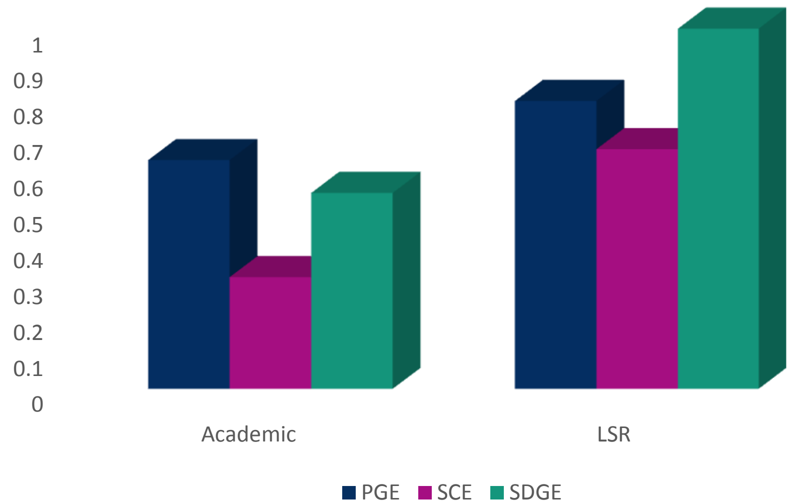


FIGURE 27: AVERAGE NUMBER OF QPCR MACHINES PER LAB: COMPARISON AMONG SERVICE TERRITORIES

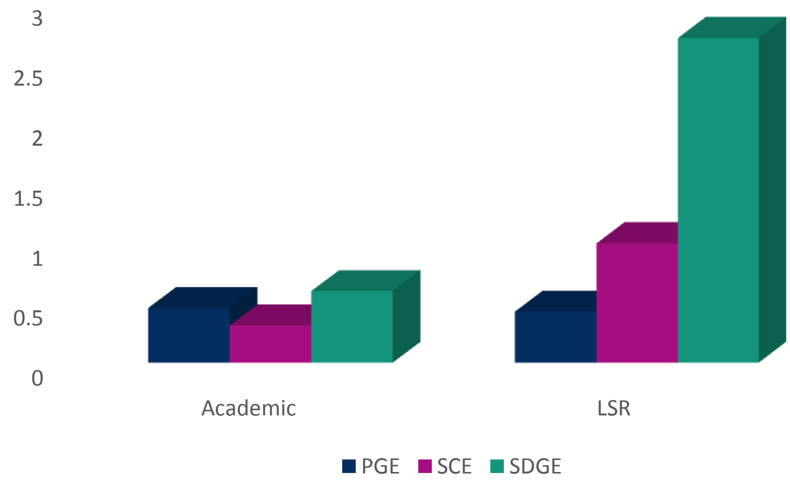


FIGURE 28: AVERAGE NUMBER OF INCUBATORS PER LAB: COMPARISON AMONG SERVICE TERRITORIES

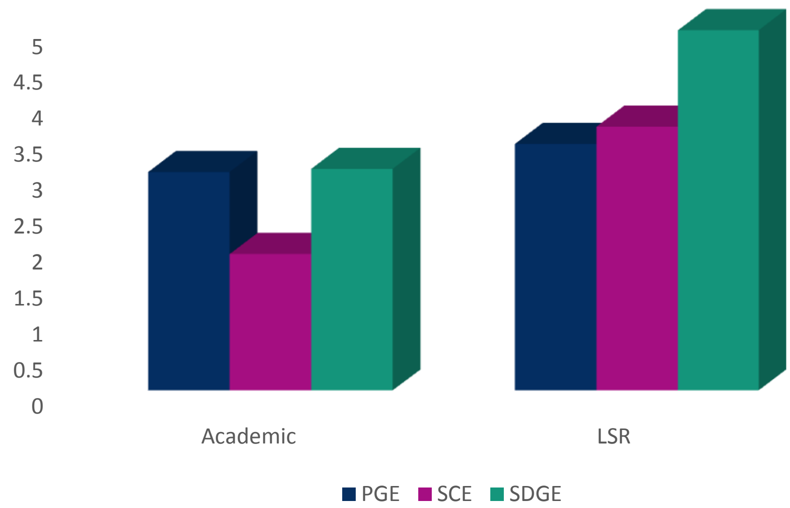


FIGURE 29: AVERAGE NUMBER OF TISSUE CULTURE HOODS PER LAB: COMPARISON AMONG SERVICE TERRITORIES

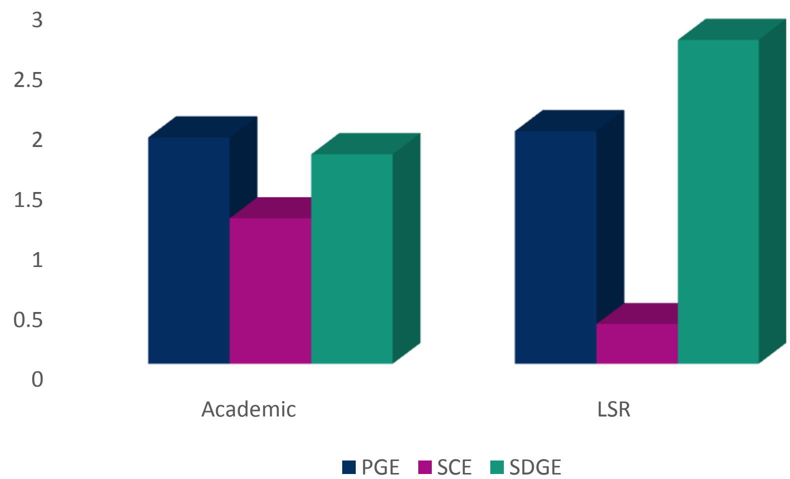
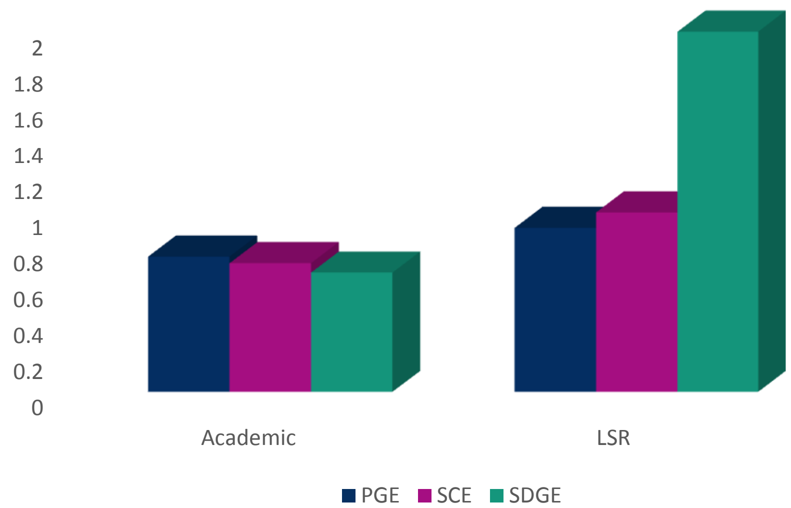


FIGURE 30: AVERAGE NUMBER OF SONICATORS PER LAB: COMPARISON AMONG SERVICE TERRITORIES



As was seen for the other types of equipment, SDG&E's territory reported having an average of more equipment per lab than the other service territories in the LSR market segment. Again, this may be due to the fact that the sample size for SDG&E was smaller than for the other territories, or it may be due to the fact that the composition of the life sciences market is different in SDG&E's territory than in the others. This result is discussed in more detail in Chapter 7.

5.2.6 HOSPITAL EQUIPMENT

Large pieces of hospital equipment are known to be used in research, usually in a clinical setting. Respondents were asked about three pieces of hospital equipment that are also used in research. Eighty-five percent of survey respondents responded to this question.

A summary of the data is below.

A. MRI

TABLE 65: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF MRIS PER LAB

	0	1	2	3	4-9	>10
MRI	99.1%	0.4%	0%	0%	0.4%	0%

Very few laboratories surveyed had an MRI machine. Of the few that did, they were evenly split between using it 1-3 hours and 8-10 hours per day.

B. CT Scanner

TABLE 66: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF CT SCANNERS PER LAB

	0	1	2	3	4-9	>10
CT Scanner	98.7%	0.9%	0%	0%	0.4%	0%

Less than 2% of respondents reported having a CT scanner in their laboratory. As with MRI machines, CT scanners were said to be used either 1-3 hours or 8-10 hours per day.

C. X-Ray Machine

TABLE 67: SURVEY RESPONSES IN CALIFORNIA – NUMBER OF X-RAY MACHINES PER LAB

	0	1	2	3	4-9	>10
X-Ray Machine	96%	3.6%	0%	0%	0.4%	0%

Whereas it was clear that the same people who had an MRI machine also had a CT scanner, a few more people reported also having an X-ray machine in their lab. The sample size was too small to analyze effectively, but the majority of those who responded said that they use their X-ray machines 1-3 hours per day.

Because so few data on these pieces of equipment were collected, no further analysis into a nationwide or market segment comparison was done.

5.2.7 Environmental Rooms

Table 68: Survey Responses in California – Number of Warm Rooms per Lab

	0	1	2	3	4-9	>10
Warm Room	86.8%	9.6%	1.8%	0%	1.8%	0%

Only 13% of scientists surveyed indicated that they had a warm room in their laboratory. Given the prevalence of incubators and the number of labs doing life science research in the state it is somewhat surprising that this number was not higher.

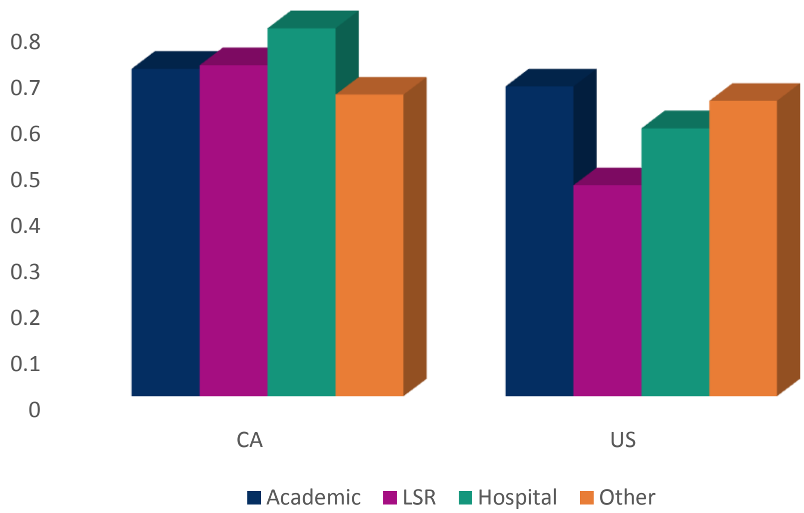
Table 69: Survey Responses in California – Number of Cold Rooms per Lab

	0	1	2	3	4-9	>10
Cold Room	49.8%	42.1%	4.3%	0.4%	3%	0.4%

Unlike warm rooms, nearly 50% of scientists reported having at least one cold room in their laboratory. The need for cold storage in labs is consistent with the previous findings regarding the average number of freezers in the labs surveyed.

An investigation into the average number of cold rooms per lab in California versus the rest of the US can be seen below. The average number of cold rooms per lab in California is 0.7; it is 0.6 nationally.

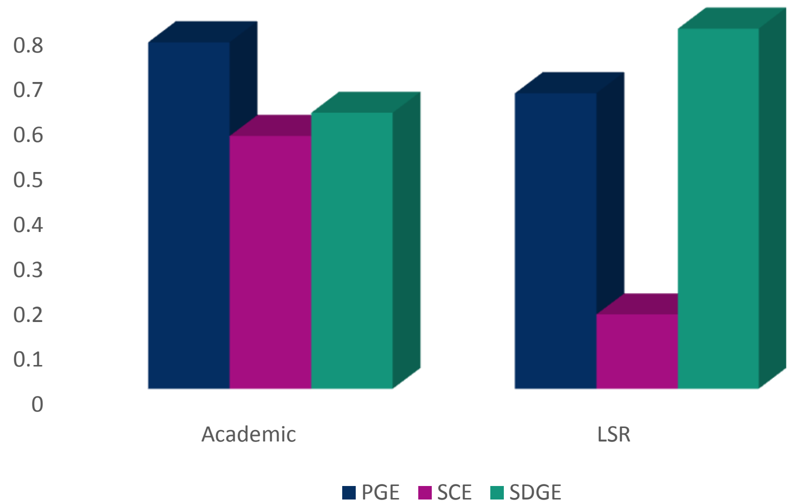
FIGURE 31: AVERAGE NUMBER OF UNITS PER LAB: COLD ROOM COMPARISON BETWEEN CALIFORNIA AND THE UNITED STATES



An analysis of the data presented in Figure 31 by market segment reveals that the number of cold rooms in the LSR market in California is 60% higher than the number seen in the LSR market outside of California. This is also true, though by a smaller margin, for the hospital sector.

A comparison of average number of cold rooms per lab among the investor owned utility service territories is below.

FIGURE 32: AVERAGE NUMBER OF COLD ROOMS PER LAB: COMPARISON AMONG SERVICE TERRITORIES

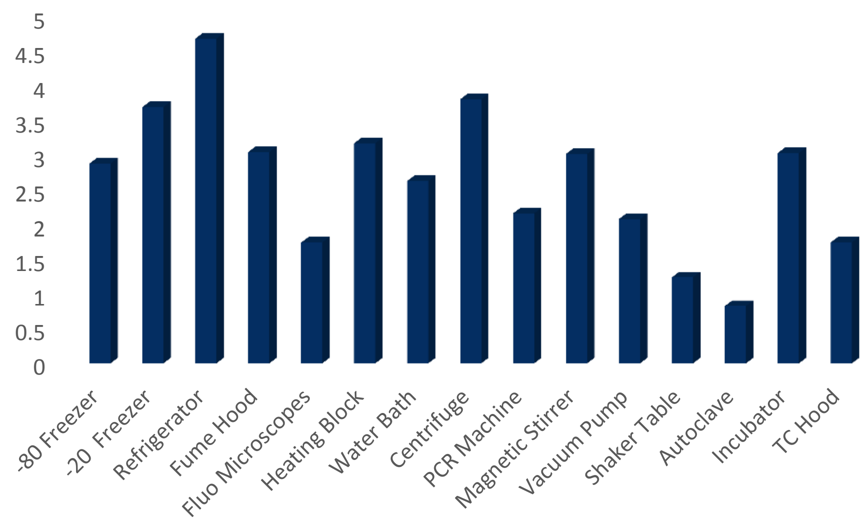


The average number of cold rooms per lab in academia appear to be consistent across service territories; the average number of cold rooms per lab in the life sciences market varies, with SCE's territory having very few, and SDG&E's territory having more than the others.

5.2.8 SUMMARY

A summary of the most commonly found pieces of equipment in laboratories in California is below.

FIGURE 33: RELATIVE AVERAGE NUMBER OF PIECES OF EQUIPMENT PER LAB IN CALIFORNIA

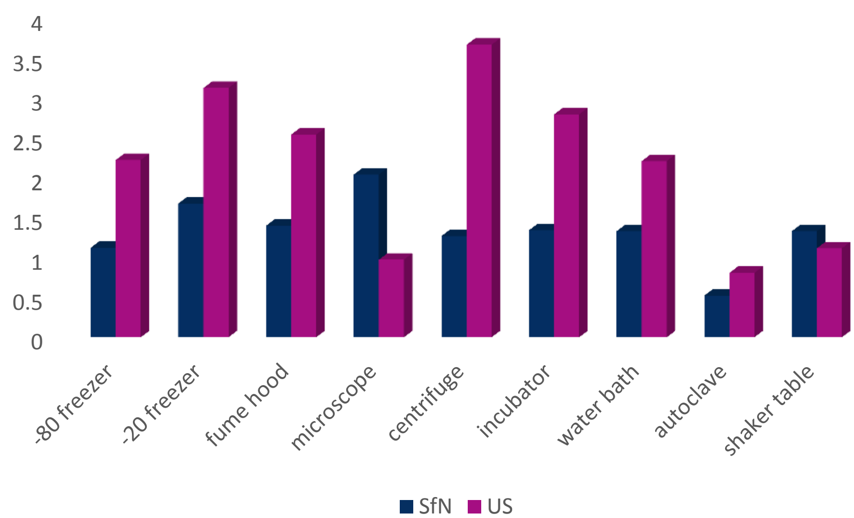


As Figure 33 shows, equipment density in labs varies widely depending on the type of equipment. Refrigeration is among one of the more commonly found types of equipment in the lab, and it is also the most densely distributed. Of the equipment surveyed, benchtop equipment was also found to be in labs with high frequency, although only centrifuges rivaled refrigerators in the number of units per lab. It is not surprising that large laboratory equipment was found, overall, to be less commonly occurring in labs. Large pieces of equipment are often shared among labs, thus reducing the frequency that they would be reported in the survey as belonging to a particular lab. Many of the pieces of equipment surveyed are also very expensive, and would likely only be found in a small subset of labs that could afford them.

5.3 SOCIETY FOR NEUROSCIENCE MEETING RESULTS

In addition to surveying scientists online, 366 scientists were surveyed at the Society for Neuroscience (SfN) meeting in Washington DC in November 2014. These scientists were asked to complete a shorter, paper version of the online survey. A summary of the results, compared with the results from the rest of the US, are presented below. The sample size of Californian respondents alone was not statistically significant, but the overall sampled population yielded results with a 95% confidence level with a confidence interval of 5.

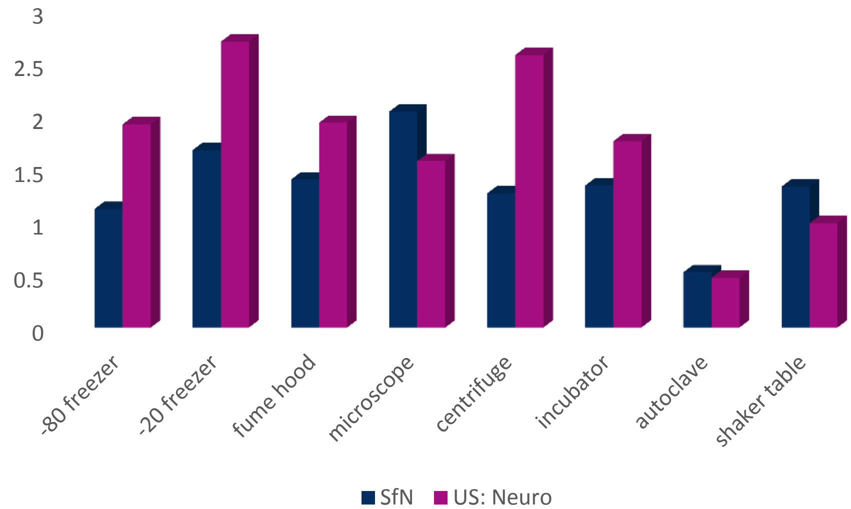
FIGURE 34: COMPARISON BETWEEN ONLINE AND SOCIETY FOR NEUROSCIENCE CONFERENCE RESULTS



The average number of pieces of equipment reported by conference attendees was significantly lower than what was reported by respondents online. There are two plausible explanations for this discrepancy: a) the scientists surveyed at the SfN conference were exclusively Neuroscientists, and this population of scientists have different equipment needs from the general population; b) scientists were not accurately remembering the quantity of equipment in their lab.

The first hypothesis can be tested, the results of which are below.

FIGURE 35: COMPARISON BETWEEN ONLINE NEUROSCIENTIST SURVEY RESPONDENTS AND SFN RESULTS



While accounting for the Neuroscience bias made the discrepancy between the data sets less severe, several pieces of equipment were still not in alignment with the US data set. It is likely that these were simply underreported due to the setting in which the survey was conducted. The mode and the median of the SfN conference dataset was 1. This suggests that people might have been remembering the pieces of equipment they themselves used, and not all of the equipment in the lab. It may also be the case that respondents were only accounting for privately-owned laboratory equipment, and not shared equipment found in common lab spaces. This will be discussed in more detail in Chapter 6.

5.4 ONLINE SURVEY RESULTS FROM NON-SCIENTIST RESPONDENTS

An additional 78 laboratory-affiliated non-scientist personnel were surveyed online. People in this category included facility managers, energy managers, sustainability directors, and people in Environmental Health and Safety. Nineteen of the 78 responses were from organizations in California. This is not a large enough sample size to be evaluated on its own. Therefore the results will be presented from the perspective of the entire US, and any trends that were seen in California that diverged from the norm will be noted. The majority of respondents classified themselves as 'Building/Facility Managers', both in the US and in CA (Figures 36 and 37).

FIGURE 36: CALIFORNIA NON-SCIENTIST SURVEY RESPONSES BY ORGANIZATIONAL ROLE

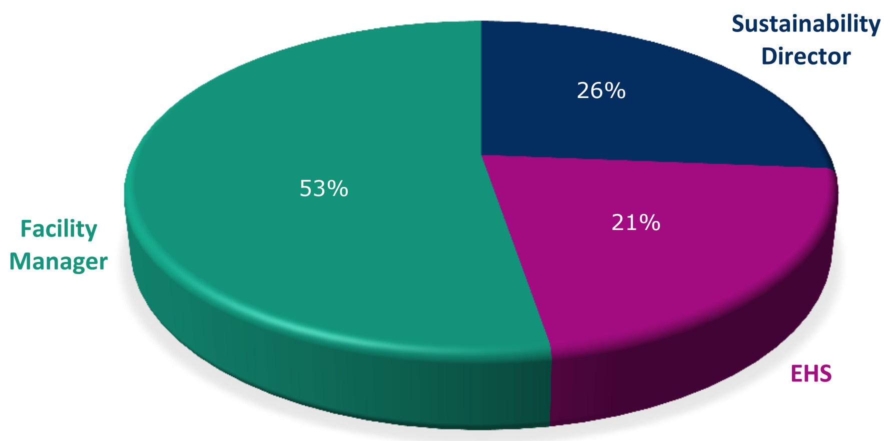
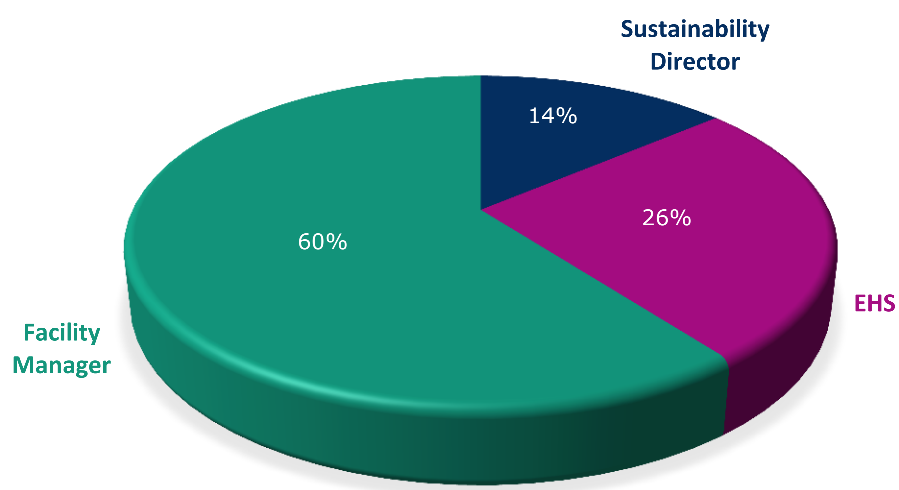


FIGURE 37: UNITED STATES NON-SCIENTIST SURVEY RESPONSES BY ORGANIZATIONAL ROLE



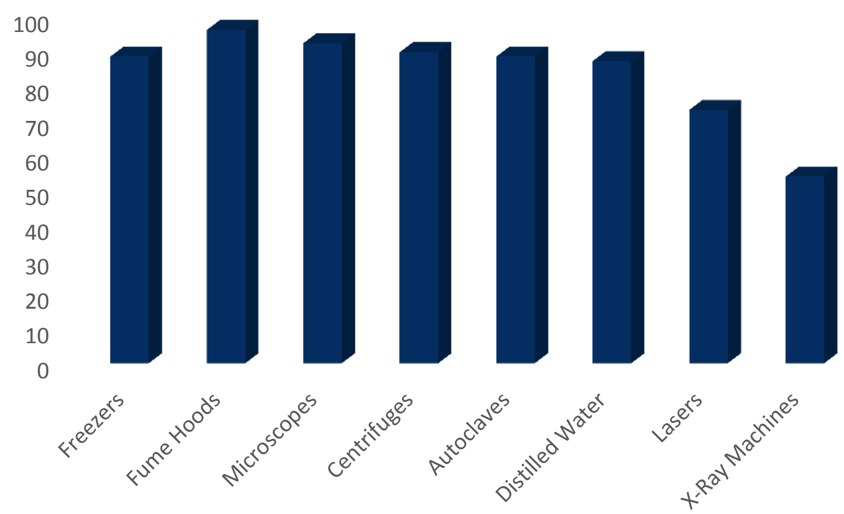
5.4.1 Laboratory Spaces – General

Respondents were asked if they had any spaces in their facilities that they would classify as being laboratories. Ninety-six percent of respondents answered 'yes' to this question. Notably, all respondents who answered 'no' later confirmed that they had at least one piece of equipment that is commonly considered to be laboratory equipment, such as a microscope, fume hood, refrigerator and the like.

5.4.2 Laboratory Equipment – General

Respondents were asked if their facilities or properties had any of the following pieces of equipment: freezers, fume hoods, microscopes, centrifuges, autoclaves, on-site distilled water, lasers, and x-ray machines. As can be seen in Figure 38, nearly all of the respondents had at least one of these pieces of equipment. Even X-ray machines were accounted for in over 50% of the responses.

Figure 38: Percentage of Facilities in the United States containing Laboratory Equipment



One observation from Figure 38 is that the results from the scientist-only survey may understate the prevalence of shared pieces of equipment. The data obtained from facility managers give valuable insight into the widespread existence of equipment found in a laboratory facility building.

5.4.3 Laboratory Equipment – Specific

Non-scientist respondents were also asked the approximate number of specific pieces of laboratory equipment in the labs at their facility. The range of responses varied widely, as some people were clearly responding for their building and others were responding for their entire facility. Nevertheless the data are interesting for several reasons. First, some of the data corroborate the findings from the survey for the scientists. Secondly, the data make clear the argument that was initially made in the previous section – laboratories contain a lot of equipment.

Table 70: Survey of Laboratory Equipment in US Facilities

	Average Number	Total Number	Responses
-80°C Freezers	151	9,633	64
-20°C Freezers	236	14,888	63
Fume Hoods (Total)	320	23,050	72
VAV Fume Hoods	196	11,391	58
Autoclaves	67	4,331	65

A similar analysis was done using just the data collected from California. Although the data are not statistically significant, the trends between the two data sets are consistent and can therefore be spoken of in general terms.

Table 71: Survey of Laboratories in California Facilities

	Average Number	Total Number	Responses
-80°C Freezers	315	3,776	12
-20°C Freezers	547	6,561	12
Fume Hoods (Total)	617	8,020	13
VAV Fume Hoods	304	2,732	9
Autoclaves	137	1,643	12

Comparing Tables 70 and 71 it is clear that the density of equipment is much higher in California's laboratory facilities than it is in other places in the US. Respondents in California averaged 2-3 times more pieces of equipment per response than the rest of the country. While it is possible that this is an accurate depiction of the density of laboratory equipment in California, no valid conclusions can be drawn from it because the sample size was so small; trends must be studied instead. One of the noticeable trends in both the US and California data sets is that the total number of VAV fume hoods is approximately 50% of the total number of fume hoods in a given facility. This is consistent with the data reported by the scientists' survey. There also tend to be more -20°C freezers than -80°C freezers in a facility or building, which is also consistent with the results obtained from the survey of scientists.

5.4.4 Laboratory Operations

Plug load is only one of the factors contributing to the high energy consumption of laboratories – ventilation and space conditioning systems are also critical, as are lab "utilities" such as compressed air, process chilled water, and vacuum systems.

Respondents who have direct knowledge of their facilities were asked questions about the utilities that they use in their organizations. As Table 72 shows below, the majority of respondents had all of the utilities in question operating in their organization.

Table 72: Utilities found in Laboratory Buildings

	Percent Affirmative Responses
Compressed Air	97.5%
Distilled Water	93.8%
Gas Storage	92.0%
Vacuum System	93.2%
Supplied Gas	94.7%
Process Chilled Water	87.7%
Supplied Ultra-Pure Water	83.3%
Dry Solvent Delivery System	37.5%
Point Source Exhaust System	83.3%

Temperature set-backs and varying flow rates of HVAC systems are two known ways of reducing energy consumption in laboratories. Facility managers and other non-scientists were asked about the adoption of these measures at their organizations. Forty-four percent of respondents said that they adjusted the temperature in their laboratories when they are unoccupied. Nearly 75% of respondents answered that they are able to vary the flow rates of their HVAC systems, but only 50% of those who have the ability to vary their flow rates actually do so in their laboratories.

Queries into the normal operating hours of the laboratories yielded several unique responses. While many respondents called attention to the fact that there are no 'normal' operating hours in laboratories, others responded with answers like '24/7' and '24 hours'. The next most common response was approximately 12 hours, followed by 10 hours.

The data obtained from facilities managers and other non-scientists about laboratory equipment and laboratory operations will be called upon again in Chapter 6 in order to estimate energy consumption in laboratories.

5.5 In-person Interview Accounts about Laboratory Equipment

In-person interviews were conducted at 14 institutions in California. The data presented in this report from these interviews has been anonymized, as in many cases the information provided could be considered proprietary. A summary of the laboratory equipment findings is presented below. A correlation of these responses with the data obtained from the survey can be found in Chapter 6.

Of the three universities studied, only one had performed a laboratory equipment inventory. This university found that it had 1520 laboratory freezers (both -80°C and -20°C), 1600 incubators, 986 water baths, 1759 lab refrigerators (4°C), 167 autoclaves, 644 shaker tables, 2746 centrifuges, and 1649 microscopes.

Several life science research companies were also interviewed for this study. One large pharmaceutical company estimated that for approximately 600 laboratories, they had 1000 biosafety cabinets, 300 fume hoods, and 3000 -80°C freezers. A smaller company found that they had 13 -80°C freezers, 19 tissue culture hoods, 27 fume hoods, 17 incubators, and 4 autoclaves in 34,000 square feet of laboratory space. One of the medical device companies interviewed for the study indicated that they have 15-25 fume hoods and tissue culture hoods, 20-30 -80°C freezers, and 2 cold rooms in approximately 36,000 square feet of laboratory space.

A correlation of these responses with the data obtained from the survey can be found in the next section.

CHAPTER 6: ESTIMATED EQUIPMENT - AND HVAC - RELATED LOADS IN LABORATORIES

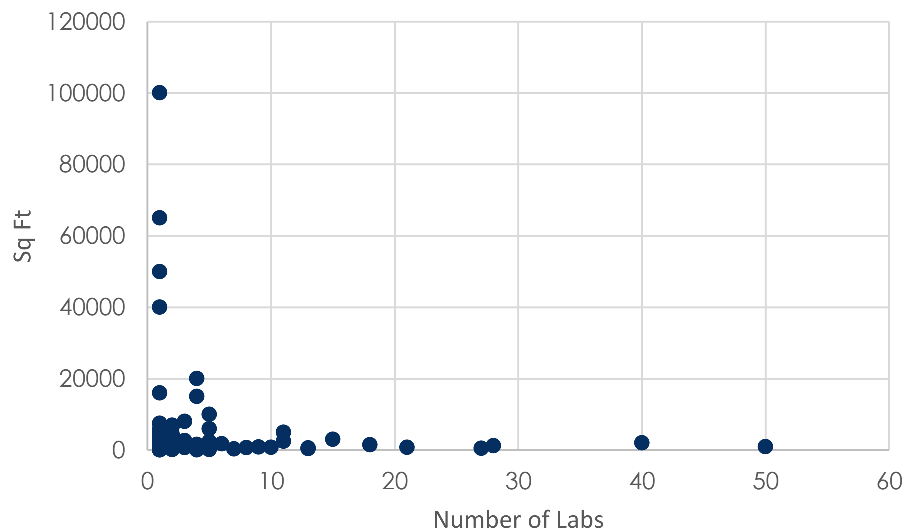
The previous two sections estimated the total laboratory square footage in California, and the average number of pieces of equipment found in an average lab in California. This section will combine these two findings in order to determine a) the estimated average number of pieces of equipment across the state of California, and b) the estimated energy consumption of laboratories in California as a function of laboratory operations and equipment.

6.1 Estimated Average Number of Pieces of Equipment in California

As shown in Table 14, the estimated square footage of laboratories in California is just over 116 million square feet for the market segments studied in this report. This number has yet to be translated into a total number of laboratories. Online survey respondents were asked to estimate the square footage of their lab – the same space for which they were answering questions about equipment. If they did not know the square footage, respondents were encouraged to write 'I don't know' in an effort to prevent too many guesses from entering into the data pool.

Only 23% of respondents in California were able to estimate the square footage of their laboratories. This amounted to 63 labs. A larger population was needed to provide an accurate estimate of laboratory square footage, and thus the entire data set from the online survey was analyzed. Of the over 1,300 respondents to the survey, 369 were able to approximate the square footage of their lab. The average square footage was 3,100 sq ft per laboratory. The mode was 1,000 sq ft, and the median was 1,200 sq ft. A distribution of the range of reported square footage is below.

FIGURE 39: DISTRIBUTION OF LABORATORY SPACE SQUARE FOOTAGE AMONG SURVEY RESPONDENTS



It is difficult to clearly see the distribution in the lower range due to the 18 laboratories that reported having square footage greater than 10,000 sq ft. The chart below demonstrates the distribution of square footage without those data points.

FIGURE 40: DISTRIBUTION OF LABORATORY SPACE SQUARE FOOTAGE AMONG SURVEY RESPONDENTS – UNDER 10,000 SQ FT

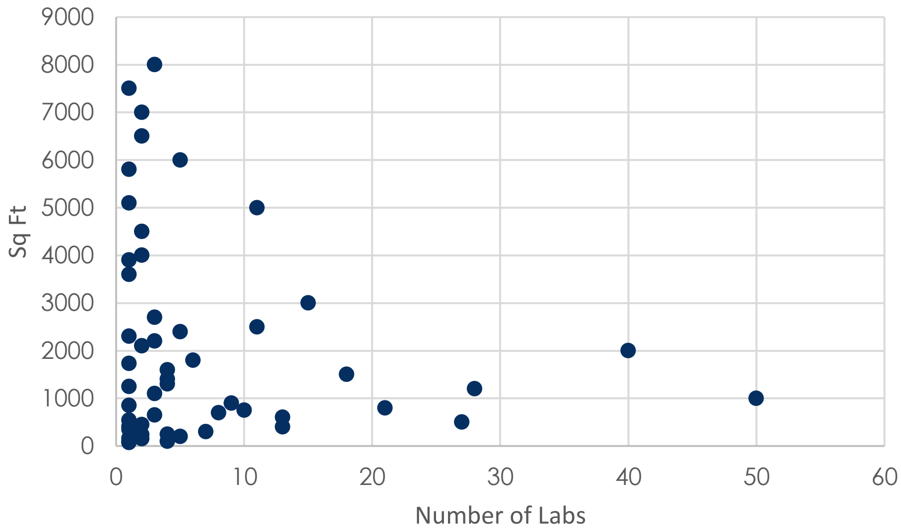


Table 73 below shows the estimated square footage per lab by market segment, as well as the estimated total number of labs in California. Note that the number for academia comes from Californian laboratories. Unfortunately, there were not enough California-based respondents in the other market segments who know the square footage of their laboratories. As a result, in order to achieve statistical significance, the below values for the LSR, hospital, and other segments were derived from the nationwide data, which covered 292 non-academic labs.

TABLE 73: ESTIMATED NUMBER OF LABORATORIES BY MARKET SEGMENT IN CALIFORNIA

MARKET SEGMENT	ESTIMATED AVERAGE SQ FT PER LAB	TOTAL SQ FT (M) OF LAB SPACE IN CA	ESTIMATED NUMBER OF LABS
Academia	2,000	24.7*	12,400
LSR	2,900	68.3	23,400
Hospitals	2,300	7.7	3,400
Other	2,800	3.0	1,100
Total		**103.3**	**40,300**

*This number does not include teaching lab space, for which there were no reliable survey data

It is important to remember the operational definition of a lab for most scientists. In academia and the non-profit sector, a 'lab' is all of the space occupied by a principal investigator and his/her students and postdocs; for a person working in a biotech company or hospital, the 'lab' is the space occupied by a group or department.

What people do not consider when reporting lab space is the space that is dedicated to equipment or shared occupancy, what will be termed 'lab support space' in this report. The standard ratio of lab-to-lab support space is 1:1 [43]. Therefore, the estimated square footage of each total lab space identified by the respondents is more likely to be twice what they reported. Because no data were collected on the average size of a teaching lab, those numbers were removed from this analysis.

TABLE 74: ESTIMATED NUMBER OF LABORATORIES (ADJUSTED) BY MARKET SEGMENT IN CALIFORNIA

MARKET SEGMENT	ESTIMATED AVERAGE SQ FT (M) PER LAB	ESTIMATED NUMBER OF LABS
Academia	4,000	6,200
LSR	5,800	11,700
Hospitals	4,600	1,700
Other	5,700	540
Total		**20,100**

The importance of lab support space was seen in Chapter 5. The data collected from the SfN conference do not appear to account for lab support space, as the numbers of reported equipment were nearly half that of what was reported for the online survey from both scientists and facilities managers.

Respondents to the online survey were asked 'how many pieces of (x) type of equipment are found in your lab?' not 'how many pieces of (x) type of equipment are found every 1,000 square feet?' Therefore, the only way to understand the laboratory equipment market is to take the estimated number of labs statewide and multiply it by the average number of a particular piece of lab equipment found in each lab. In other words:

$$AE / L * TL = TE$$

where: AE / L = average number of a piece of equipment per lab; TL = total number of labs in CA; TE = total number of pieces of equipment in the state

The results of this calculation are shown in Table 75. This calculation was done for the most common pieces of equipment in the lab.

TABLE 75: ESTIMATED TOTAL NUMBERS OF LABORATORY EQUIPMENT IN CALIFORNIA

EQUIPMENT	AVERAGE NUMBER PER LAB REPORTED IN CA	ESTIMATED TOTAL NUMBER IN CA
-80°C Freezer	2.9	58,000
-20°C Freezer	3.7	74,000
Refrigerator	4.7	95,000
Fume Hood	3.0	60,000
Fluorescence Microscope	1.7	34,000
Heating Block	3.0	60,000
Water Bath	2.6	52,000
Centrifuge	3.8	76,000
PCR Machine	2.2	44,000
Magnetic Stirrer	3.0	60,000
Vacuum Pump	2.1	42,000
Shaker Table	1.2	24,000
Autoclave	0.8	16,000
Incubator	3.0	60,000
Tissue Culture Hood	1.7	34,000

The data presented above are based on self-reported data from the survey. It is possible that respondents did not know the area of their lab, and therefore even after accounting for the lab support space, the estimated lab square footage used above may be incorrect. In an attempt to mitigate the potential errors that may arise from self-reporting, the same standard used to determine laboratory square footage in the LSR market was applied to the data set from the online survey. The results of this method of analysis can be found in Appendix II.

There are no previously published studies against which to validate these findings. Of the pieces of equipment surveyed in this study, only the numbers of fume hoods and -80°C freezers have been estimated in California. Fume hood estimates in California from 2006 put the number of fume hoods at 75,000 [44]. Assuming an average growth rate of 5% per year, the total quantity of fume hoods in California today would be approximately 111,000, substantially more than the number predicted by this study.

Several studies on ultra-low temperature freezers (-80 freezers) have estimated the market at 15,000 units in California [45]. A cursory look at a few organizations in California reveal that this number is far too low: The University of California schools alone have an estimated 10,000 ultra-low temperature freezers, two private universities interviewed are estimated to have at least 1,000 each, and just two pharmaceutical companies in California have 4,000 between them. This yields 16,000 -80°C freezers without accounting for the remaining 3,600 biopharmaceutical companies and nearly 1,100 medical device companies in the state, not to mention the Cal State Universities, hospitals, and non-profit institutions. If all of the remaining organizations were to have only one freezer each, they would account for an additional 5,000 freezers in California.

There are two primary reasons why freezer (and other laboratory equipment) estimates may be understated. First, the numbers are often reported by equipment manufacturers, and these manufacturers do not always sell into all of the market segments studied. For example, the type of freezer required by a hospital or other organization with specific temperature requirements may not be the same type of freezer that is sold into an academic research environment. Therefore, the view of one manufacturer, or several manufacturers in the same market segment, about the overall market may not be accurate. Secondly, industry market data is usually reported in dollar amounts, not units. At best it might be possible to assume an average sale price for a category of equipment and calculate unit sales based on this average, but given that the prices of equipment in a given product category can vary widely, the result of this calculation would not be very accurate.

Conversations with other manufacturers, including those making autoclaves, microscopes, and centrifuges, have verified that the numbers above are plausible estimates for the state.

Explaining the results is important and necessary, but validating them with examples is a more powerful approach. This validation was accomplished through in-person interviews and contact with facility managers who are intimately familiar with their facilities.

The academic case will be considered first. Data from three universities, two in Northern California (A&B), and one in Southern California (C) are presented below. Two of these universities are public and one is private. These universities all had information about their -80°C freezers. The predicted and reported numbers of -80°C freezers is shown below.

TABLE 80: VALIDATING THE DATA ANALYSIS METHOD USING DATA REPORTED FROM ACADEMIA; -80 FREEZERS

	UNIVERSITY A	UNIVERSITY B	UNIVERSITY C
-80°C Freezer	812 – predicted ~800 – reported	943 – predicted 1,100 – reported	362 – predicted 170 – reported

University A also completed an equipment survey of most of their campus laboratories. Validation of these data is shown in Table 81.

TABLE 81: VALIDATING THE DATA ANALYSIS METHOD USING DATA REPORTED FROM UNIVERSITY A

	PREDICTED	ACTUAL
Incubator	840	1,600
Water Bath	728	986
Refrigerator	1,316	1,759
Autoclave	224	167
Shaker Table	336	644
Centrifuge	1,064	2,746
Microscope	476	1,649*

*Note – not all of these are fluorescence microscopes

The results in Tables 80 and 81 demonstrate that the prediction often underestimates the actual values observed at the University. This is not surprising as the lower estimates of all calculations have been taken throughout the study in an effort to prevent overestimating the market size.

The data analysis method was also tested in the LSR market. Company A represents a large pharmaceutical company; Company B is a medium-sized biotech company, and Company C is a medium-sized medical device company. The average square footage of lab space for Companies B & C was assumed to be the value calculated in Table 74. The total number of labs was known for Company A.

TABLE 82: VALIDATING THE DATA ANALYSIS METHOD USING DATA REPORTED FROM THE LSR INDUSTRY

	COMPANY A	COMPANY B	COMPANY C
-80°C Freezer	Predicted: 300 Actual: 3,000	Predicted: 16 Actual: 13	Predicted: 18 Actual: 20 – 30 (est)
Fume Hood	Predicted: 404 Actual: 300	Predicted: 17 Actual: 27	
Tissue Culture Hood	Predicted: 229 Actual: 1,000	Predicted: 10 Actual: 19	
Incubator		Predicted: 17 Actual: 17	

The data presented here strongly argue in favor of using a large sample size to determine estimates of laboratory equipment values. Unfortunately many of the companies interviewed had not completed an equipment inventory and were unable to provide the data necessary to fully validate the methodology described above. Neither the hospital nor the non-profit sectors provided data on laboratory equipment as a function of square footage. Therefore, without an additional method for verification, and because this study seeks to remain conservative in its estimates, it was decided that this method of analysis was the best way to evaluate the data.

The data obtained from the survey given to non-scientists was also used to test the methodology for calculating laboratory equipment. Table 83 evaluates the ability of the data analysis method to predict the number of pieces of equipment at a given facility based on the square footage of that facility. Values that were overestimated by more than a factor of 2 are in red; values that were underestimated by more than a factor of 2 are in blue. It is worthwhile noting that the 135,000 and 147,000 square foot spaces belonged to chemical companies. It seems plausible that laboratories focusing on chemistry would tend to have more fume hoods than the model would predict, and fewer -80°C and -20°C freezers; laboratories whose research falls into the Life Sciences category tend to have freezer counts closer to the prediction, and fume hood counts much lower than the prediction. This finding is a strong argument in favor of averaging over a large sample population.

TABLE 83: VALIDATING THE DATA ANALYSIS METHOD USING DATA REPORTED BY FACILITY MANAGERS

SQUARE FOOTAGE	-80 EST, -80 ACTUAL	-20 EST, -20 ACTUAL	FH* EST, FH ACTUAL	AUTOC** EST, AUTOC ACTUAL
4,500	2, 3	4, 4	**3, 8**	**1,3**
6,000	**4, 10**	6, 10	**5, 56**	1, 2
14,000	7, 4	9, 5	7, 6	2, 1
21,000	15, 12	19, 15	16, 19	4, 4
40,000	**20, 1**	**25, 4**	20, 12	5, 4
70,000	50, 50	**65, 200**	**53, 25**	14, 20
80,000	58, 75	74, 75	**60, 30**	**16, 6**
90,000	46, 50	58, 75	**47, 13**	13, 11
135,000	**67, 15**	**86, 30**	69, 120	**19, 5**
147,000	**75, 12**	**95, 20**	77, 150	**21, 4**
200,000	102, 75	130, 75	**105, 30**	28, 20
280,000	203, 150	259, 200	210, 150	**56, 20**
350,000	222, 200	283,300	**230,100**	**61,30**
1,800,000	1305, 726	**1665, 700**	1350, 985	**360, 160**
3,000,000	**2175, 1000**	2775, 3000	2250, 3000	**600, 200**
% Accurate	**67%**	**67%**	**53%**	**47%**
Total (Est, Act)	**4378, 2683**	**5608, 4713**	**4502, 4704**	**1191, 553**

*FH = fume hood; **AutoC = autoclave

Key: Red: overestimated by a factor of 2; Blue: underestimated by a factor of 2

Taking the data set in its entirety, the number of pieces of laboratory equipment across these 15 university and biotech organizations was accurately predicted within a factor of 2 for all but autoclaves. There are a few caveats to this analysis: 1) the square footage was self-reported, and was likely an estimate in many cases; 2) the numbers of pieces of equipment in the larger organizations were also likely estimates, as only one institution reported anything other than numbers ending in 5 or 0; 3) it was not clear whether the space being reported included research support space. Nevertheless, the methodology does a relatively good job of predicting laboratory equipment numbers.

It is also important to note that while an increase in square footage is consistent with an increase in the number of pieces of equipment, this trend does not scale linearly. Very large organizations often have fewer pieces of large equipment than predicted, likely owing to the fact that much of the equipment is shared, and operations are much more streamlined. Put another way, nearly every start-up is going to need at least one -80°C freezer, -20°C freezer, and refrigerator, even if there are only 2 people working in the lab. But a company with 5,000 scientists may not need 828 freezers (average square footage of lab space for 5,000 people multiplied by 2.9 freezers per lab), especially as projects change and samples are routinely inventoried. Thus the number at the high end is likely to be much more variable than at the lower end.

The total amount of equipment in the US can be predicted, assuming that the total laboratory square footage calculated for California is approximately 10% of the US number.

TABLE 84: ESTIMATED EQUIPMENT COUNTS IN THE UNITED STATES

EQUIPMENT	AVERAGE NUMBER PER LAB REPORTED IN THE US	ESTIMATED TOTAL NUMBER IN THE US*
-80°C Freezer	2.2	440,000 – 890,000
-20°C Freezer	3.1	620,000 – 1,250,000
Refrigerator	4.4	810,000 – 1,200,000
Fume Hood	2.5	500,000 – 1,000,000
Fluorescence Microscope	1.0	200,000 – 400,000
Heating Block	2.4	480,000 – 970,000
Water Bath	2.2	440,000 – 890,000
Centrifuge	3.7	740,000 – 1,490,000
PCR Machine	2.0	400,000 – 810,000
Magnetic Stirrer	3.1	620,000 – 1,250,000
Vacuum Pump	1.7	340,000 – 680,000
Shaker Table	1.1	220,000 – 440,000
Autoclave	0.8	160,000 – 320,000
Incubator	3.0	560,000 – 1,100,000
Tissue Culture Hood	1.7	280,000 – 560,000

* Not including CA

6.2 ESTIMATED ENERGY CONSUMPTION OF LABORATORY EQUIPMENT

Average energy consumption data were taken from reports published by I^{2}SL, S-Labs, Caltech, and the University of British Columbia [46,47,48,49]. These values were confirmed against recent field measurements whenever possible [50]. Very little information exists about the energy consumption of laboratory equipment in the United States. There is a Labs21 online database of energy consumption of laboratory equipment, but the database is often lacking measured data. Further complicating matters is the fact that even for a particular subset of laboratory equipment there exists a large range of sizes, and with that a large range of energy consumption values. Even equipment that is of the same product category and size can vary widely in energy consumption among manufacturers.

Table 85 shows the energy consumption values that are available for the pieces of equipment studied. Previously published accounts of some of these pieces of equipment assumed 'typical' operating hours; this study produced an estimate of the operating hours based on feedback from the survey, and those estimates were used to guide the energy consumption calculations.

TABLE 85: ESTIMATED ENERGY CONSUMPTION RANGES FOR LABORATORY EQUIPMENT

EQUIPMENT TYPE	AVG HRS OF USE PER DAY	ENERGY CONSUMPTION RANGE (PUBLISHED)	ENERGY CONSUMPTION RANGE (KWH/YR)
-80°C Freezer	24	3900 – 13,666 kWh/year	3900 – 11,100
-20°C Freezer	24	1690 – 4876 kWh/year	1690 – 4876
Refrigerator	24	199 - 2686 kWh/year	199 – 2686
Fume Hood	24	30 - 60 kWh/day	10,950 – 21,900
Fluo Microscope	3	0.5 – 1 kWh/day	183 – 365
Centrifuge	3	3.2 – 57 kWh/week	166 – 2964
Water Bath	13.5	2025 – 3850 kWh/year	2205 – 3850
Heating Block	3	243 kWh/year	243
PCR Machine	4	788 kWh/year	788
Incubator	24	13.1 – 167 kWh/week	681 – 8684
Shaker	3	42 kWh/week	2184
Autoclave	3	32 – 630 kWh/week	1664 – 32760
Vacuum Pump	3	0.09 kWh – 7.5 kWh/day	33 – 2730
Tissue Culture Hood	4	60 – 88 kWh/week	3120 – 6862

Multiplying the estimated number of pieces of equipment by the estimated energy consumption per piece provides an estimate of the energy consumption of laboratory equipment in California. The lower estimates correspond to the lower estimated energy consumption values in Table 85; the higher estimates come from the higher estimated energy consumption values in Table 85.

TABLE 86: ESTIMATED ENERGY CONSUMPTION OF LABORATORY EQUIPMENT IN CALIFORNIA

	EST NUMBER OF PIECES OF EQUIPMENT	EST ANNUAL ENERGY CONSUMPTION (GWH, LOWER)	EST ANNUAL ENERGY CONSUMPTION (GWH, HIGHER)
-80°C Freezer	58,000	230	650
-20°C Freezer	74,000	130	360
Refrigerator	95,000	20	250
Fume Hood	60,000	660	1,300
Fluo Microscope	34,000	6.6	12
Centrifuge	76,000	13	230
Water Bath	52,000	115	200
Heating Block	60,000	15	
PCR Machine	44,000	35	
Incubator	60,000	41	530
Shaker	24,000	53	
Autoclave	16,000	27	530
Vacuum Pump	42,000	1.4	115
Tissue Culture Hood	34,000	110	230

Based on the data, the lowest energy estimate for the equipment above is 1,450 GWh/year and the highest energy estimate is 4,500 GWh/year in California. Fume hoods are not considered part of plug loads, so the plug load energy estimate for the equipment in Table 86 is: 790 – 3,200 GWh/year. Note that these values are for the conservative estimate of lab square footage derived in Chapter 4. If the higher estimate of total lab square footage in California were to be used, the energy consumption estimates would be twice as high. It is also worth noting that the equipment shown in Table 86 represents a subset of the equipment studied in this report, which is just a fraction of all of the equipment found in a lab. It is unfortunate that more energy consumption data are not available for the other pieces of equipment in the survey so that they could be added to the totals. It is also unfortunate that more accurate metering data for the pieces of equipment in Table 86 were not available. Clearly the energy consumption of laboratories in California is much higher than even the highest estimate stated above. Appendix IV gives more detail justifying the plug load estimates above.

The energy estimate for California can be broken down by service territory. Total energy estimates for the IOU service territories are shown in Table 87. These estimates were made by multiplying the total square footage of laboratory space in California by the percentage of space associated with each territory. Note, academic institutions and hospitals were assumed to be reasonably evenly distributed throughout the state; LSR institutions were re-allocated according to Table 9.

TABLE 87: LABORATORY PLUG LOAD AVERAGE ENERGY CONSUMPTION BY SERVICE TERRITORY

SDG&E	260 – 1,100	GWh/yr
SCE	230 – 930	GWh/yr
PG&E	300 – 1,200	GWh/yr

Energy estimates for the US (excluding California) are shown in Table 88.

TABLE 88: ESTIMATED ENERGY CONSUMPTION OF LABORATORY EQUIPMENT IN THE UNITED STATES

	EST ANNUAL ENERGY CONSUMPTION (GWH, LOWER)	EST ANNUAL ENERGY CONSUMPTION (GWH, HIGHER)
-80°C Freezer	1,730	4,900
-20°C Freezer	1,050	3,040
Refrigerator	160	2,160
Fume Hood	5,500	11,000
Fluo Microscope	37	73
Centrifuge	125	2,200
Water Bath	1,000	1,700
Heating Block	120	120
PCR Machine	320	320
Incubator	390	4,900
Shaker	480	480
Autoclave	270	5,300
Vacuum Pump	11	930
Tissue Culture Hood	880	1,900

6.3 ESTIMATED ENERGY CONSUMPTION OF LABORATORY OPERATIONS

Although the survey was mostly focused on plug-in laboratory equipment, important information was also collected from facility managers on the utilities provided at their facilities. For example, an overwhelming majority of managers noted having point exhaust systems. As with fume hoods, each cfm of exhaust can cost the facility $5-$9 per year in energy consumption, amounting to $500-$900/yr for a typical snorkel exhaust. A central compressed air system may cost $5k-10k/yr in electricity for a 100,000 sf lab facility. Providing chilled water cooling for a single MRI machine can consume 50,000 kWh/yr. Efficiency opportunities abound for these systems, e.g. free (economizer) cooling for process chilled water, leak repairs for compressed air systems, and hibernating unused snorkel exhausts.

The average total annual site energy usage for lab facilities is approximately 330 kBtu per gross square foot (based on data from the Labs21 Benchmarking Tool database). Space conditioning and ventilation systems are responsible for the majority (often 60%) of the energy consumed by lab buildings. The challenges facing lab HVAC energy efficiency differ from those found in the equipment market: exposure control considerations and HVAC control system capabilities pose additional challenges to ventilation system efficiency efforts.

The electricity consumed by lab equipment ultimately heats the air in the lab. Space conditioning systems and equipment loads are closely linked: among their functional requirements, lab HVAC systems must remove the heat generated by the lab equipment.

Uncertainties regarding the amount of heat dissipated by lab equipment, coupled with risk aversion regarding chemical hazards, frequently lead to the blanket application of conservative airflow policies in an attempt to ensure occupant safety and comfort. However, lab HVAC energy savings of 50% have been shown to be routinely achievable in tandem with safety enhancements [51]. Reduced plug loads will enable even deeper energy savings, both directly and also indirectly through reduced loads on lab HVAC systems. The ultimate impact on the HVAC system depends on the specific lab environment (and its supply air reheat requirements) and the CEEL aims to provide guidance on the energy savings potential for a range of lab types and for the population as a whole.

CHAPTER 7: DISCUSSION

7.1 DISCUSSION OF THE RESULTS

The findings in this report clearly demonstrate that laboratories comprise a large, significant market in California that, because of their operations and equipment, consume a substantial amount of energy. An assessment of the overall size and composition of the market showed that just four of the nearly ten different market segments associated with labs – academic, LSR, hospitals and non-profit – accounted for a minimum of 116 million square feet of laboratory space in the state. Inside of those 116 million square feet are a multitude of highly specialized pieces of equipment that were found to consume many GWh of energy every year in aggregate. The estimated energy consumed by just the approximately 58,000 -80°C freezers in California is equivalent to the energy consumed by 95 million similarly-sized residential refrigerators.

This report is the first time that the energy consumption of laboratory equipment has been thoroughly investigated, but it is not the first time that energy savings opportunities in labs have been recognized. Energy efficiency measures have been implemented in laboratories throughout the state in the form of operational changes and equipment retrofits.

On the facilities side, one of the most widespread measures implemented has been the reduction of the number of air changes per hour (ACH) of lab ventilation. Reductions from 15-20 ACH to 6 ACH in occupied lab spaces (4 ACH in unoccupied spaces) are relatively common in academic institutions and in large LSR companies (see 7.3). Other energy saving measures introduced in laboratory facilities have included occupancy sensors and fume hood retrofits (from CAV to VAV).

Ultra-low temperature freezers (-80°C) have long been the focus of equipment retrofits. Several field studies have been conducted over the past five years on the energy consumption of various models of -80°C freezers. The most recent study, published by the Better Buildings Alliance in 2014, looked at the energy consumption of four different models of -80°C freezers at three universities [52]. The study found that the newer freezer models consumed less energy than the older models and that at least one of the models tested was more energy efficient than the others. The study noted that the energy savings associated with the more energy efficient model was at least 5.3 kWh/day. Additional independent field studies have confirmed that the energy savings opportunities for -80°C freezers range from 5–10 kWh/day. Because of this, customized incentive programs have been utilized across the state to provide financial incentives for the purchase of energy efficient -80°C freezers. In fact, the opportunity around this piece of lab equipment has been recognized as so substantial that the EPA has developed a test method for -80°C freezers with a goal of identifying models to be recommended for ENERGY STAR ratings. This test method addresses laboratory refrigeration in general, including -20°C freezers and refrigerators.

The EPA and ENERGY STAR have also published a preliminary test method for Medical Imaging Equipment, such as MRIs, CT Scanners, and X-Ray machines. As demonstrated in this study, these pieces of equipment are found in laboratories as well.

Other categories of laboratory equipment surveyed in this report, such as benchtop equipment and large laboratory equipment, have not yet been studied to the same extent as refrigeration and medical imaging equipment. Nevertheless, recognizing the significant value in identifying energy efficient products, select equipment manufacturers and academics have performed their own metering. Autoclaves, vacuum pumps, microscope lights, and incubators have all been field tested to some extent, and some manufacturers of these products have begun advertising their energy efficient solutions.

The results shown in Chapters 4, 5 and 6 have intentionally been presented as conservative estimates. Yet the energy savings predicted by this study for -80°C freezers alone is upwards of 37 GWh/year, assuming that just 25% of the market is addressed with freezers that are only 35% more efficient [53]. This is the equivalent of replacing 31 million old household refrigerators from 1996 with ENERGY STAR models. Energy savings from smaller, research grade autoclaves have been found to be up to 27,900 kWh/year per autoclave, and the amount of energy that could be saved by switching from metal halide bulbs to LEDs in just 25% of the fluorescence microscopes in the state would be more than 1.6 GWh/year [54]. These savings are equivalent to turning off 750,000 desktop computers for a year.

In addition to the observations about the market size and opportunities for energy savings, the results of this study also point to some additional key findings. It was found that, on average, California has at least 20% more equipment per lab than laboratories in the rest of the US. The most plausible explanation for this is that funding for laboratory equipment is more readily available in California than in the rest of the country, and the results shown in Chapter 5 corroborate this theory. Nevertheless, this finding is significant because it underscores the importance of addressing plug loads in California in particular as California stands to benefit disproportionately from energy saving measures.

The study also found that the LSR market tends to have more equipment per lab than academia or hospitals, both in California and the wider US. Given the correlation between funding and laboratory equipment density, it is not surprising that this would be the case; publicly- and privately-funded LSR companies often receive more money for research than their academic counterparts. The fact that the LSR market has more equipment may be beneficial in a campaign to reduce plug loads because this market is uniquely positioned to be receptive to energy savings. Unlike academia, utility bills are often paid for directly by the company, and a reduction in overhead costs can have a direct impact on research (to say nothing of profitability). A more complete discussion of the economic drivers behind reduced energy consumption in laboratories is presented in 7.3 below. Suffice it to say that since the LSR market in California comprises at least 50% of all laboratory space, and contains even a greater percentage of laboratory equipment, there are substantial opportunities for energy savings to be had in this sector.

Within California it was found that SDG&E's territory tended to have a higher density of laboratory equipment than the rest of the service territories. It is possible that the composition of the market in San Diego, especially that of the LSR market sector, is the driver behind the observed differences. San Diego was found to have a higher concentration of CROs than the rest of the regions in the state (Table 6), and CROs often have a high density of equipment due to the nature of the work done in their facilities. The evidence for market composition being the cause of the higher equipment counts in SDG&E

comes from the observations that fume hood, centrifuge, PCR machine, shaker table, autoclave, qPCR machine, incubator, tissue culture hood, sonicator, and cold room quantities in academia are relatively the same among the service territories. For these pieces of equipment, SDG&E's numbers are comparable to PG&E's (SCE's territory tends to exhibit similar or lower values). However, for the same pieces of equipment, the numbers reported by SDG&E's LSR market sector were often 25 – 75% higher. While the small sample size may have skewed the reported equipment results, the difference in market composition is a more plausible explanation for the observations in this study.

In contrast, SCE's service territory reported a lower density of laboratory equipment than either of the other two IOU territories. As shown in Table 6, SCE's territory appears to contain a greater proportion of medical device companies than the rest of the state. Moreover, this specifically comes at the expense of the territory's allotment of CRO companies (and their high equipment densities), the proportion of which is less than half of its value in SDG&E's territory. Medical device companies do not tend to do as much basic research as LSR companies, and as a result would not be expected to have as much common equipment as a pharmaceutical or biotech company. In fact, the equipment most likely to be found in a medical device company would be the equipment made and sold by that company, not the generic equipment surveyed in this study. Unfortunately, the number of responses from SCE's territory was also not high enough to be statistically significant, and therefore an undersampling bias also may be the explanation for the observed values. Section 7.2 provides valuable insight into how this equipment might be addressed.

Regardless of the region in California, it is clear that with over 116 million square feet of laboratory space and at least 750 GWh/year in energy consumption due to plug loads alone, this market needs to be a prime focus of energy savings programs.

7.2 Opportunities for Energy Efficiency Identified Through In-Person Interviews

Knowing the energy consumption of labs in California is the first step to understanding energy efficiency opportunities. Fourteen different organizations across California were interviewed about projects that they had undertaken to improve the energy efficiency in their laboratories. These projects ranged from addressing building operations, to specifically incentivizing the purchase of energy efficient laboratory equipment. A sampling of those projects is below.

Two universities in California, University D and University E, have both undertaken organized efforts to optimize facility operations in laboratory buildings. University D has optimized its chilled water loop, and examined windspeed directions in order to control exhaust stack velocity. The latter is something that University E has considered as well, although it noted that this type of project is very expensive. A centralized demand-controlled ventilation system has been installed in two buildings at University D and is likely to be installed in at least one building at University E in 2015. Several years ago UC Berkeley began a program that billed labs based on their energy use over a 3-year established baseline, and this method of managing energy consumption in laboratories on campus was cited by both University D and University E as being an effective means to drive down energy costs. University E is also in the process of a lighting and HVAC retrofit in all lab buildings.

On the equipment side, Universities D and E have both offered rebates for energy efficient ultra-low temperature freezers (aka -80s) in the past. University D replaced 15-20 freezers under this program; University E replaced 60. Both programs were offered as a result of funds from the California IOUs. University E began a pilot program in 2012 involving an energy monitoring software for ultra-low temperature freezers. It was reported that scientists view this software favorably, as it allows them to receive communications about possible failures. This software is also useful for University E as it allows them to see real-time energy consumption of their freezers.

University E replaced a gas laser with a solid state diode laser in 2014. The money for this replacement came wholly from University E.

Both Universities D and E noted that they have plans to continue the expansion of their laboratory spaces in the next few years.

University D has a well-established, widely recognized Green Labs program on campus that specializes in outreach and education. Among many other things, this group of students and staff works diligently to reduce the amount of energy consumed by laboratories. University E just recently started a Green Labs program on their campus. Energy efficiency has been an important focus of University E's group as well.

Regarding studies into energy efficient equipment, University D said that laboratory equipment is uncharted territory – right now there are no standards or guidelines around energy efficiency for laboratory equipment and plug loads. There are clear guidelines for office spaces, with ENERGY STAR and GreenSeal being two examples of standards, but nothing like this exists for laboratories. The Labs21 Benchmarking Tool provides valuable information about energy consumption in laboratories, yet plug loads are not addressed by this tool specifically. In addition, University D explained that there is little third party certification and few energy metrics for lab equipment. University E echoed these sentiments, saying that it is not clear what uses a lot of energy in laboratories, and that even just having this information would be valuable. All universities interviewed for this study expressed the unanimous opinion that the proposed work of the CEEL is necessary to address energy use of laboratory equipment.

Life Science Research and Medical Device companies were not unlike Universities in their efforts to reduce energy consumption in their laboratory spaces. Profiled below are the efforts of six companies to improve energy efficiency in their laboratories:

Company A: LSR, Pharmaceutical

Company B: LSR, Biotech

Company C: LSR, Pharmaceutical

Company D: Medical Device

Company E: CRO

Company F: Medical Device

Company A has reduced the number of air changes per hour (ACH) down to a minimum of 6 in occupied lab spaces and to a minimum of 4 in unoccupied lab spaces. Chemistry labs are always set to 10 ACH, however, due to safety regulations. HVAC setbacks in biology are linked to lighting occupancy sensors. Energy efficient lighting has been installed throughout Company A's facilities, and nighttime setbacks for fume hoods have been implemented (they operate at 100 ft/min face velocity during the day and 60 ft/min at night). Occupancy sensors for lights and fume hoods have been piloted in the chemistry labs, and, if the pilot is successful, it will be rolled out to all labs, including biology labs.

Company B, which rents and does not own its property in Northern California, tried to install solar panels on its laboratory buildings, recognizing that the labs consumed a substantial amount of energy. This project did not proceed, but an onsite battery has been installed to handle peak demands, and it has been shown to be effective in reducing utility bills. Water-saving initiatives have also been implemented at Company D.

Company C has implemented a fume hood sash management project, and as a result of this project, 99% of VAV fume hoods are closed on a regular basis. Company E has also changed the run times for small chiller units, and has modified the dead band set points for the HVAC system. Old chillers have been replaced, and an LED retrofit was done as well. A 240 kW solar array was installed on one building.

Company D tried to do an energy audit with their IOU on the HVAC systems in the building. The audit determined that one wing was eligible for incentives but the other was not. Company E has also taken steps to optimize energy efficiency in the lab, from addressing ventilation to positioning equipment in a more intelligent location in order to minimize the impact on the HVAC system.

Of those surveyed, only Company A has targeted its laboratory equipment specifically as a means of reducing energy consumption. Company A has a very robust initiative to replace ultra-low temperature freezers with more energy-efficient models. Several hundred energy efficient freezers have been purchased since 2014, of which about 25% were replacement freezers. Company A specifically cited a deemed rebate for ultra-low temperature freezers as a priority for them. They also mentioned gathering information on other forms of cold storage (-20 freezers, refrigerators) and autoclaves as priorities.

Importantly, all companies surveyed indicated that a lack of data has been the reason that they have not specifically addressed the energy consumption of their laboratory equipment. Company C, which has had an energy conservation initiative in place since 2004, said that benchmarking of laboratory equipment is "exactly what is needed" to make the case for purchasing more energy efficient equipment. Company C continued to say that if there were rebates available for energy efficient laboratory equipment, the company would be interested in taking advantage of them, not only for the financial incentive, but also because rebates are viewed as a way to engage scientists.

Companies B and E both said that it would be helpful to have feedback on the energy consumption and performance of equipment. Companies D and F, both medical device companies, agreed and took it one step further, saying that they would be interested in having their products tested for energy efficiency if that were a possibility. Significantly, not only are Companies D and F interested in benchmarking the equipment they use, they are also interested in benchmarking the equipment they make.

A hospital was also interviewed. Hospital A provided valuable insight into the state of energy efficiency in hospital laboratories. This hospital's new buildings are being certified with a goal of LEED Gold, and many of its older buildings have been re-certified through LEED-EBOM. Many of the pieces of equipment found in Hospital A were on uninterrupted power supplies (UPS), which reject a large amount of heat, impacting cooling systems. In all possible instances, Hospital A has switched from individual UPSs' to centralized ones. Some manufacturers will not accept a centralized UPS – they will void their warranties if equipment is not placed on its own UPS. Finally, Hospital A is installing LED lights wherever possible in place of fluorescent lighting.

Hospital A also noted the very specific temperature requirements that are unique to their particular environment. Many pieces of equipment – and samples – must be maintained within a very narrow temperature range, causing Hospital A to expend a tremendous amount of energy just to maintain space temperature. A current pilot is underway to control the heating and cooling of a building depending on the position of the sun and where it hits the building.

When the topic of rebates and incentives for energy efficient laboratory equipment was raised, interviewees at Hospital A all said that they would "absolutely take advantage of them."

Academic institutions, LSR companies, and hospitals all echoed the same sentiment – energy efficiency in laboratories is important, and, with some guidance, they are willing to take the steps necessary to reduce energy consumption in their labs. They also made it very clear that they were not going to invest in projects that had long ROIs, and that independent, 3rd party standards were necessary in order to feel comfortable making and acting upon equipment recommendations.

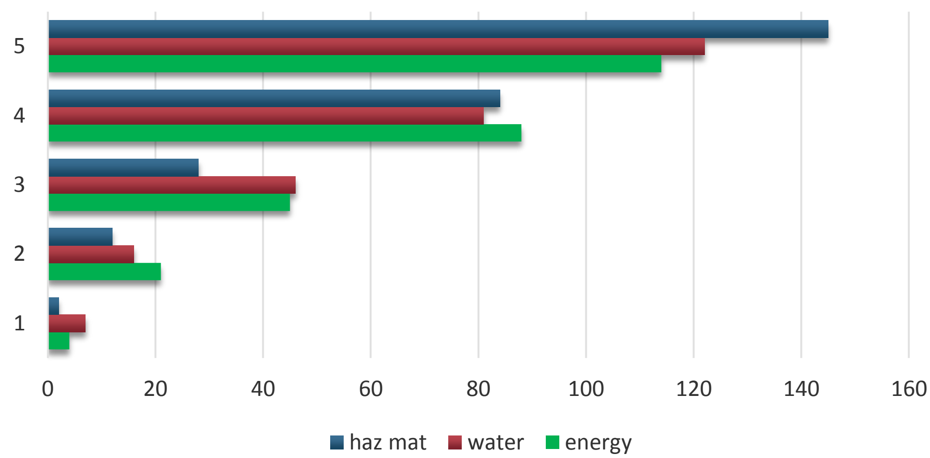
7.3 Attitudes about Energy Efficiency

The fact that energy efficiency projects have already been successfully implemented in some organizations lends credence to the idea that laboratories represent an opportunity for energy savings. However, many of these projects were focused on laboratory operations, not plug loads, and unlike operations, reducing plug loads requires the support of scientists and manufacturers.

'Scientists don't care about energy efficiency' is an oft-heard myth about scientists' relationship with energy in their labs. People usually presume that because scientists do not pay their own energy bills, they have no motivation to take an interest in their energy usage. In contrast to this supposition, while it is true that scientists are currently not financially motivated to change their behavior, this study has shown that they do in fact value energy efficiency.

Survey respondents were asked to rate the importance of energy efficiency, waste efficiency, and elimination of hazardous chemicals from their work environment, provided that these changes did not affect the integrity of their work. The results from 256 Californian responses are presented in Figure 41. In summary, over 70% of respondents said that it was either 'very important' or 'important' (a 4 or 5 on the rating scale) to have equipment that was energy-efficient (green bar), water-efficient (red bar), and free of hazardous chemicals (blue bar).

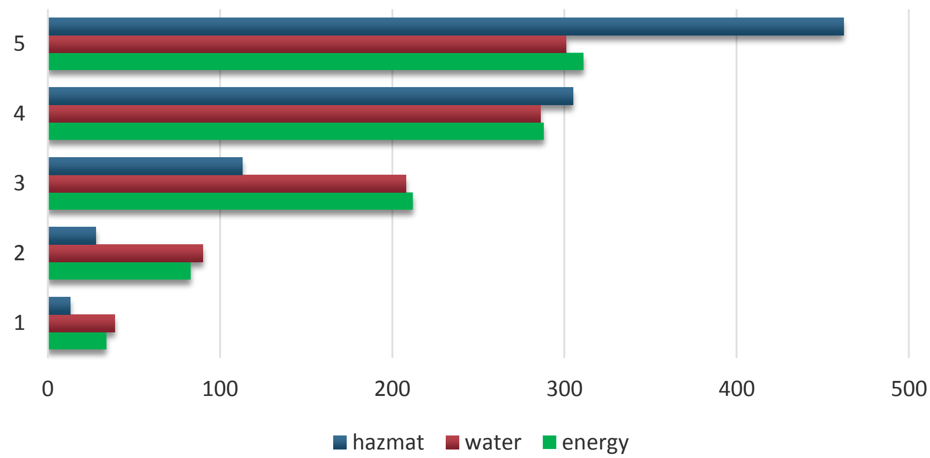
FIGURE 41: SURVEY RESPONSES REGARDING THE IMPORTANCE OF ENERGY AND WATER EFFICIENCY, AND REDUCTION OF HAZARDOUS MATERIALS IN CALIFORNIA



When asked what pieces of equipment they would like to replace with a more energy efficient model, the majority of respondents answered the question with something other than 'none'. The most commonly cited pieces of equipment were freezers, refrigerators, incubators, centrifuges, and microscope lights and lasers.

California scientists were not unique in their feelings about the importance of energy and water efficiency and reduction of hazardous materials; the trends seen in California were also seen throughout the United States. Over 60% of the 940 respondents nationwide reported that these factors are important to them, with more than half choosing option 5 – 'very important'. Notably, both in California and across the US, less than 5 % of respondents chose option 1 – 'not important' – for any of these areas of consideration.

FIGURE 42: SURVEY RESPONSES REGARDING THE IMPORTANCE OF ENERGY AND WATER EFFICIENCY, AND REDUCTION OF HAZARDOUS MATERIALS IN THE UNITED STATES



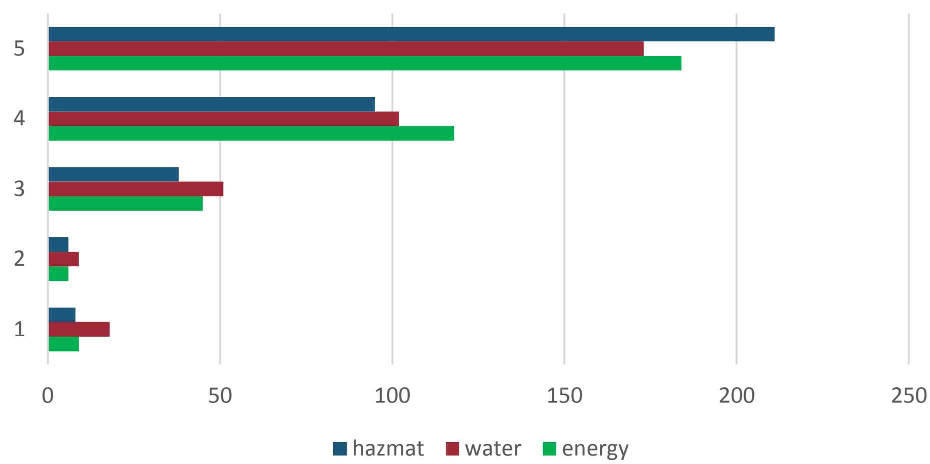
National respondents also reported wanting to replace similar pieces of equipment for more energy efficient models, with freezers, refrigerators, incubators, and centrifuges being high on the list. Also on the list were PCR machines, water baths, drying ovens, HPLC, spectrophotometers, microscope lighting, and autoclaves.

PIs and lab managers responded to these questions in the same manner as staff scientists, postdocs, graduate students, and other people working in the lab. Over 60% of key decision-makers in laboratories said that energy efficiency, water efficiency and the elimination of hazardous materials were either 'very important' or 'important' to them. In all cases less than 5% of PIs and lab managers responded that these attributes were 'not important'.

It could be argued that the reason the survey collected such positive attitudes about energy efficiency and other sustainability measures was that only people who already believed in the importance of these topics would be willing to devote the time to participate. In order to verify that the results were not biased in this way, the responses from scientists who attended the SfN conference were also analyzed. As reported in Chapter 2, these scientists did not seek out the booth at the conference; over 85% of respondents were stopped by booth personnel to take the survey. They were not informed about the nature of the survey prior to taking it and therefore the population of respondents was not biased based on its *a priori* opinions about the topic of this study. The responses from over 350 conference attendees at SfN mirrored those seen in California and in the rest of the United States. Less than 5% of people thought that energy efficiency in products was not important; the vast majority said that it was 'very important' or 'important'.

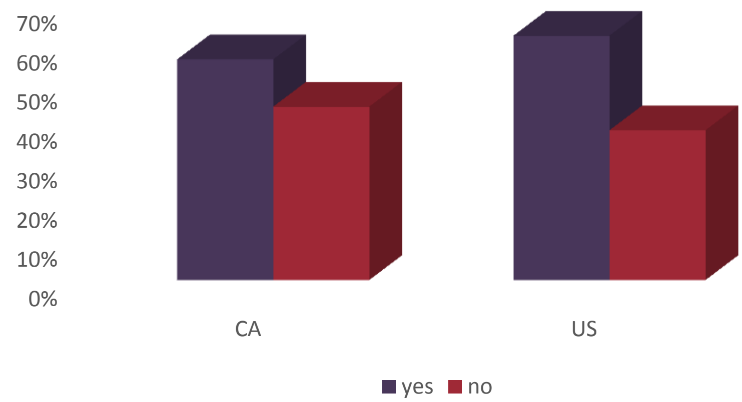
One of the benefits of conducting this survey at a conference was the ability to speak with respondents after they completed their survey. The overwhelming response to the study was 'thank you'. From PIs to graduate students, nearly everyone commented on how necessary it was to address the issues of energy consumption in laboratories. It did not matter where they were from – people from all over the world were in agreement on the importance of this topic. They also agreed that lack of information and financial considerations are the two biggest obstacles to implementing change in the lab.

FIGURE 43: SURVEY RESPONSES REGARDING THE IMPORTANCE OF ENERGY AND WATER EFFICIENCY, AND REDUCTION OF HAZARDOUS MATERIALS AT SFN



Given the respondents' overwhelming recognition of the importance of energy efficiency, it would follow that they would consider energy efficiency when purchasing new equipment. The survey results confirmed this conclusion, with 56% of respondents in California and 62% of respondents in the US saying that they consider energy efficiency when purchasing new equipment.

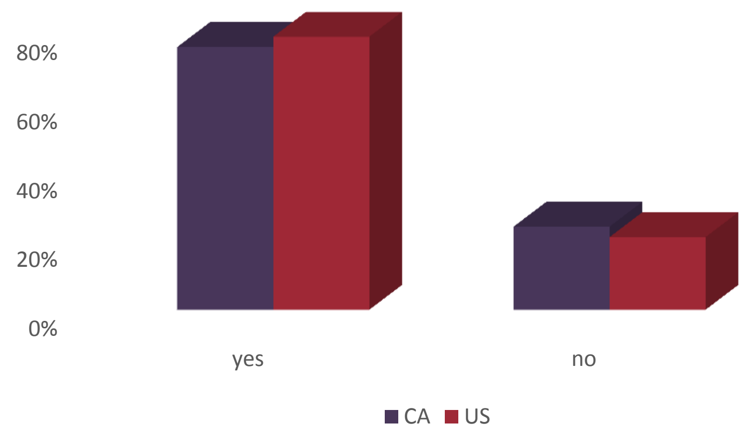
FIGURE 44: CONSIDERATIONS OF ENERGY EFFICIENCY WHEN PURCHASING NEW EQUIPMENT



Although this result makes sense in the context of the other results, it was somewhat unexpected because the lack of an energy efficiency scale for laboratory equipment makes the notion of 'considering energy efficiency' vague. Opportunities to clearly and predictively reduce energy consumption through new equipment purchases rarely exist, and none have been independently verified. Energy efficiency is conspicuously missing from most of the marketing material for laboratory equipment (with the notable exception of freezers, and more recently tissue culture hoods). It would have been interesting to understand which pieces of equipment researchers were purchasing with this in mind, but unfortunately that question was not asked.

Survey respondents were also asked about the influence an ENERGY STAR rating would have on their purchasing decisions. Although ENERGY STAR is not the only energy efficiency standard, it is one of the most well-known.

FIGURE 45: INFLUENCE OF AN ENERGY STAR RATING ON PURCHASING DECISIONS



Clearly an ENERGY STAR rating would have a significant impact on the purchases made by the respondents, regardless of where they are located. This is a critical piece of data – no laboratory equipment is currently ENERGY STAR certified, but these results suggest strongly that equipment should be.

Considering how important energy efficiency appeared to be, scientists were asked how much more they would be willing to pay for a piece of equipment that was energy efficient. They were also asked what premium (if any) they would be willing to pay to reduce their long-term maintenance costs, an often noted side effect of improved energy efficiency. Respondents indicated that they would be willing to pay 10% on average more for a product that would reduce their long-term maintenance costs. By comparison, they would be willing to pay closer to 5% for improved energy efficiency.

The lack of precise energy consumption data renders this question very speculative. Much like the aforementioned facilities managers, individuals will make purchasing decisions based on projected return on investment, and will be willing to pay a greater dollar premium for a piece of equipment that is more efficient than their baseline. Much as it did with household appliances, the roll-out of an ENERGY STAR certification, or other energy efficiency program will take the guesswork out of these calculations and allow buyers to make thoughtful justifications of more expensive purchases in the name of well-defined and predictable future savings.

FIGURE 46: PREMIUM WILLING TO BE PAID FOR REDUCED LONG-TERM MAINTENANCE COSTS

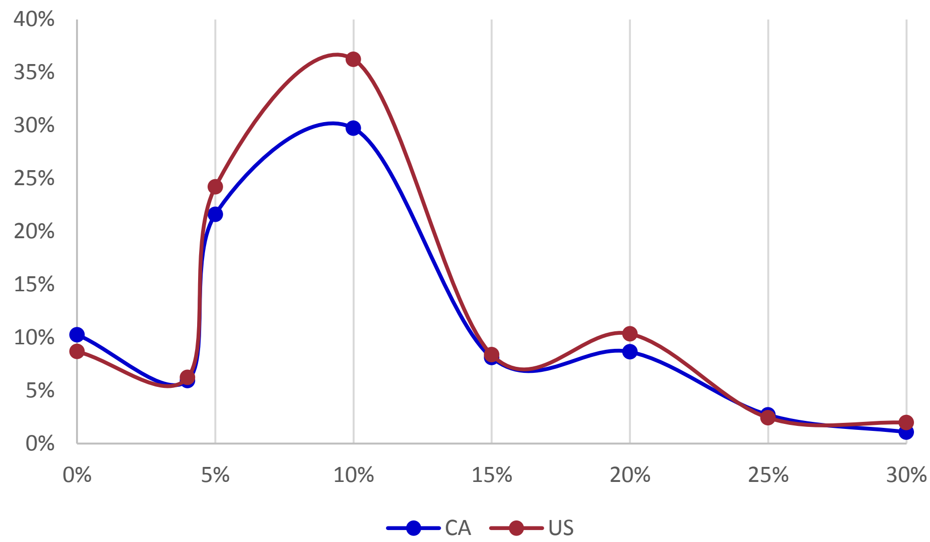
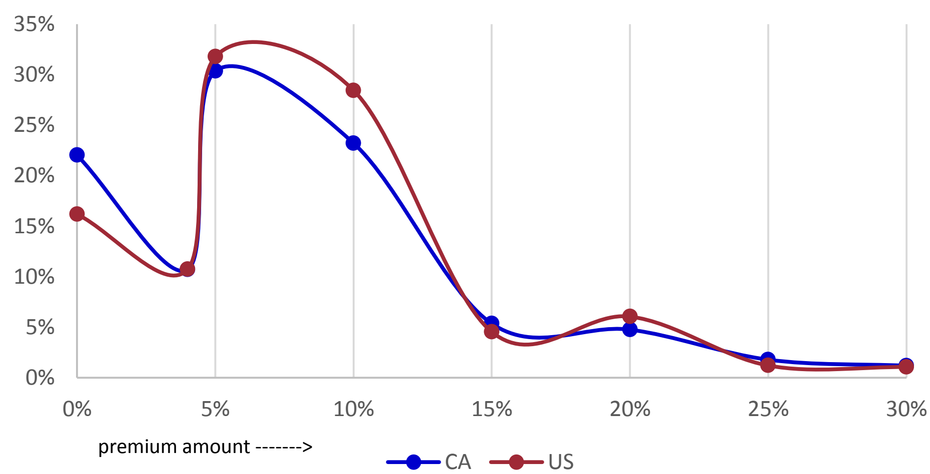
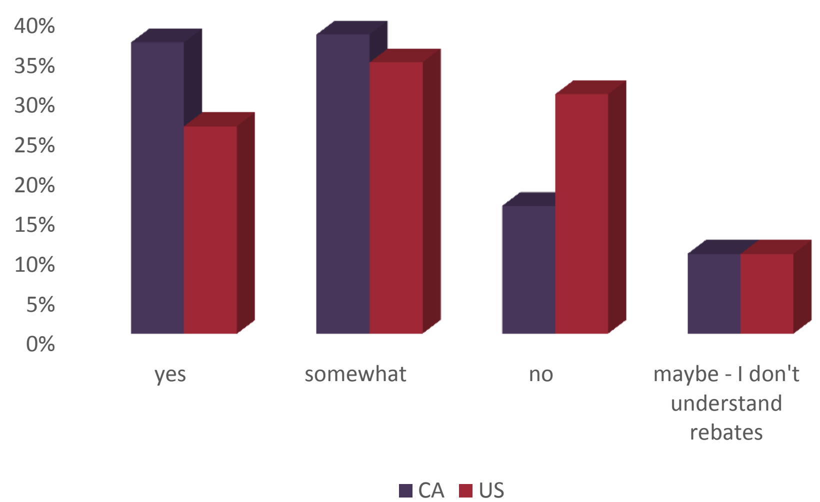


FIGURE 47: PREMIUM WILLING TO BE PAID FOR IMPROVED ENERGY EFFICIENCY



Lack of financial resources is a commonly cited reason for not purchasing more energy-efficient equipment (when there is an option available, of which there are very few). Considering that respondents were willing to pay between 5-10% for improved energy efficiency, which is not enough to cover the costs associated with this, the survey sought to determine whether a financial incentive would be sufficient to motivate scientists to purchase equipment that is more energy-efficient. This question was asked in two different ways – directly in the form of 'Would a rebate from the utility company influence your decision to purchase equipment?' and it was asked indirectly as 'What functions would you like to see the CEEL perform?' (results shown in Table 89). It was deemed insufficient to simply ask about rebates because in most cases a rebate would not go back to the scientist; it would go to the department or institution at which the scientists work. If the scientist does not receive the rebate money, a rebate cannot be considered a financial incentive from his or her perspective. Many respondents pointed this out in the comments section of the survey, saying that they either chose 'no' to the rebate question because they assumed they themselves would not see the money, or that they chose 'yes' to the question, but only if the money were going to be coming back to them. Therefore, it may be more successful to target lab equipment manufacturers and local distributors with an upstream or midstream incentive rather than a downstream rebate/incentive. A summary of the responses is below.

FIGURE 48: IMPACT OF REBATES ON PURCHASING DECISIONS

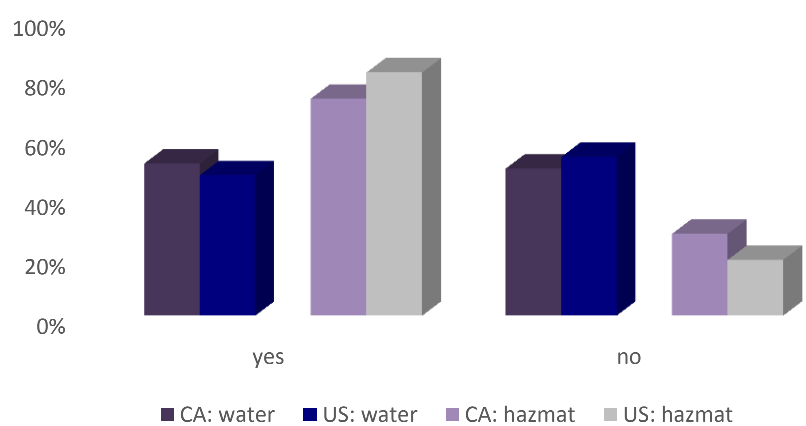


Scientists in California seem to be more likely to be influenced by a rebate than scientists in the rest of the US, although in both cases the percentage of respondents who chose 'yes' or 'somewhat' was at least 60%.

PIs and lab managers exhibited the same trend as the whole data set. Fifty-six percent of them said that rebates would to some extent influence their decision to purchase equipment. Over 10% of respondents chose to write a comment, and over 75% of these comments referenced the inability of the PI or lab manager to claim a rebate. For example, one person wrote, 'If it was an 'instant rebate' that would be much better'. Another said, 'Too hard to get through University system – build it into the price'. Thus, it is likely that the number of people responding positively to a rebate would have been even higher if they were to be the beneficiary of that rebate.

In addition to energy efficiency, respondents also considered water efficiency and the reduction of hazardous materials to be important.

FIGURE 49: CONSIDERATIONS OF WATER EFFICIENCY AND HAZARDOUS MATERIALS WHEN PURCHASING NEW EQUIPMENT



Surprisingly, water efficiency was not given greater priority in California than in other states. And although over 50% of respondents felt that water efficiency was worthy of consideration, more people seemed to prioritize the reduction of hazardous materials in equipment.

Taken together, these data suggest that, contrary to popular belief, scientists and other lab occupants are concerned about sustainability in the lab. These data also point to the fact that while scientists clearly value energy efficiency – they not only responded that it was important to them, but that an ENERGY STAR rating would influence their purchasing decisions – the amount more that they would be willing to pay for that improved energy efficiency is likely not enough to cover the cost differential. This is where rebates or other incentives become necessary to drive action, and respondents qualified that need through their insights on the value of rebates.

In addition to scientists, facility managers were also asked their opinions about the importance of energy efficiency. Of the 163 respondents who answered the question, 71%

said that they consider energy efficiency when purchasing a new product. When asked what ROI they would need to see for improved energy efficiency of a product, 34% required a payback period of 'less than 3 years', 20% said 'less than 5 years', and 18% indicated that they would always purchase a more energy efficient product.

The trends among facility managers matched those seen among the scientists. Energy efficiency is important, and if the cost can be justified with a reasonable investment payback horizon, people will be willing to invest the required capital. The same can be said of water efficiency. The advent of an ENERGY STAR standard, and studies like this one, will go a long way toward providing purchasers with the objective and relative information needed to justify these expenditures.

7.4 INTEREST IN A CENTER FOR ENERGY EFFICIENT LABORATORIES (CEEL)

Respondents were asked about what functions, if any, they would like to see a Center for Energy Efficient Laboratories perform. The results from scientists and non-scientists are compiled in Table 89.

TABLE 89: SUMMARY OF RESPONDENTS' THOUGHTS ON POTENTIAL FUNCTIONS FOR A CEEL

		Total Selections				Response Frequency			
	Survey		Non-Scientists				Non-Scientists		
	Choice	Scientists	California	Other US	Total	Scientists	California	Other US	Total
Provide financial incentives for "greener" lab equipment	A	193	14	45	252	71.7%	73.7%	77.6%	72.8%
Provide low- or no-cost energy and water audits of lab facilities	B	133	13	42	188	49.4%	68.4%	72.4%	54.3%
Provide energy, water, and waste engineering consulting	C	129	11	34	174	48.0%	57.9%	58.6%	50.3%
Training on energy efficiency in the laboratory	D	151	13	46	210	56.1%	68.4%	79.3%	60.7%
Partnerships with manufacturers to improve energy & water efficiency for lab products	E	137	16	43	196	50.9%	84.2%	74.1%	56.6%
Procurement Support	F	89	12	23	124	33.1%	63.2%	39.7%	35.8%
Independent, objective, 3rd-party testing and benchmarking of lab equipment efficiency	G	107	11	39	157	39.8%	57.9%	67.2%	45.4%
Total selections		939	90	272	1,301	n/a	n/a	n/a	n/a
Total respondents		269	19	58	346	n/a	n/a	n/a	n/a
Selections per respondent		**3.49**	**4.74**	**4.69**	**3.76**	**n/a**	**n/a**	**n/a**	**n/a**
Most frequent selection		A	E	D	A	71.7%	84.2%	79.3%	72.8%
Second-most frequent *(in case you people are inclined to pick "A" fist)*		D	A	A	D	56.1%	73.7%	77.6%	60.7%
Least frequent selection		F	G	F	F	33.1%	57.9%	39.7%	35.8%

Note: "Scientists" refer to scientists in California only.

Choice 'A' – the idea that a CEEL would provide financial incentives for 'greener' laboratory equipment – was the most desired function by a significant margin. The rest of the choices were analyzed to determine whether respondents had widespread interest in other functions. In addition, because the most frequently selected response – 'A' – was also the first available, a complete analysis of the data was conducted to ensure that people were not simply choosing 'A' for expediency and moving on to the next questions.

Scientists in California were most interested in financial incentives for 'greener' lab equipment. This is not surprising given their support of a rebate program. Interestingly, more people responded positively to this statement than to the one about rebates, suggesting that direct financial incentives are the motivating factor, not a financial incentive that may be remitted to a department or institution. The second-most frequent selection after 'A' was 'D – training on energy efficiency in the laboratory. Outreach is one of the cornerstones on which the CEEL plans to be built, and it was encouraging to see that this function was nearly as important to scientists as financial incentives. Partnerships with manufacturers to improve energy and water efficiency for laboratory products were also important to scientist respondents. No dependency was found on the financial choices alone. In fact, the most common responses by scientists were, in order, 1) all choices; 2) A; 3) all but F; 4) D; 5) ADE.

Non-scientists had a different opinion of what functions the CEEL should perform. In California, partnerships with manufacturers was considered to be the most important function whereas outside of California, training on energy efficient products was regarded as most desirable. These were both followed by financial incentives for 'greener' lab products. Perhaps not surprisingly, audits also ranked high on both lists. The most frequent selections for non-scientists in California were 1) all choices; 2) AEF; 3) ADEFG; 4) DEFG and 5) ABCDFG. The most frequent selections for non-scientists in California were 1) ABCDEFG; 2) ABCDEG; 3) ABDEG; 4) ABCD and 5) BCDEG.

Importantly, 100% of respondents nationwide answered this question, and not one of them said that they would not be interested in any of the functions described. Thirty-two people also chose to write in additional comments such as, 'It would be great if equipment manufacturers worked toward creating more energy efficient equipment'; 'Let us trade in old equipment with new energy saving equipment without the high cost… Energy savings would have to outweigh the cost of buying new equipment'; 'I think providing information such as reports or research that showed positive results to upper management would help transition labs to better and more efficient systems. Incentives might also help … labs decide sooner… to go green'; and 'Would be happy to use more energy efficient equipment but won't go out of my way to do so, but if better products were available, especially if a bit cheaper (subsidized somehow), then they would be used'.

One respondent said it best when writing, 'Many of these functions are sorely needed'. The market assessment, the survey results, the interview responses, and the energy calculations all point to a clear and immediate need for the CEEL.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

This study represents the largest, most comprehensive investigation into the laboratory research market to date. The results presented here provide support for creating energy efficiency programs specifically targeting laboratory equipment. Not only does this study clearly show that there are tremendous potential energy savings for laboratories, but it also points to several independent efforts by the EPA and individual organizations to identify, and whenever possible incentivize, energy efficient equipment and operations.

Over 116 million square feet of laboratory space were found to exist in California in just the academic, LSR, hospital, and non-profit sectors alone. It is likely that, when accounting for all market segments, laboratory space in California is equivalent to or exceeds the amount of space occupied by the food service industry. In these 116 million square feet were found many different types of equipment, many of which are left on for several hours every day. As a result, the total energy consumption due to plug loads of just the 12 pieces of equipment studied was found to be 0.8 – 3.2 TWh/year. This is a significant amount of energy; it equates to nearly 1% of the annual energy usage in California's commercial buildings. A summary of the findings is presented below in Table 90:

TABLE 90: SUMMARY OF FINDINGS

CALIFORNIA LAB EQUIPMENT ESTIMATES	EQUIPMENT DENSITY (UNITS/LAB)	EST. NUMBER OF PIECES OF EQUIPMENT	EST. ENERGY CONSUMPTION (GWH/YR)
-80°C Freezer	2.9	58,000	228 – 648
-20°C Freezer	3.7	74,000	126 – 363
Refrigerator	3.7	95,000	19 – 254
Fume Hood*	3.0	60,000	661 – 1322
Fluo Micro	1.7	34,000	6 – 12
Centrifuge	3.8	76,000	12 – 227
Water Bath	2.6	52,000	115 – 201
Heat Block	3.0	60,000	15
PCR Machine	2.2	44,000	35
Incubator	3.0	60,000	41 – 524
Shaker	1.2	24,000	53
Autoclave	0.8	16,000	26 – 527
Vac Pump	2.1	42,000	1 – 115
TC Hood	1.7	34,000	106 – 235

* HVAC electricity consumption due to fume hoods

This study's results of lab equipment loads also provide a vital piece of information to establish typical space conditioning requirements. A holistic approach to the lab environment, including equipment selection, occupant behavior, exposure control, and HVAC operations and maintenance, will be required to fully optimize facility energy efficiency. A major goal of the CEEL is to investigate the interplay of these factors to systematically understand and remove the obstacles to energy savings in laboratories.

Although California has the highest density of laboratories in the country, the actual number of laboratories, their distribution, size, type, energy consumption, plug loads, and other key attributes has not been quantified. This fact alone poses a tremendous opportunity to study the electrical loads of laboratories, the quantity and types of equipment, and the energy use of these individual units. Of the 13 pieces of equipment for which energy data existed, laboratory refrigeration and fume hoods, which have been studied extensively, emerged as clear opportunities for energy savings. However, of the 32 pieces of equipment included in this study, 18 equipment types still require further study into their energy consumption—both at the lab level and in California as a whole. Further study of these units will allow for a more accurate quantification of the energy impacts of individual lab equipment, and ultimately lead to a better estimate of the energy intensity of laboratories in California.

For example, although water baths may not consume as much energy as a freezer, and thus do not reflect as high an energy impact per unit, the cumulative energy use and larger quantities of water baths found in labs when compared with freezers could suggest greater total energy savings through innovative design changes. Perhaps an energy-efficient water bath with an automatic shut-off mechanism would result in more savings than an energy-efficient freezer. Further study of these units will allow for a more accurate quantification of the energy impacts of individual lab equipment, and ultimately lead to a better estimate of the energy intensity of laboratories in California.

Operators generally purchase the equipment used in their individual labs. This study has shown that most scientists have an interest in considering energy efficiency as a purchasing factor when choosing laboratory equipment. However, there are currently no objective data on which to base their decisions, much less a mechanism to provide that data to the operator. This lack of objective data gained through standardized test procedures and third-party testing facilities, as well the lack of effective outreach programs to operators, facility managers, and even the account managers, have made it difficult to establish the true energy costs of inefficient laboratory equipment. This situation is similar to that which was seen in data centers more than a decade ago; if energy efficiency is not a feature requested by purchasers, manufacturers will not make it a priority, and building designers will not factor it into their new building designs. Although there have been isolated instances in which vendors have promoted energy consumption—ultra-low temperature freezer manufacturers have started marketing their products as 'energy efficient', for example—these manufacturers have been unable to provide objective data to support their claims.

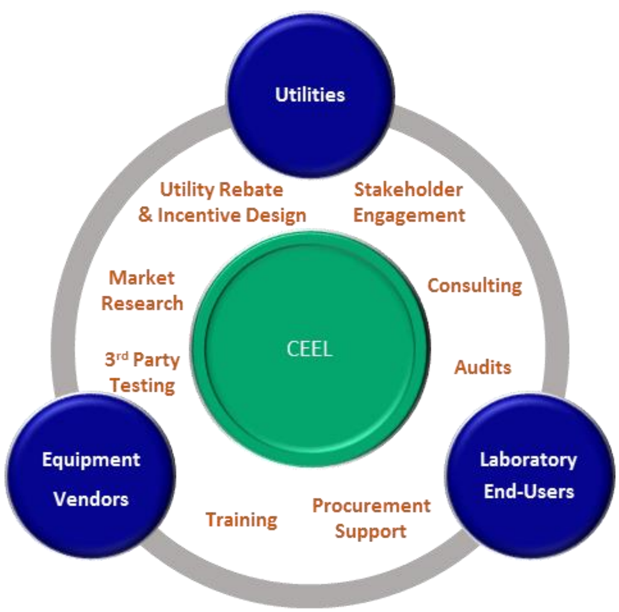
Interviews with facility managers and laboratory personnel reinforced the need for outreach, and perhaps outreach training of account managers. Moreover, existing deemed and calculated program offerings are not reaching the laboratory market segment. Once a baseline of energy consumption is established, and laboratory equipment tested against that baseline, these programs would provide objective information to both the utilities and the laboratory equipment market. Through these targeted efforts, account managers would have the information needed to help educate their customers on incentives in their area, equipment purchasers would be educated on how energy-efficient equipment could reduce costs in their facilities, and dealers and manufacturers would continue to be updated on the incentives that are available on their equipment in respective utility territories.

Additionally, the interviews conducted in this study suggest that there is a pervasive disconnect between the facility managers who design the lab and pay the utility bills and the operators who specify the equipment. Without visibility into the energy bills, operators have no insight into the recurring costs of their equipment. And without the knowledge of what equipment the operators are specifying, facility managers will not be able to optimally design the facilities where the equipment will be installed. This disconnect between facility managers and operators, the lack of awareness to specify energy-efficient equipment by laboratory procurement departments, and the lack of motivation by manufacturers and their respective distribution channels to promote energy-efficient products could all be addressed through a series of targeted outreach programs.

This market study uncovered many additional opportunities for the IOUs to provide assistance through their energy efficiency programs. Given some of the interview responses, establishing periodic reviews of the effectiveness of energy-efficiency programs through key performance indicators would provide a true indication of how the CEEL is impacting the laboratory equipment market. Best practices should be developed, which would continue to enhance the program. Finally, coordinating a steering committee made up of equipment manufacturers, key decision makers (scientists, facility managers, procurement specialists), and utility companies would provide energy efficiency recommendations as well as program feedback and guidance—something that would be especially useful at this early phase.

The work done in this study supports the need for a coordinated, fully-integrated approach to energy efficiency in laboratories, incorporating not only equipment testing but also laboratory facility audits, outreach, financial incentives, and stakeholder engagement. A concerted, comprehensive approach to laboratory equipment and operations should be taken, and existing efforts centralized and streamlined. Figure 50 outlines the proposed functions of such an effort, the CEEL. The efficacy of this model has been proven in the food service industry with PG&E's Food Service Technology Center (FSTC), which has been providing a similar holistic approach to addressing energy efficiency in the food service industry for over 27 years. Two of these functions – market research (in the form of this report) and stakeholder engagement – have already been implemented.

FIGURE 50: THE PROPOSED FUNCTIONS OF THE CENTER FOR ENERGY EFFICIENT LABORATORIES



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APPENDIX I: LABORATORY EQUIPMENT & FACILITIES SURVEY

Laboratory Equipment and Facilities Survey

We all know laboratories consume a lot of energy and water. Our organization wants to decrease lab-related energy and water consumption and operating expenses. Please help us better understand the type of equipment used in your lab and what opportunities you see for energy and water efficiency. Your input is invaluable – you are the only one who knows how your lab operates, and your insights into how it might operate more efficiently will allow us to develop financial incentives and services to help you do so. Thank you in advance for your time!

*** 1. What best describes your role in your organization?**

- Principal Investigator (PI)
- Lab Manager
- Staff scientist/postdoc/grad student/undergrad/other lab member
- Building/Facilities Manager
- Sustainability Director
- EHS
- Other, non-scientist (please specify)

Laboratory Equipment and Facilities Survey

General Info

Please note that all of your responses will remain CONFIDENTIAL. We request the name and location of your organization simply so that we can analyze the data by market segment and region.

2. What is the name of your organization?

***3. Where are you located?**

City/Town:

State:

ZIP:

4. Please note the surname of your PI (information not required, requested only to prevent duplicates)

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Laboratory Equipment and Facilities Survey

***5. Which of the following best classifies the research done in your lab?**

- Biology
- Biochemistry
- Biomedical Engineering
- Cell Biology
- Chemistry
- Computational
- Engineering
- Forensics
- Marine Biology
- Molecular Biology
- Neuroscience
- Pathology
- Plant Biology
- Physics
- Systems Biology
- Testing
- Other (please specify)

***6. Assuming NO compromise in performance, how important is it to you to have equipment that is**

	1 (not important)	2	3	4	5 (important)
energy efficient?					
water efficient?					
free of any/all hazardous materials that cannot be readily recycled or disposed of?					

7. What pieces of equipment would you like to replace with a more energy efficient version?

Laboratory Equipment and Facilities Survey

***8. Would a rebate from the utility company influence your decision to purchase equipment?**

- Yes
- No
- Somewhat
- Maybe - I don't understand rebates

Other (please specify)

9. Do peak demand rates affect when you operate lab equipment?

- Yes
- No
- I think about it sometimes
- I don't know

10. Have you ever received training in laboratory sustainability?

- Yes, within the past 2 years
- Yes, >2 years ago
- No
- I'm not sure

11. If you answered 'yes' to the question above, was it effective?

- Yes
- Somewhat
- No

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Laboratory Equipment and Facilities Survey

***12. If a Center for Sustainable Laboratories were to exist, which of the following functions would you like to see it perform?**

- ☐ Provide financial incentives for "greener" lab equipment
- ☐ Provide low- or no-cost energy and water audits of lab facilities
- ☐ Provide energy, water, and waste engineering consulting
- ☐ Training on energy efficiency in the laboratory
- ☐ Partnerships with manufacturers to improve energy and water efficiency for laboratory products
- ☐ Procurement Support
- ☐ Independent, objective, 3rd-party testing and benchmarking of laboratory equipment efficiency

Other (please specify)

Laboratory Equipment and Facilities Survey

Laboratory Equipment

Below are several types of equipment commonly found in laboratories.
In the first section, please indicate the number of each in operation in your lab.
In the second section, please indicate the number of hours/day the equipment is in operation.

*13. REFRIGERATION

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
-80 freezer	○	○	○	○	○	○	○	○	○	○	○
-20 freezer	○	○	○	○	○	○	○	○	○	○	○
refrigerator	○	○	○	○	○	○	○	○	○	○	○

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Laboratory Equipment and Facilities Survey

Laboratory Equipment

* 14. FUME HOODS

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
total number of fume hoods	○	○	○	○	○	○	○	○	○	○	○
variable air volume fume hoods	○	○	○	○	○	○	○	○	○	○	○

15. For how many hours/day do you operate this equipment (i.e. how many hours/day are you in the hood)?

	0	1-3	4-7	9-10	11-23	24
fume hoods (total)	○	○	○	○	○	○
variable air volume fume hood	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

Laboratory Equipment

16. MICROSCOPES

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
fluorescence microscopes	○	○	○	○	○	○	○	○	○	○	○
confocal microscopes	○	○	○	○	○	○	○	○	○	○	○
electron microscopes	○	○	○	○	○	○	○	○	○	○	○

17. For how many hours/day is this equipment in operation? If your lab has more than one of each type, please indicate the approximate average usage.

	0	1-3	4-7	8-10	11-23	24
fluorescence microscope	○	○	○	○	○	○
confocal microscope	○	○	○	○	○	○
electron microscope	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

Laboratory Equipment

18. BENCHTOP EQUIPMENT

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
heating block	○	○	○	○	○	○	○	○	○	○	○
water bath	○	○	○	○	○	○	○	○	○	○	○
centrifuge	○	○	○	○	○	○	○	○	○	○	○
PCR machine	○	○	○	○	○	○	○	○	○	○	○
magnetic stir plate	○	○	○	○	○	○	○	○	○	○	○
vacuum pump	○	○	○	○	○	○	○	○	○	○	○
water distiller	○	○	○	○	○	○	○	○	○	○	○

19. For how many hours/day is this equipment in operation? If your lab has more than one of each type, please indicate the approximate average usage.

	0	1-3	4-7	8-10	11-23	24
heating block	○	○	○	○	○	○
water bath	○	○	○	○	○	○
centrifuge	○	○	○	○	○	○
PCR machine	○	○	○	○	○	○
magnetic stir plate	○	○	○	○	○	○
vacuum pump	○	○	○	○	○	○
water distiller	○	○	○	○	○	○

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Laboratory Equipment and Facilities Survey

Laboratory Equipment

20. LARGE LABORATORY EQUIPMENT

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
shaker table	○	○	○	○	○	○	○	○	○	○	○
autoclave	○	○	○	○	○	○	○	○	○	○	○
gas laser	○	○	○	○	○	○	○	○	○	○	○
qPCR machine	○	○	○	○	○	○	○	○	○	○	○
NMR	○	○	○	○	○	○	○	○	○	○	○
mass spectrometer	○	○	○	○	○	○	○	○	○	○	○
gas chromatograph	○	○	○	○	○	○	○	○	○	○	○
HPLC	○	○	○	○	○	○	○	○	○	○	○
FACS	○	○	○	○	○	○	○	○	○	○	○
incubator	○	○	○	○	○	○	○	○	○	○	○
tissue culture hood	○	○	○	○	○	○	○	○	○	○	○
sonicator	○	○	○	○	○	○	○	○	○	○	○
vacuum chamber	○	○	○	○	○	○	○	○	○	○	○
air table	○	○	○	○	○	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

21. For how many hours/day is this equipment in operation? If your lab has more than one of each type, please indicate the approximate average usage.

	0	1-3	4-7	8-10	11-23	24
shaker table	○	○	○	○	○	○
autoclave	○	○	○	○	○	○
gas lasers	○	○	○	○	○	○
qPCR machine	○	○	○	○	○	○
NMR	○	○	○	○	○	○
mass spectrometer	○	○	○	○	○	○
gas chromatograph	○	○	○	○	○	○
HPLC	○	○	○	○	○	○
FACS	○	○	○	○	○	○
incubator	○	○	○	○	○	○
tissue culture hood	○	○	○	○	○	○
sonicator	○	○	○	○	○	○
vacuum chamber	○	○	○	○	○	○
air table	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

Laboratory Equipment

22. HOSPITAL EQUIPMENT

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
MRI	○	○	○	○	○	○	○	○	○	○	○
CT scan	○	○	○	○	○	○	○	○	○	○	○
x-ray machine	○	○	○	○	○	○	○	○	○	○	○

23. For how many hours/day is this equipment in operation? If your lab has more than one of each type, please indicate the approximate average usage.

	0	1-3	4-7	8-10	11-23	24
MRI	○	○	○	○	○	○
CT scan	○	○	○	○	○	○
x-ray machine	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

Laboratory Equipment

24. ENVIRONMENTAL ROOMS

How many of these are in operation in your lab?

	0	1	2	3	4	5	6	7	8	9	10+
warm room	○	○	○	○	○	○	○	○	○	○	○
cold room	○	○	○	○	○	○	○	○	○	○	○

Laboratory Equipment and Facilities Survey

Purchasing Considerations

25. What new equipment do you foresee having to purchase in the next 3 years?

***26. Do you consider energy efficiency when purchasing new equipment?**

- Yes
- No

***27. Would an energy efficiency rating, such as Energy Star, influence your decision to purchase a product?**

- Yes
- No

***28. Do you consider water efficiency when purchasing a new product for the lab?**

- Yes
- No

29. When purchasing a new product, you consider whether it contains hazardous materials?

- Yes
- No

30. To reduce my long-term maintenance costs, I would be willing to pay a premium of (%):

31. For improved energy efficiency of a product, I would be willing to pay a premium of (%):

32. For a less-hazardous version of a product, I would be willing to pay a premium of (%):

33. For improved water efficiency of a product, I would be willing to pay a premium of (%):

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Laboratory Equipment and Facilities Survey

34. For a reduction in experimental costs (e.g. less reagents used, takes less time), I would be willing to pay a premium of (%):

Laboratory Equipment and Facilities Survey

General Lab Information

35. How many people work in your lab?

36. In the last 3 years, the number of people working in the lab has

- increased
- decreased
- stayed the same

37. What is the estimated square footage of your lab space? If you don't know please write 'I don't know'.

***38. In the last 3 years, the square footage of the lab space has**

- increased
- decreased
- stayed the same

If you chose increased or decreased, by how much? (%)

Laboratory Equipment and Facilities Survey

General Info

*39. What is the name of your organization and where are you located (city and state)? This information is necessary for us to segment the data properly; it will not be used for any other purpose.**

40. Does your organization have ... (check all that apply)?

- ☐ Fume Hoods
- ☐ Microscopes
- ☐ Centrifuges
- ☐ Ultra-low Temperature Freezers (-20 or -80)
- ☐ Autoclaves
- ☐ On-Site Distilled Water
- ☐ X-ray Machines
- ☐ Lasers

Other Laboratory Equipment (please specify)

*41. Do you have any spaces that you consider to be laboratories?**

- ○ Yes
- ○ No

42. If you answered yes above, how many of them are there? Please try to be as accurate as possible.

43. If you answered yes to #4, what percentage of your space do laboratories occupy?

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Laboratory Equipment and Facilities Survey

44. Would you be interested in a utility-sponsored program for ... (check all that apply)?

- ☐ Energy Efficiency
- ☐ Water Efficiency
- ☐ Waste Reduction
- ☐ Hazardous Chemicals/Materials Reduction
- ☐ None of the Above

If you chose 'none of the above', what ype of program would interest you?

***45. Is your facility already enrolled in a utility-sponsored energy efficiency program?**

- ○ Yes
- ○ No
- ○ I don't know

46. Is your facility LEED certified or are you interested in LEED certification?

- ○ Yes
- ○ No
- ○ I don't know

47. Is your facility Energy Star certified or are you interested in Energy Star certification?

- ○ Yes
- ○ No
- ○ I don't know

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Laboratory Equipment and Facilities Survey

***48. If a Center for Sustainable Laboratories were to exist, which of the following functions would you like to see it perform?**

- ☐ Provide financial incentives for 'greener' lab equipment
- ☐ Provide low- or no-cost energy and water audits of lab facilities
- ☐ Provide energy, water, and waste engineering consulting
- ☐ Training on energy efficiency in the lab
- ☐ Partnerships with manufacturers to improve energy and water efficiency for lab products
- ☐ Procurement Support
- ☐ Independent, objective, 3rd-party testing and benchmarking of lab equipment efficiency

Other (please specify)

Laboratory Equipment and Facilities Survey

Facility Overview

*49. What is the approximate total square footage of the laboratories at your organization? Please indicate whether the number you are writing is for the entire institution, several buildings, a single building, etc.

50. In the past 3 years, the total square footage of laboratory space at your organization has

- increased
- decreased
- stayed the same

If you selected increased or decreased please indicate by what percentage, and why it has changed:

*51. In the next 3 years, the total square footage of laboratory space at your organization is expected to

- increase
- decrease
- stay the same

If you selected increased or decreased please indicate by what percentage, and why you think it will change:

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Laboratory Equipment and Facilities Survey

Laboratory Operations

52. Do you have the following utilities in operation at your organization?

	Yes	No
compressed air	◯	◯
distilled water	◯	◯
gas storage	◯	◯
vacuum system	◯	◯
supplied gas	◯	◯
process chilled water	◯	◯
supplied ultra-pure water	◯	◯
dry solvent delivery system	◯	◯
point source exhaust system	◯	◯

Please indicate the scope of the information provided above (e.g. for a single department or one building)

***53. What type of HVAC system do you use in your laboratories?**

54. What are the normal occupied hours of your laboratories?

55. Do you adjust the temperature in your laboratories when they are unoccupied?

◯ Yes

◯ No

***56. Can you vary the flow rates of your HVAC system?**

◯ Yes

◯ No

57. If yes, do you reduce ventilation flow to laboratory spaces when they are unoccupied?

◯ Yes

◯ No

Laboratory Equipment and Facilities Survey

Laboratory Equipment

58. How many of the following pieces of equipment are in operation at your organization?

-80 freezers	
-20 freezers	
fume hoods (total)	
VAV fume hoods	
autoclaves	

Laboratory Equipment and Facilities Survey

Purchasing Considerations

***59. Does your institution measure and set targets for energy consumption, greenhouse gas emissions, water consumption, and waste generation?**

- Yes, for all of the above
- Yes, for some of the above
- No

60. Are you compensated for saving energy for your organization?

- Yes
- No

61. Would you consider enrolling your facility in an incentive program?

- Yes
- No
- I do not have the authority to make that decision
- Our facility is already enrolled

***62. Do you consider energy efficiency when purchasing a new product?**

- Yes
- No

63. For improved energy efficiency of a product, I would want to see a return-on-investment of:

- 1 year
- <3 years
- <5 years
- <7 years
- I would always purchase a more energy efficient product.
- I would not be willing to pay a premium for energy efficiency.

Laboratory Equipment and Facilities Survey

64. In your estimation, what is your energy consumption relative to other facilities?

- Our facility is more energy efficient
- We are on par with comparable facilities
- Our facility is less energy efficient

65. Would you be interested in a LEED-for-labs program?

- Yes
- No
- I don't know what this is

66. Would you be interested in an Energy Star for labs program?

- Yes
- No
- I don't know what this is

Laboratory Equipment and Facilities Survey

Thank you!

The information you provided above is invaluable - your contribution will affect the future of how we manage our resources in our labs. Thank you so much for your time! If you have friends and colleagues who might also be able to help, please forward them the link to this survey.

67. So that we may publicly thank you for your contribution, what is your name?

68. What is your zip code?

69. If you would like to be entered into the drawing for a MacBook Air - drawing to take place in Jan 2015 - please provide us with your name, email address, and phone number below. All responses will remain confidential.

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APPENDIX II: PAPER SURVEY

paper survey

1. What is the name of your organization?

2. Name of PI

3. Type of research done in the lab

4. How many of the following pieces of equipment are in your lab

	0	1	2	3	4	5	6	7	8	9	10-15	15+
fume hoods												
-20												
-80												
x-ray												
incubators												
microscopes												
lasers												
centrifuges (rt)												
centrifuges (4)												
amplifiers												
distilled water												
water baths												
autoclaves												
shakes												
other												

Other (please specify)

5. Assuming NO compromise in performance, how important is it to you

	5	4	3	2	1
Energy Efficient					
Water Efficient					
Free of Hazardous Materials					

paper survey

6. Which pieces of equipment would you like to replace with a more energy efficient model?

7. What is the approx sq ft of the lab?

8. In the next 3 yrs the sq ft of the lab is expected to

- increase
- decrease
- stay the same

9. Would a rebate for energy influence your decision?

- Yes
- No
- Somewhat
- Maybe-I don't understand rebates

10. Do peak demand electricity rates affect when you operate lab equipment?

- Yes
- No
- I think about it sometimes
- I don't know what this is

11. Have you ever received training in lab sustainability?

- Yes, within past 2 yrs
- Yes, more than 2 yrs ago
- No
- I'm not sure

12. If you answered 'yes' to question above, was it effective?

- Yes
- Somewhat
- No

paper survey

13. If a Center were to exist...

- Provide financial incentives for greener lab equipment
- Provide low- or no-cost energy and water audits of lab facilities
- Provide energy, water, and waste engineering consulting
- Training on energy and water efficiency in the lab
- Procurement support
- Partnerships w manufacturers to improve energy and water efficiency for lab products
- Ind, obj, 3rd party testing

Other (please specify)

APPENDIX III: ESTIMATING PLUG LOAD CONSUMPTION – ALTERNATIVE METHOD

Respondents reported the total number of people in their labs, and those data were used to determine the total square footage of lab space using the standard of three people per 1000 sq ft of lab space. The total derived square footage was then organized according to size: ≤ 1000 sq ft, 1000 > 2000, 2000 ≥ 5000, 5000 > 10000, ≥ 10000. Each size was assigned a weight according to the number of labs with that square footage. The total estimated square footage of the market segment was then multiplied by the weighted values, and divided by the estimated square footage per lab in that size group. For example, the LSR market was determined to have 68.3 million sq ft of lab space. In this market segment, 16% of labs had <1000 sq ft, 23% of labs had 1001-2000 sq ft, 36% of labs had between 2001-5000 sq ft of space, 16% of labs had 5001-10000 sq ft, and 8% of labs had over 10,000 sq ft of lab space. The total LSR square footage was then broken down according to these percentages, i.e. 11.2 million sq ft was attributable to labs having square footage less than 1000. This square footage was subsequently divided by the average laboratory space in its size category, i.e. 1000 sq ft in the example above, in order to determine the number of laboratories in that size category. For example, it was determined that there are 11,200 labs in the LSR market in California that are less than 1000 sq ft. Table 91 shows the derivation for the life science research sector.

TABLE 91: NUMBER OF LABORATORIES IN THE LSR MARKET IN CALIFORNIA, DERIVED FROM THE NUMBER OF PEOPLE WORKING IN THE LAB

	[A]	[B]	[C]	[D]	[E]
	Number of Labs from Data Set	Represented as a Percentage	Related To Total Sq Ft =68,382,479*B	Divide By Average Sq Ft For Number Of Labs = C/sq ft	Number Of Labs Statewide = D
333-1000 sq ft	28	16%	11,200,000	11,200	11,200
1001-2000 sq ft	40	24%	16,000,000	8,000	8,000
2001-5000 sq ft	61	36%	24,000,000	4,900	4,900
5001-10000 sq ft	28	16%	11,200,000	1,000	1,000
>10000 sq ft	14	8%	5,600,000	280	280
Total	**171**	**100%**	**68,000,000**		**25,500**

TABLE 92: NUMBER OF LABORATORIES IN ACADEMIA IN CALIFORNIA, DERIVED FROM THE NUMBER OF PEOPLE WORKING IN THE LAB

	[A] Number Of Labs From Data Set	[B] Represented As A Percentage	[C] Related To Total Sq Ft =24,741,675*B	[D] Divide By Average Sq Ft For Lab Size = C/Sq Ft	[E] Number Of Labs Statewide = D
333-1000 sq ft	85	15%	3,700,000	4,700	4,700
1001-2000 sq ft	210	37%	9,000,000	5,500	5,500
2001-5000 sq ft	216	38%	9,500,000	2,900	2,900
5001-10000 sq ft	40	7%	1,800,000	240	240
>10000 sq ft	11	3%	500,000	25	25
Total	**551**	**100%**	**24,700,000**		**13,000**

TABLE 93: NUMBER OF LABORATORIES IN THE NON-PROFIT SECTOR IN CALIFORNIA, DERIVED FROM THE NUMBER OF PEOPLE WORKING IN THE LAB

	[A] Number Of Labs From Data Set	[B] Represented As A Percentage	[C] Related To Total Sq Ft =3,073,900*B	[D] Divide By Average Sq Ft For Lab Size = C/Sq Ft	[E] Number Of Labs Statewide = D
333-1000 sq ft	46	25%	770,000	900	900
1001-2000 sq ft	47	25%	770,000	500	500
2001-5000 sq ft	51	26%	800,000	200	200
5001-10000 sq ft	27	14%	430,000	50	50
>10000 sq ft	19	10%	310,000	20	20
Total	**190**	**100%**	**3,100,000**		**1,600**

A statistically significant sample size for the hospital market was not collected so the average, non-weighted square footage of lab space was used to derive the number of labs – 2,300 sq ft per lab; 3,400 hospital laboratories in California. This resulted in a total number of 44,000 labs in California.

The number of labs derived from this method was then used to calculate the total number of pieces of equipment in California. A weighted average of the equipment counts was used as the multiplier. The results are shown in Table 94.

Table 94: Estimated Total Numbers of Laboratory Equipment in California, Derived from the Number of People Working in the Lab

	Estimated Weighted Avg, Number Per Lab	Total Number In CA
-80°C Freezer	2.1	92,000
-20°C Freezer	3.2	141,000
Refrigerator	3.9	171,000
Fume Hood	2.8	123,000
Fluo Microscopes	0.9	41,000
Heating Block	2.5	110,000
Water Bath	2.3	101,000
Centrifuge	3.4	149,000
PCR Machine	2.0	88,000
Magnetic Stir Plate	3.1	136,000
Vacuum Pump	1.9	84,000
Shaker Table	1.1	48,000
Autoclave	0.8	36,000
Incubator	2.9	128,000
Tissue Culture	1.4	62,000

Table 95: Estimated Energy Consumption of Laboratory Equipment in California using Alternative Method

	Est Number of Pieces of Equipment	Est Annual Energy Consumption (GWh, Lower)	Est Annual Energy Consumption (GWh, Higher)
-80°C Freezer	92,000	370	1020
-20°C Freezer	140,000	240	686
Refrigerator	170,000	34	460
Fume Hood	120,000	1800	2700
Fluo Microscope	40,000	8.0	15
Centrifuge	110,000	18	330
Water Bath	100,000	220	390
Heating Block	150,000	36	
PCR Machine	90,000	70	
Incubator	80,000	57	730
Shaker	50,000	110	
Autoclave	36,000	61	1200
Vacuum Pump	130,000	4.2	350
Tissue Culture Hood	62,000	192	420

These values were deemed to be too high based on what was already known about plug loads and energy consumption in laboratories. A more thorough analysis of this can be found in Appendix IV.

APPENDIX IV: CONFIRMING RESULTS AGAINST KNOWN CALIFORNIA MARKETS

In this section we briefly assess this study's results in relation to the overall population of commercial buildings in California. The findings are summarized in Table 96 and are described in more detail below.

TABLE 96: MARKET SUMMARY

	AREA (SQ FT)	WHOLE BUILDING USAGE (KWH/YR)	PLUG LOAD USAGE (KWH/YR)	
All CA commercial real estate	7 billion	100 billion	14 billion	
Labs in CA	116 million (1)	9 billion (2)	Total	Surveyed
			1.5 billion (3)	0.8 billion (4)
% in Labs	1.6%	9%	11%	6%

1. Net lab area from this study
2. Gross lab building consumption, assuming 50% net-to-gross lab area ratio; kWh/sf/yr from Labs21 Benchmarking database
3. Plug load kWh/sf/yr from UC Irvine and UC Davis studies and from Labs21 database
4. Surveyed equipment from this study

Total lab building area in the US

The Federal government regularly publishes data on its facilities. Approximately 177 million square feet of laboratory buildings (9,851 buildings) are owned or leased by the government[1]. Data on other market sectors are less readily available. An oft-quoted estimate of total lab building area in the US (source unknown) is 1 billion sq ft. A conservative estimate is that there is 659 million sq ft of lab space spread across 9,000 facilities in the US. The total net lab area of 116 million sq ft derived in this study represents a significant fraction of this conservative estimate, but does not appear to be out of line with more generous estimates.

California commercial building market size

California contains approximately 7 billion sq ft of commercial real estate, consuming a total of approximately 100 billion kWh/yr of electricity[2]. The total net lab space derived in this

[1] GSA (2012): http://www.gsa.gov/portal/mediaId/179655/fileName/FY_2012_FRPP_intro_508.action
Next 10 (2010), 'Untapped Potential of Commercial Building Energy Use and Emissions'.

study corresponds to approximately 1.7% of California's commercial real estate space. Assuming a typical net-to-gross area ratio of 50%, lab buildings would then constitute around 3.5% of commercial real estate by area.

Total energy used by lab buildings

The Labs21 Benchmarking Tool, a free online utility, draws upon the largest available database of lab facility energy consumption (approximately 100 million sq ft over 570 peer-group buildings) to produce statistics on lab energy use intensity. The average lab building electrical consumption (on which a significant pool of data is available) is 38 kWh/sf/yr; this number does not vary significantly with climate zone. Using the derived total lab building area of 230 million sf in CA, the total electrical consumption of lab buildings would then be 9 billion kWh/yr, i.e. 9% of total commercial building electricity usage.

Total energy used by lab equipment

The results of the 2006 California Commercial End Use Survey (CEUS) indicate that plug loads (the sum of office equipment, miscellaneous equipment, and process equipment categories) in commercial buildings consume around 14 billion kWh/yr[3].

The Labs21 database contains only limited submetering data on plug load energy usage. Based on the available data, the average plug load consumption is 12 kWh/sf/yr. Assuming that 75% of the plug load usage occurs in lab spaces and using the total lab building area of 230 million sq ft, lab plug load usage in CA is expected to amount to 2.1 billion kWh/yr.

Plug load studies at UC Irvine and UC Davis have revealed that lab equipment loads are significantly lower than design estimates (due to diversity in equipment use). The UC Irvine data indicate an average over lab and lab support spaces of approximately 13 kWh/sf/yr; the UC Davis numbers are in broad agreement with this finding. Plug load energy consumption in California's labs would then be expected to be around 1.5 billion kWh/yr.

Based on the available data prior to this study, the *expected* total lab plug load energy consumption is therefore 1.5-2.1 billion kWh/yr (1.5-2.1% of the total CA electrical consumption and 11-15% of total CA plug load energy consumption).

The results of the survey indicate that the electrical usage by the specific pieces of lab equipment on which respondents were polled amounts to 0.8-3.2 billion kWh/yr (excluding HVAC energy consumption as a result of fume hood use). Assuming that these equipment types amount to half of the total, the low end of the survey results are consistent with expectations for the lab population. As discussed elsewhere, the higher end of the estimated range is not expected to apply because most lab equipment is not used at its maximum capacity.

Discussion

This study represents the first attempt to understand the energy consumed by specific types of laboratory equipment. The results are broadly consistent with other available data on the

[3] Itron, Inc (2006), 'California Commercial End-Use Survey Results'.

population of labs and their plug load energy consumption. The market size for lab plug loads is substantial, amounting to perhaps 2% of total commercial building electrical energy consumption in California. Significant uncertainties remain, particularly in the energy consumed by various classes of lab equipment when used under typical conditions in the field and under standardized testing conditions; these topics will be the focus of future efforts of the CEEL.

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Rochelle Owen
Rocio Banos
Rodello
Rodney Arcenas
Rodney Mauricio
Rosa Ye
Roy Morello
Russell Li

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S. McClain
S. Sigmann
S.C. Long
Sam Pinto
Samantha Wong
Samar Rezq
Samuel Grant
Samuel Huber
Sandeep Sharma
Sandra Calderon
Sandra Diaz
Sandy
Sankar Swaminathan
Sarah Clark
Sarah Gullett
Sarah Joyce
Sarah Millonig
Sarah Schmeltzer
Sarah Southcott
Sasha Rose
Satomi
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Scott Luaders
Scott Wolfe
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Seth Levin
Seth Sharp
Shan Zhao
Shane Morgan
Shannn Daniels
Shannon
Shannon L. Horn
Shannon Maynard
Shanti
Sharena Rice
Sharon Rasmussen
Sheila Judge
Sheila Lockwood
Sheldon
Sheila Pittman
Shelly Carpenter
Sheryl Horstman
Shirley Pan
Shyue-An Chan
Sierra Simpson
Silke Nock
Silvia Jenni
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Siu-Pok Yee
Siv Watkins
SK Nooti
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Sollo Kamanga-Sollo
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Sommer
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Stephanie Dotson
Stephanie Greene
Stephanie Shopbell
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Stephen Geogre
Stephen Ramey
Steve Erdody
Steven Cooper
Steven Kumpf
Steven Olsen
Sucha Singh
Sudhakar Reddy
S. Ponnerassery
Sue Katz Amburn
Sue Klein
Sue Sriwiriyanont
Sufeng Mao
S. Venkataraman
Sumeet Sharma
Sunil Verma
Sunny
Susan Griswold
Susan Hubchak
Susan McCormick
Susan Vargas
Suwimol
Suzanne Johnson
Sydney Stoner
Syed Khund Sayeed
Sylvia Vazquez
Tamela Steindorf
Tammy Krauss
Tanea Reed
Tanmoy
Tannon Woodson
Thelma
Theresa Mathieson
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Thom Stone
Thomas Carlile
Thomas Eng
Thomas Gross
Thomas Lawton
Thomas Martinez
Thomas Mota
Thuy
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Timothy M White PE
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Tina Truong
Ting Wu
Todd Romigh
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Vincent Huyot
Vinod Gaur
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Xinchun Ding
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Yossi Weizmann
Yu-Chen Su
Yvonne
Zhihao Wu
Zhiping Zhou
Zimei Huang