Title
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Publication Date
2017-03-13

LBNL-1007254

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BERKELEY NATIONAL LABORATORY

Characterizing the Laboratory Market

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Energy Technologies Area

March 2017

This work was supported by the Federal Energy Management Program (FEMP) of the U.S. Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

CITATION

Shehabi, A., Ganeshalingam, M., DeMates, L., Mathew, P., Sartor, D. 2017. Characterizing the Laboratory Market. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-1007254

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Introduction

Laboratories are estimated to be 3-5 times more energy intensive than typical office buildings and offer significant opportunities for energy use reductions.[1] Although energy intensity varies widely, laboratories are generally energy intensive due to ventilation requirements, the research instruments used, and other health and safety concerns. Because the requirements of laboratory facilities differ so dramatically from those of other buildings, a clear need exists for an initiative exclusively targeting these facilities. The building stock of laboratories in the United States span different economic sectors, include governmental and academic institution, and are often defined differently by different groups. Information on laboratory buildings is often limited to a small subsection of the total building stock making aggregate estimates of the total U.S. laboratories and their energy use challenging. Previous estimates of U.S. laboratory space vary widely owing to differences in how laboratories are defined and categorized. A 2006 report on fume hoods provided an estimate of 150,000 laboratories populating the U.S. based in part on interviews of industry experts,[2] however, a 2009 analysis of the 2003 Commercial Buildings Energy Consumption Survey (CBECS) generated an estimate of only 9,000 laboratory buildings.[3] This report draws on multiple data sources that have been evaluated to construct an understanding of U.S. laboratories across different sizes and markets segments. This 2016 analysis is an update to draft reports released in October and December 2016.

Methodology

Laboratories are defined in this analysis as, *any space equipped to conduct testing and experiments with a primary focus on biological science labs*. This definition of lab space is aligned with a study performed by the Center for Energy Efficient Laboratories (CEEL) on behalf of California utilities.[4] The CEEL study focused on labs in California and provided a detailed look at the laboratory market through a combination of market research, online surveys, in-person interviews, and a literature review. By aligning definitions of lab space, this study leverages the CEEL's comprehensive analysis of the California lab market to extrapolate national values.

Four key market segments contribute to laboratory floor space: (1) life science research companies, (2) research institutions, (3) teaching laboratories, and (4) clinical diagnostic laboratories. Unfortunately, there is no comprehensive, detailed database of laboratories for any of these segments. The general approach in this analysis to overcome this dearth of data is to use proxies in each market segment that have been shown to be highly correlated with lab floor space from previous studies. Regional data aggregated at the state-level is used to construct a geographic distribution of lab space over the U.S.

Life Science Research Companies

Life science research companies are defined in this report as companies with the following classifications: medical devices; research, testing, and medical laboratories; and drug and pharmaceutical companies. The floor space of laboratories associated with life science research companies is estimated using employment statistics from the Census of Employment and Wages (CEW) that are compiled by the U.S. Bureau of Labor Statistics.[5] Employment data are reported using the North American Industry Classification System (NAICS), which is used by Federal statistical agencies in classifying business establishments. By identifying NAICS codes likely to involve life science laboratories, the number of employees was aggregated across life-science related industries to estimate the total number of employees in the industry. However, not all companies in life-science related industries will directly be involved with conducting research in laboratory settings. Table 1 shows results for the number of employees engaged in research in each identified NAICS code related to life science research.

Table 1: National employee estimates for companies classified as life science research

NAICS Code	Industry Description	Industry Classification	Employees Engaged in Research
325411	Medicinal and Botanical Manufacturing	Drugs and pharmaceuticals	11,324
325412	Pharmaceutical Preparation Manufacturing	Drugs and pharmaceuticals	113,841
325413	In-Vitro Diagnostic Substance Manufacturing	Drugs and pharmaceuticals	11,124
325414	Biological Product (except Diagnostic) Manufacturing	Drugs and pharmaceuticals	11,948
334510	Electromedical/Electrotherapeutic Apparatus Manufacturing	Medical devices and equipment	22,954
334516	Analytical Laboratory Instrument Manufacturing	Medical devices and equipment	13,567
334517	Irradiation Apparatus Manufacturing	Medical devices and equipment	4,779
339112	Surgical and Medical Instrument Manufacturing	Medical devices and equipment	46,008
339113	Surgical Appliance and Supplies Manufacturing	Medical devices and equipment	39,752
339114	Dental Equipment and Supplies Manufacturing	Medical devices and equipment	4,908
541380	Testing Laboratories	Research, testing, and medical laboratories	18,492
541711	Research and Development in Biotechnology	Research, testing, and medical laboratories	91,062
541712	Research and Development in the Physical	Research, testing, and medical laboratories	74,354
621511	Medical Laboratories	Research, testing, and medical laboratories	110,610

CEEL estimates that 58% of employees in the medical device sector, and 83% of employees in the other bioscience sectors (i.e., research, testing, and medical laboratories and drug and pharmaceutical companies), work in a facility that conducts research requiring a laboratory. The CEEL study also estimates 70% of the people in a life science research company are engaged in research, and that 1,000 ft^2 of lab space is represented for every 3 lab employees engaged in research, based on information from real estate developers with knowledge of the commercial laboratory market. Applying these employee percentage values to the compiled CEW employment statistics estimates the number of labs employees that are engaged in research at 575,000 in the U.S. The ratio of lab space to employees established in the CEEL report for California (30.8 million ft^2 of bioscience lab space for 55k employees and 5.9 million ft^2 of medical device lab space for 6,900 employees) is then applied to this national employee count, resulting in nearly 360 million ft^2 of laboratory space for life science companies in the U.S.

Research Institution Lab Space

The definition of research institution lab space in this study includes academic research labs, hospital research labs (often associated with medical schools), and non-profit research institutions. Although information regarding lab floor space is sometimes available from individual institution websites, identifying relevant data through websites and press releases is neither plausible nor guaranteed to be complete. This analysis of research institution lab space instead relies on National Institute of Health (NIH) funding as a proxy for the lab floor space associated with an organization. Although this is a simplifying assumption that does not take into account other funding sources for life science research, NIH funding represents the single largest funding source for academic laboratories and research institutions.[4] Additionally, it is reasonable to assume the size of the lab is correlated with funding levels given that NIH funding is directly used to support laboratory-based scientific research.

NIH awardees and funding amounts are based on publically available funding information for grants and contracts awarded between 2012-2016.[6] Over this 5 year period, a total of 260,057 projects were funded corresponding to $116 billion. Funded projects not directly allocated to research requiring a laboratory were eliminated from the sample using proposal activity codes and institution department name. Of the 239 possible proposal activity codes, 175 are identified as being related to research. Eliminated activity codes were related to proposals categorized for public health, conference organizing, and educational projects. Proposals eliminated by institution department name were related to public health, computer science, and biostatistics. The final sample contains 216,504 projects relevant to research institution lab space, corresponding to a total of $96 billion. This relevant NIH funding was aggregated by state and normalized relative to the total amount. The CEEL study provides an estimate of 34.9 million ft^2 of lab space for academic research institutions, hospital research, Veteran Affairs facilities, and non-profit research institutions for the state of California. The California laboratory floor space from CEEL was then extrapolated to the rest of the country by using the relative variation of NIH funding across all 50 states, resulting in a total U.S. floor space of 223 million ft^2 for Research Institutions.

Post-Secondary Teaching Labs

National enrollment statistics in postsecondary schools is used as a proxy in this analysis to estimate teaching lab space. Integrated Postsecondary Education Data System (IPEDS) is a mandatory survey of postsecondary schools for all institutions that receive federal funding under Title IX of the Higher Education Act.[7] Data collected includes institution characteristics on enrollment and degrees conferred by field of study. The total dataset consists of 12.8 million full-time enrolled (FTE) students in 7,117 institutions. IPEDS data are used to identify postsecondary institutions that award associate's, bachelor's, or graduate degrees in the biological sciences or health-related fields, which culls our sample to 12.0 million FTE students in 4,578 institutions. Enrollment of FTE students was aggregated by state to develop a picture of the geographic distribution national enrollment. A study by Paulien & Associates reports a range of values for average teaching laboratory floor space per FTE student between 11-16 ft^2 per student, depending on the institution type (i.e., community college, four-year college, or research institution) and the number of FTE students at the institution.[8] We average across institution type to derive average values of lab square footage per FTE student based on the number of FTE students enrolled in the institution. We find 15.0 ft^2 per FTE for schools with less than 3,000 FTE students, 14.7 ft^2 per FTE for schools with more than 3,000 and less than 6,000 FTE students, 13.3 ft^2 per FTE for schools with more than 6,000 and less than FTE 10,000 students, and 12.7 ft^2 per student for schools with more than 10,000 FTE students. Applying these values to the IPEDS data-set results in an estimated 164 million ft^2 of teaching lab space. Table 2 shows the number of schools and students in each category of FTE students.

Table 2: Number of schools and students that award bioscience or health-related degrees for each category of FTE students

Number of FTE Students	**Number of Schools**	**Numbers of Students (millions)**
< 3,000	3,488	2.8
3,001-6,000	455	1.9
6,000-10,000	232	1.8
> 10,000	270	5.5

Clinical Diagnostic Testing Labs

The definition of laboratories in this analysis includes facilities with space dedicated to clinical diagnostic testing of human blood and/or tissue samples. The "diagnostic testing" part of the definition is important to note, as the are many clinical spaces used for collecting samples that will be diagnosed elsewhere (e.g., phlebotomy labs) that are casually referred to as a "clinical lab" but would not meet that definition applied in this analysis.

Laboratories registered under Clinical Laboratory Improvement Amendments (CLIA) are used in this analysis to estimate lab floor space attributed to clinical diagnostics. CLIA compliance is required for facilities that test human subjects for a health assessment or to diagnose, prevent, or treat disease.[9] Laboratories that receive a CLIA certificate of compliance are found to meet all applicable CLIA requirements. The national list of CLIA certified labs indicates that California represents 9.2% of clinical diagnostic testing facilities. The CEEL study estimates 0.5 million ft^2 of clinical diagnostic lab space in the state of California. Extrapolating from the CEEL estimate indicates approximately 5.4 million ft^2 nationally.

Labs in CBECS

CBECS is a nationally representative survey of commercial buildings in the United States conducted by the U.S. Energy Information Administration (EIA). The survey provides a snapshot of energy-related building characteristics of U.S. commercial building stock. For 2012 CBECS, EIA surveyed 6,720 buildings and weighted their sample to be nationally representative of commercial building stock. The publicly released dataset is anonymized to remove any characteristics that could possibly be used to identify individual buildings. As part of this process, the location of buildings is made available at the Census division level (groups of 4-9 states).

CBECS reports 41 records of buildings that identify their principal building activity as a laboratory. However, one of the buildings in the sample reports a high quantity of computer servers and using approximately 80% of its annual energy use for computing indicating that its primary activity is likely a data center. We omit this building from our sample of CBECS laboratories. Applying the weightings for each remaining 40 records of laboratory building results in total of 14,715 laboratory buildings in the U.S that combined consume 113 TBTU of energy annually. These are buildings in which "laboratory" is identified as the "principal building activity," where that activity represents at least 50% of the building floor space. However, EIA provides no formal definition for laboratories, which leaves the selection of "laboratory" as a principal building activity open to interpretation in the survey. Note that since CBECS only includes labs where laboratories are the principal activity in the building, smaller labs within other building types, such as hospitals or educational buildings, would not be accounted for in these datasets. Assuming 70% of the laboratory building footprint is actual laboratory space,[10] we find that buildings identified as laboratories correspond to 326 million ft^2. This floor space estimate is similar but less than the estimate for Life Science Research companies in this study, and much less when including the floor space of Research Institutions, Post-Secondary Teaching, and Clinical Diagnostic Testing laboratories. The most likely explanation is that many buildings with laboratories do not identify their principal building activity as a laboratory.

The 2012 version of CBECS indicates an increase in the number of laboratories, but a decrease in the total floor space and energy use of laboratory building stock since the 2003 version. The average site energy intensities in CBECS 2012 also indicates a reduction since 2003.[1] The comparison between the two CBECS dataset sets indicate a possible trend towards smaller labs with less energy demand. Table 3 compares the 2012 laboratory characteristics with the characteristics in the 2009 report, which were obtained from the previous (2003) version of CBECS.

Table 3: Comparison of CBECS 2003 and 2012 data. Note that no other CBECS versions were released between these two periods.

CBECS 2003	**CBECS 2012**
9000 Laboratory Buildings	15,000 Laboratory Buildings
654 million ft^2	466 million ft^2
Total Site energy use: 200 TBTU	Total Site energy use: 113 TBTU
Average annual site intensity: 305 kBTU/ ft^2.	Average annual site intensity: 242 kBTU/ ft^2

Conclusions regarding laboratories solely based on CBECS are limited, however, given the small sample size in the overall data set. Figure 1 shows the probability distribution for the number of laboratories in the United States using replicate weights from CBECS. The standard deviation listed in Figure 1 provides a sense of the uncertainty in these CBECS findings.

[1] Note that this site intensity has been updated from the 161 kBTU/ft^2 value provided in a memo on July 28. The previously lower value was the result of an erroneous record in the CBECS database at the time, which has since been corrected by EIA.

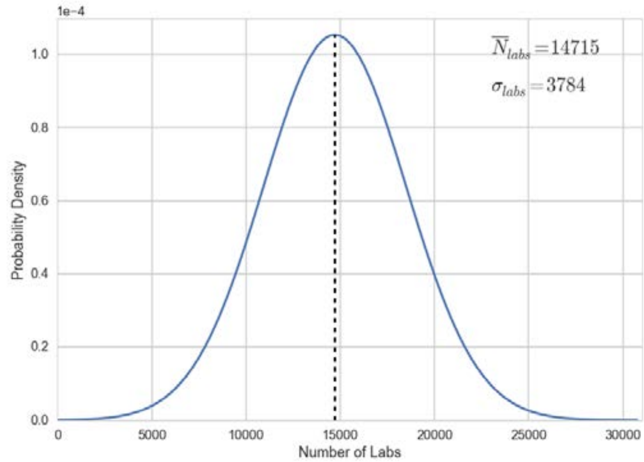

Figure 1: Probability distribution of total U.S. laboratory count in CBECS 2012 data.

CBECS 2012 also includes a survey question on whether buildings have laboratory equipment. However, CBECS does not specifically define laboratory equipment for respondents which could potentially lead to confusion in responses. When aggregating other buildings with laboratory equipment we find 126,000 buildings corresponding to 4.3 billion ft^2 of lab space. Curiously, 28% of buildings identified as laboratories report having no lab equipment. These values indicate that the laboratory equipment survey question may include items not associated with

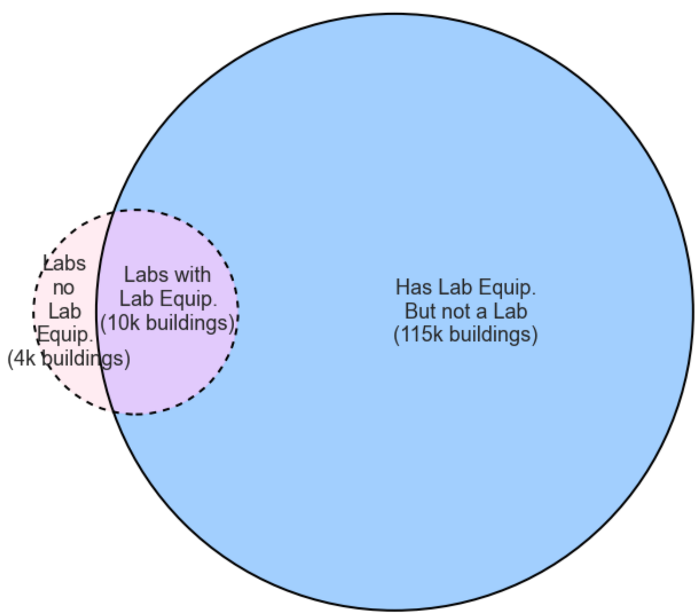

Figure 2: Venn diagram of buildings that report laboratory as their principal building activity and buildings that identify as having laboratory equipment.

laboratory space, as defined in this study, while the laboratory equipment survey question may also not actually capture all laboratory space identified as the principal building activity. Figure 2 shows a Venn diagram of buildings that report laboratory as their principal building activity and those that identify as having lab equipment.

The distributions in energy intensity for two samples of buildings within CBECS are compared: (1) Buildings that have a principal building activity of laboratory and (2) buildings that identify as having lab equipment. The energy intensity for each building was calculated by dividing the reported total annual energy consumption in kBTU by the estimated total square footage. Note that this comparison assumes the reported energy consumption is completely attributed to operation of the laboratory. While this is a reasonable assumption for buildings with principal building activity of laboratory, it is not necessarily the case for buildings containing lab equipment. Self-identified labs have the highest average energy intensity of 242 kBTU/ft^2-yr compared to 141 kBTU/ft^2-yr for buildings with lab equipment. For comparison, buildings without lab equipment had an average energy intensity of 86 kBTU/ ft^2-yr.

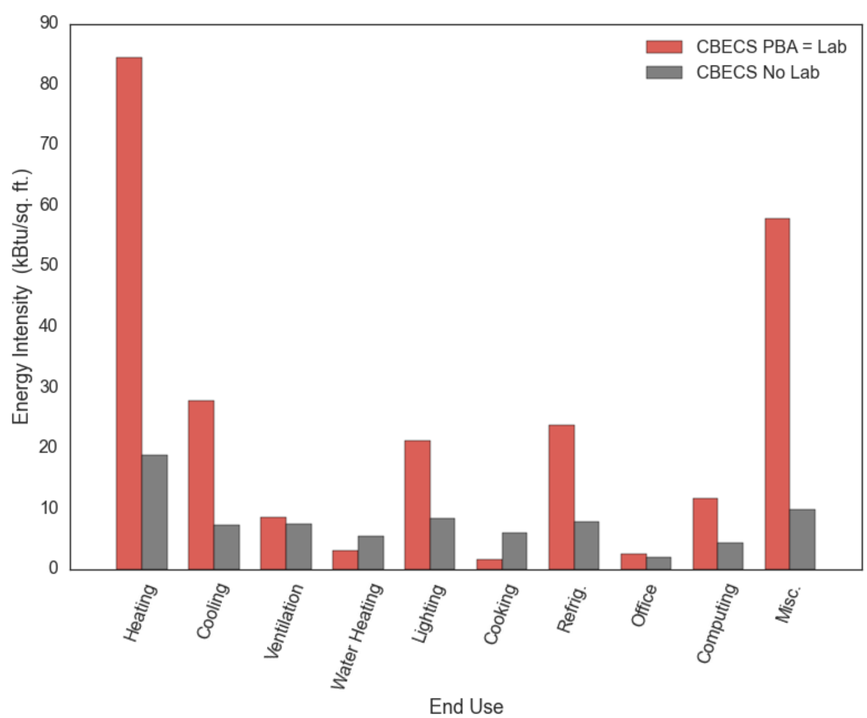

Figure 3: Comparison of energy intensity by end use for buildings that identify as laboratories (red) and buildings that identify as not having lab equipment (grey).

Reported annual major fuel usage estimates in CBECS were used to calculate the average energy intensity by end use for the lab sample compared to the no lab equipment sample. Figure 3 shows results by major end-use. Energy intensity in labs is higher for most end uses. Notably, the average lab has higher heating and cooling energy intensity relative to buildings without lab equipment. Laboratories also report significantly higher energy intensity for miscellaneous equipment, which likely captures the high-energy draw of specialty lab equipment. Surprisingly, there is no significant difference in ventilation energy intensity between the two samples despite the necessity of energy-intense fume hood ventilation systems in most biotech and chemical laboratories.

Labs21

Labs21 is an energy benchmarking tool developed by Lawrence Berkeley National Laboratory that provides lab operators a means of uploading data related to lab energy consumption and building characteristics for a comparison against labs with similar characteristics. Collected data are anonymized and added to a database where users can compare their laboratory characteristics to other entries. The Labs21 database includes vetted data for 614 facilities, representing a total building space of over 117 million ft^2 and total energy use of 40 billion kBTU. The average site energy intensity of labs in the Labs21 database is 319 kBTU/ ft^2-yr. The energy intensity for individual facilities varies from 51 kBTU/ ft^2-yr to 968 kBTU/ ft^2-yr. Note that these intensities are based on gross building area, not net lab area. Energy intensity of facilities in the Labs21 database have not changed significantly since the 2009 analysis, which showed an average site energy intensity of 324 kBTU/ ft^2-yr with energy intensity for individual facilities varying from 45 kBTU/ ft^2-yr to 1,012 kBTU/ ft^2-yr. Since data in the Labs21 database are provided by a self-selective group of operators interested in energy benchmarking, these energy intensities may not necessarily reflect a nationally representative sample of laboratories. As noted in the 2009 analysis, the Labs21 dataset tends to have larger and more energy intensive labs. However, the data provide a rich detailed snapshot of energy consumption characteristics within a large dataset of over 2,300 laboratories, which has been used to verify trends observed in more nationally representative datasets.

Figure 4 shows the cumulative distribution function of energy intensities for the Labs21 and CBECS building samples. The distribution of energy intensities for Labs21 buildings is significantly higher than the CBECS labs sample. The median value in the CBECS Labs distribution corresponds to approximately the 20th percentile in the Labs21 sample. As mentioned previously, the Labs21 sample comes from a self-selective group of building operators and is not necessarily nationally representative. However, it is hard to explain the relative dearth of energy-intense labs in the CBECS labs sample. It is possible that they are not well represented in the relatively small sample of 40 records in CBECS. Both the CBECS labs and Labs21 samples are shifted to higher energy intensities relative to CBECS buildings that report having lab equipment (but are not identified as a laboratory) and all other CBECS buildings (not a lab and having no lab equipment).

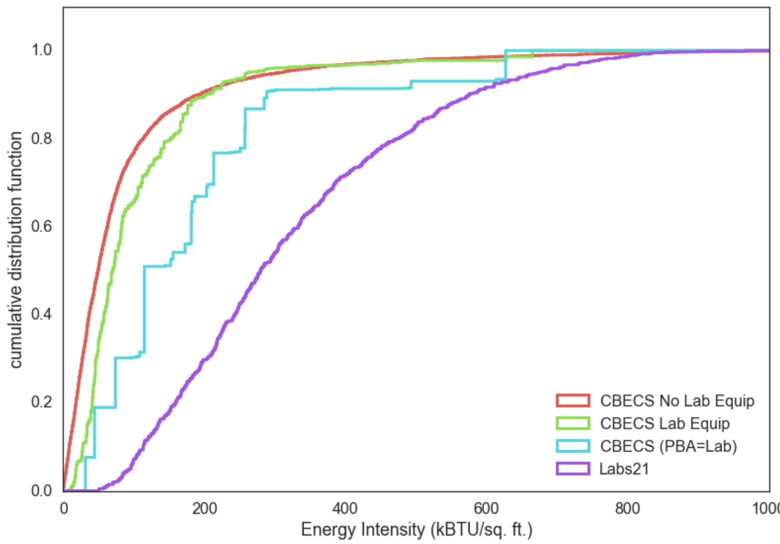

Figure 4: Comparison of cumulative distribution functions of energy-use intensity for CBECS and Labs21 building samples.

Results Summary

In aggregate, this analysis estimates that the total lab floor space in the U.S. is approximately 750 million ft². Figure 5 provides a regional distribution of this floor space by state.

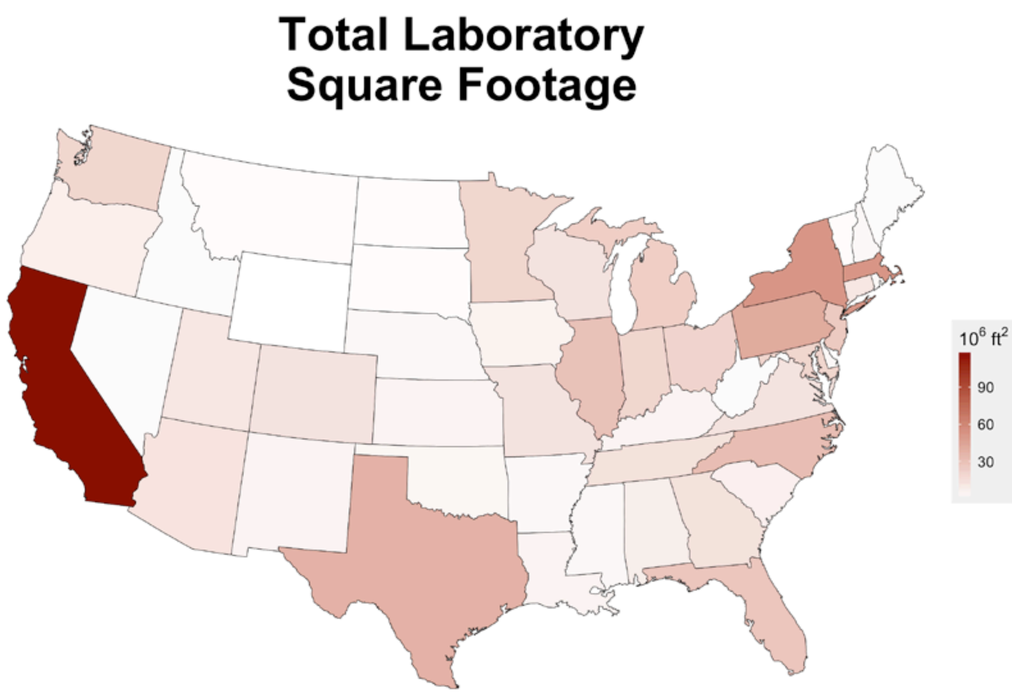

Figure 5: Regional variation of laboratory floor space

Estimates for lab floor space are also converted into the number of laboratories and total energy use using average lab space floor space and the total energy use used in the CEEL and CBECS 2012 data, respectively. The CEEL study provides estimates for the average lab floor space when including lab space and associated support space. The CEEL study provides an estimate for the average lab floor space for research, commercial, and clinical diagnostic lab spaces of 4,300, 5,800, and 3,500 ft^2 per laboratory, respectively. Applying these estimates, and assuming the average floor space of teaching labs is similar to research institutions, we estimate 153,300 labs in the U.S. The CEEL study did not report average lab sizes for teaching clinical labs so the average size of research institutions labs is used as a proxy. A summary of our results is presented in Table 4.

Table 4: Floor space and laboratory counts for laboratories associated with life science research, research institutions, teaching, and clinical diagnostic.

Market Segment	Floor space (millions)	Numbers of labs
Life Science Research	359	61,800
Research Institutions	223	51,900
Teaching	164	38,100
Clinical Diagnostic	5.37	1,500
Total	**751**	**153,300**

CBECS 2012 indicates an energy intensity of approximately 242 $kBTU/ft^2$ annually. Applying this energy intensity to the floor space estimates in Table 4 indicates an annual total site energy use of 182 TBTUS. Labs21 case studies indicate savings of 30-50% relative to standard practice. When applied to the total site energy use from this analysis, it represents a potential of 55-91 TBTU of annual site energy savings. While these energy and savings potential estimates apply national average metrics, the floor space and lab count estimates generated in this analysis are disaggregated by location and market segment (see appendices). Future work could provide improved estimates for savings potential by further exploring the energy use and saving potential variation across regions and lab space types.

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Appendix A: State Laboratory Floor Space

Laboratory floor space (millions ft²) disaggregated by State and market segment.

	Research	Commercial	Teaching	Clinical
Alabama	2.7	2.7	2.8	0.1
Alaska	0.1	0.1	0.2	0.0
Arizona	1.7	5.7	5.3	0.1
Arkansas	0.5	0.6	1.5	0.1
California	34.9	64.1	19.5	0.5
Colorado	3.3	7.2	2.6	0.1
Connecticut	4.9	5.4	1.9	0.1
Delaware	0.4	2.0	0.5	0.0
District of Columbia	2.0	0.6	0.8	0.0
Florida	5.0	14.2	8.2	0.3
Georgia	5.0	4.7	4.6	0.2
Hawaii	0.5	0.8	0.5	0.0
Idaho	0.1	1.1	0.8	0.0
Illinois	8.0	15.5	6.2	0.2
Indiana	2.1	14.0	3.7	0.2
Iowa	1.7	1.7	2.2	0.1
Kansas	1.0	2.7	1.9	0.1
Kentucky	1.5	1.5	2.3	0.1
Louisiana	1.5	1.3	2.3	0.2
Maine	0.7	0.8	0.6	0.0
Maryland	9.6	8.0	2.6	0.1
Massachusetts	22.4	24.4	4.5	0.2
Michigan	6.4	11.9	4.9	0.2
Minnesota	4.7	12.4	3.2	0.1
Mississippi	0.5	0.9	1.8	0.1
Missouri	4.9	4.7	3.4	0.1
Montana	0.3	0.5	0.5	0.0
Nebraska	0.8	1.0	1.2	0.0
Nevada	0.3	1.1	0.8	0.0
New Hampshire	0.9	1.1	0.9	0.0
New Jersey	1.6	20.6	3.9	0.1

New Mexico	1.0	3.2	1.0	0.0
New York	21.3	18.8	11.4	0.0
North Carolina	9.7	17.1	4.9	0.2
North Dakota	0.2	0.2	0.5	0.0
Ohio	5.4	9.1	5.8	0.2
Oklahoma	0.9	1.5	2.0	0.1
Oregon	2.8	2.9	2.1	0.1
Pennsylvania	14.5	19.2	7.2	0.3
Rhode island	1.5	0.9	0.7	0.0
South Carolina	1.5	3.2	2.4	0.1
South Dakota	0.2	0.1	0.5	0.0
Tennessee	4.8	5.9	3.2	0.2
Texas	10.7	15.5	11.0	0.6
Utah	1.7	7.6	2.5	0.1
Vermont	0.6	0.2	0.4	0.0
Virginia	3.0	5.8	4.6	0.1
Washington	9.4	6.9	3.3	0.1
West Virginia	0.3	0.5	1.1	0.1
Wisconsin	3.7	6.7	3.0	0.1
Wyoming	0.1	0.1	0.3	0.0

Appendix B: State Laboratory Counts

Laboratory count disaggregated by State and market segment

	Research	Commercial	Teaching	Clinical
Alabama	629	471	661	29
Alaska	26	13	56	4
Arizona	398	977	1,233	31
Arkansas	111	104	353	16
California	8,116	11,051	4,525	142
Colorado	761	1,239	597	28
Connecticut	1,143	925	433	15
Delaware	85	353	118	3
District of Columbia	463	100	189	4
Florida	1,156	2,440	1,910	92
Georgia	1,153	815	1,066	46
Hawaii	105	133	121	6
Idaho	26	198	195	6
Illinois	1,863	2,678	1,436	68
Indiana	494	2,412	866	44
Iowa	405	301	517	16
Kansas	235	463	437	15
Kentucky	359	260	526	31
Louisiana	340	225	539	48
Maine	157	137	147	8
Maryland	2,229	1,386	599	21
Massachusetts	5,218	4,202	1,047	44
Michigan	1,488	2,049	1,143	45
Minnesota	1,088	2,138	754	27
Mississippi	111	153	420	19
Missouri	1,139	817	788	32
Montana	67	86	119	7
Nebraska	192	180	289	10
Nevada	65	193	192	14
New Hampshire	221	189	200	8
New Jersey	382	3,549	897	24
New Mexico	228	548	230	14
New York	4,951	3,235	2,643	4
North Carolina	2,256	2,953	1,138	47
North Dakota	44	27	118	5
Ohio	1,258	1,568	1,355	69

Oklahoma	217	259	458	21
Oregon	648	505	477	18
Pennsylvania	3,376	3,309	1,672	73
Rhode island	343	147	163	6
South Carolina	343	555	556	24
South Dakota	54	12	110	7
Tennessee	1,123	1,022	737	43
Texas	2,489	2,671	2,558	160
Utah	396	1,311	578	18
Vermont	128	32	97	5
Virginia	695	996	1,058	32
Washington	2,179	1,183	775	21
West Virginia	62	84	248	15
Wisconsin	855	1,161	688	37
Wyoming	22	16	60	6