FINAL REPORT

a study of the

Economic Impact of Lawrence Berkeley National Laboratory

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Prepared for:

BERKELEY LAB

Prepared by:

Economic & Planning Systems, Inc.

The Economics of Land Use

Table of Contents

1. Executive Summary

LAWRENCE BERKELEY NATIONAL LABORATORY's contributions to science and innovation have significant and far-reaching economic impacts. This Economic Impact Report provides a comprehensive and up-to-date look at the economic impact and scientific and technological contributions of Berkeley Lab, one of the nation's oldest and most productive multipurpose, open-science laboratories.[1] The analysis goes beyond the direct stimulus of payroll and procurements and seeks to capture Berkeley Lab's more significant and multifaceted economic impacts through science and innovation.

From its beginnings, Berkeley Lab has played an important role in the evolution of the nation's innovation ecosystem, and continues today to make pioneering contributions to the fields of clean and efficient energy, sustainable environmental solutions, climate change, information technology, and health care. While innovation has always been a critical differentiator in the U.S. economy, this dynamic is especially true in the San Francisco Bay Area where high technology professions directly and indirectly account for between 60 to 80 percent of regional economic output.[2]

Berkeley Lab also provides a direct injection of spending that ripples through the broader region, State, and beyond. These stable, well-paying jobs support economic resiliency, particularly important during economic downturns, as has been precipitated by the current Covid-19 pandemic. Moreover, funding for Berkeley Lab is leveraged by a variety of corporate, nonprofit, and other public and private sources that magnify its economic impact. These combined impacts paint a robust picture of Berkeley Lab's return on investment to American taxpayers.

As further documented in this Report, Berkeley Lab is estimated to be responsible for 20,000 jobs nationwide, about half of which are located in the San Francisco Bay Area. In addition, more than 55 firms have been created based on Berkeley Lab licensed technology and numerous others benefit through on-going R&D collaboration and technology transfer. Overall, for every $100,000 in federal dollars invested, Berkeley Lab is estimated to create approximately two U.S. jobs, $102,000 in worker compensation, and $276,000 in total output.

LAB AT A GLANCE
FY 2020*

3,565
full-time employees

1,702
scientists and engineers

242
joint faculty

520
postdoctoral scholars

518
graduate and undergraduate students

14,000
national scientific facility users from throughout the nation

1,728
visiting scientists and engineers

2,000
publications per year by Lab researchers, 58% in "top journals"

14
Nobel Laureates

80
members of the National Academy of Sciences, **~4% of its membership**

* Data shown here reflect FY 2020. Data used in economic impacts analysis reflect FY 2018.

1 Berkeley Lab is a Department of Energy Office of Science national laboratory managed by the University of California. The DOE Office of Science is the nation's largest funder of the physical sciences.
2 Bay Area Council Economic Institute. California Economic Development Department. Economic & Planning Systems.

Key Findings

This study provides quantifiable metrics designed to capture the range of economic benefits generated by Berkeley Lab through its scientific endeavors, research facilities and associated spending. As illustrated in **Figure 1**, the analysis is organized around the following dependent and interrelated economic performance metrics: (1) research, innovation and knowledge transfer, (2) commercialization and firm creation, (3) strategic partnerships and collaborations, and (4) payroll, contracting, and procurement.

Research, Innovation and Knowledge Transfer

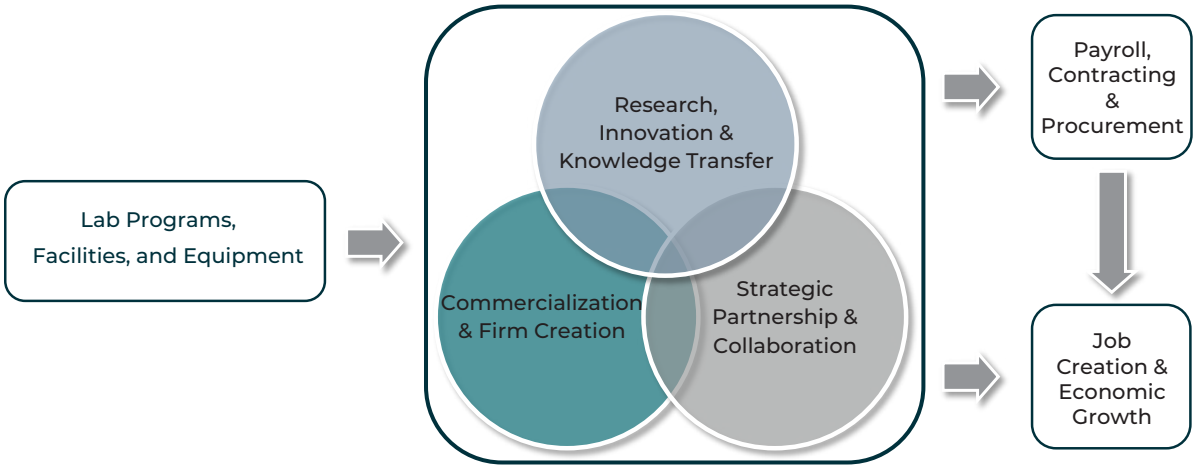
Berkeley Lab's economic contributions start with its cadre of top tier scientists and scholars as well as state of the art facilities that for 90 years have been the source of innovations and scientific discoveries with practical applications across numerous fields.

Many of these scientific milestones are now embedded in our everyday lives, from the way that doctors diagnose and treat medical conditions to how building materials are manufactured (see sidebar).

SHAPING THE WORLD IN WHICH WE LIVE FOR 90 YEARS

- Out of all the 118 elements on the periodic table, **16 were discovered at Berkeley Lab. This includes technetium-99, which has revolutionized the field of medical imaging**.
- **In 1940, Berkeley Lab identified carbon-14 as the isotope for dating biological materials**. Carbon dating is now used globally to better understand humanity's past.
- **In the 1960s, Berkeley Lab scientists revealed the good and bad sides of cholesterol**. Diagnostic tests are now used around the world to detect cholesterol and save lives.
- **In the 1990s, Berkeley Lab developed a window coating to improve insulation. Half of all windows sold contain this coating**, saving residents billions of dollars in energy bills annually.
- **In 2003, Berkeley Lab scientists engineered a method to digitally reconstruct aging sound recordings**. Millions of recordings around the world are now preserved using the technology.
- **Since 2009, Berkeley Lab has operated the world's most powerful microscope**. The electron microscope's resolution is powerful enough to image individual atoms.
- **Starting in 2010, Berkeley Lab scientists were involved in developing CRISPR, which allow geneticists to precisely edit genomes**. This powerful tool is being used to diagnose, treat and prevent diseases, **including Covid-19**.

Figure 1. Berkeley Lab Economic Impact Study Analytical Framework



Berkeley Lab's scientists and researchers regularly publish influential work that is used in both academia and industry, contributing to the type of information diffusion and knowledge transfer critical to success in technology-driven fields.

Berkeley Lab researchers and affiliated scientists consistently author over 2,000 publications per year in well-respected academic and professional journals, making it one of the top institutions worldwide in research publications. The Lab's non-classified, open research advances the state-of-knowledge in a wide range of fields, including physics and astronomy, chemistry, materials science, engineering, high performance computing, earth and environmental sciences, and biosciences.

As illustrated in **Figure 2**, a variety of performance indicators suggest that Berkeley Lab publications gain more views, citations, and are more impactful than other universities and research institutions in California and the United States. Each year, R&D Magazine presents an award to the 100 most significant new technologies. Over the past 37 years, Berkeley Lab has received 102 R&D 100 awards and one Special Recognition Award (2018).

Commercialization and Firm Creation

As a leading research institution, Berkeley Lab is directly responsible for numerous innovations and scientific discoveries that have significant commercial value, as evidenced in part through its success in obtaining patents, generating licensing revenue, and supporting firm creation.

As of 2020, more than 80 Berkeley Lab technologies, protected by more than 250 patents and patent applications, are being commercialized by the Lab's licensees. The licensing revenue, in turn, helps fund additional research. These patented technologies provide economic benefits to producers and consumers in the form of new and improved products for health care, sustainable consumer goods, clean energy production and energy efficiency, computer sciences, among others.

Berkeley Lab tracks and supports business startups that originate from and license its technology, providing on-going technical expertise, access to facilities and equipment, and entrepreneurial mentorship services. Of the total 55 startup firms founded based on Berkeley Lab technology, 55 percent are still active while 25 percent have been acquired by larger companies. As described below, the new firms originating from Berkeley Lab work provide direct economic benefits, in the

Figure 2. Summary of Berkeley Lab Knowledge Transfer Performance Indicators

Berkeley Lab Publications
• Research affiliated with Berkeley Lab generates over 2,000 publications annually
• Berkeley Lab has 58% of publications in "top journals", compared to other institutions in California at 44% and the U.S. at 35%
• Berkeley Lab ranks fifth worldwide among government research institutions according to Nature Index
Views and Citations
• Berkeley Lab's publications consistently have higher average views and citations per publication than those from institutions in California and the U.S.
• Berkeley Lab's publications consistently have higher patent citations per publication than those from institutions in California and the U.S.

form of increased jobs and output within the Bay Area and beyond. In addition to startups based on Lab technology, other spin-off firms form at the Lab through its research facility partnerships and Cyclotron Road entrepreneurship program.

Strategic Partnerships and Collaboration

Berkeley Lab participates in a variety of public-private partnerships that offer a range of benefits to both parties and demonstrate the potential economic value of the Lab's fields of inquiry and specialized facilities.

In the past 10 years (2010 to 2019), Berkeley Lab has initiated over 4,600 new partnership agreements with an associated total of $1.2 billion in funds. With a partnership agreement, companies are able to gain access to resources at Berkeley Lab, such as the user facilities, and collaborate with top scientists in a range of specialized fields of interest. For Berkeley Lab, these collaborations can bring funding and related support that advances the Lab's mission to research and find solutions to real world challenges.

Each of Berkeley Lab's five DOE user facilities offer unique capabilities that are regularly accessed by outside researchers representing industry and academia.

In FY 2020, each of the five DOE user facilities located on the Berkeley Lab campus provided around 14,000 researchers and institutions from around the world access to leading scientists and powerful scientific instruments. Berkeley Lab user facilities are among the most heavily used in the national laboratory system, accounting for over a third of all users. Because of the more cross cutting, collaborative, and often longer-term nature of the research activities at these user facilities, many of the economic metrics highlighted elsewhere in this study were at least partially attributable to work done here. In addition to the specialization and activities at each of the Berkeley Lab user facilities, **Figure 3** highlights other resources and initiatives designed to accelerate lab-to-market innovations.

Selected LBNL Startups and Licenses

Payroll, Contracting, and Procurement

Berkeley Lab supports the San Francisco Bay Area and national economy through the increased jobs, output, and employee compensation that is directly attributable to its spending, the spending of firms derived from Lab technology, and the ripple effect on industries that supply goods and services to both.

Berkeley Lab creates direct economic impacts through the spending by its 3,525 employees as well as the procurement of goods and services associated with $805.8 million in annual operating costs and $101 million in capital / construction projects in FY 2018. EPS estimates that spin-off firms directly attributable to Berkeley Lab's technology are directly responsible for about 1,900 additional jobs and $541 million in sales. This direct spending and employment creates "indirect" and "induced" economic impacts in the Bay

Figure 3. User Facilities and Additional Research Assets and Facilities

Advanced Light Source: *Specialized particle accelerator that generates bright beams of x-ray light through ≈40 beamlines to experimental end stations.*

- Hosts 50 to 100 on-site users at a time and 2,000 on-site and remote users annually (ranging from one hour to 10 days)
- 925 annual publications, 20% in "high-impact journals"

Energy Sciences Network (ESnet): *High performance, unclassified network built to support scientific research and serve the entire DOE National Lab system.*

- Linked to more than 200 research and commercial networks and scientific facilities around the world
- Carries more than 90 petabytes a month or more than an exabyte per year

Joint Genome Institute: *Multi-disciplinary research on plants and microbes.*

- 2,000 unique users in FY 2020
- Generates ≈300 human genome equivalents per day in plant and microbial DNA sequence
- Generated 326 trillion letters of genetic code in 2019

Molecular Foundry: *State-of-the-art expertise, methods, and knowledge in nanoscale science and host to National Center for Electron Microscopy.*

- 1,500 users in FY 2020
- 150 users on-site daily (ranging from several weeks to over a year)
- Over 1,000 publications, 36% in high-impact journals from FY 2016-2018

National Energy Research Scientific Computing Center: *Primary scientific computing facility for the DOE Office of Science.*

- Over 8,000 users annually
- 10,000 million computing hours every year
- Nearly 2,500 peer-reviewed publications involving computing at NERSC published in 2019

Additional Research Assets and Facilities:

Cyclotron Road — a unique program for entrepreneurs to move ideas to prototypes that includes access to leading research facilities as well as coaching and networking to translate innovations into new companies - a model now replicated by other national labs.

Agile Biofoundry and Advanced Biofuels and Bioproducts Process Development Unit (ABPDU) — state-of-the art tools to help young companies develop and produce new sustainable bio-based products.

High Performance Computing for Advanced Manufacturing (HPC4Mfg) — access to leading supercomputers, to help U.S. industries optimize production processes, lower energy costs, and become more competitive.

FLEXLAB® — the world's most advanced integrated building and grid technologies testbed, used to develop and test building energy management technologies.

The Materials Project — cloud-based computational services that allow researchers to predict the properties of materials before they are synthesized, allowing researchers in areas such as battery development to target the most promising candidate materials.

Area, California, and the nation in the form of increased jobs, output, and employee compensation in a variety of industries that supply goods and services to Berkeley Lab and its workers.

After accounting for economic multiplier effects, spin-off firms with technologies directly attributable to Berkeley Lab are estimated to be responsible for 10,000 Bay Area jobs, 11,700 jobs in California, and close to 20,000 jobs nationwide (**Figure 4**). By way of comparison, in the Bay Area nearly one in five hundred jobs is represented in Berkeley Lab's primary economic impact (one in every two thousand jobs for California and one in every 10 thousand jobs nationally).

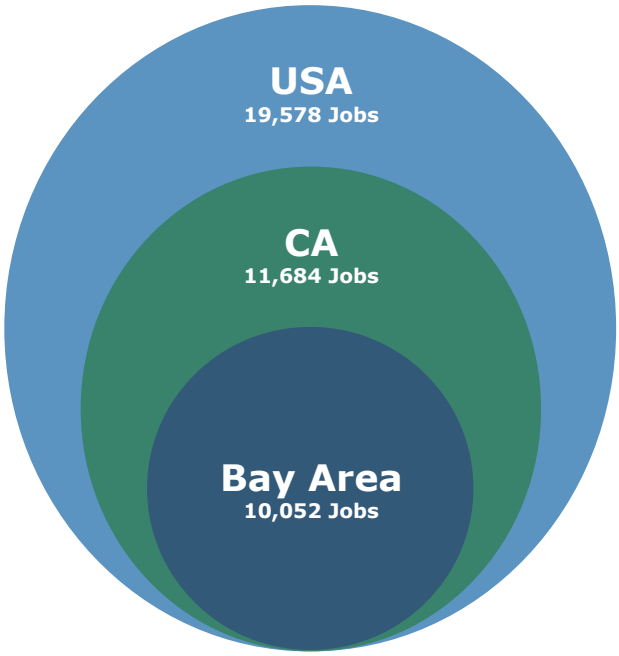
The combined effect of these spin-off firms, and the fact that about 20 percent of Berkeley Lab's funding leverages additional non-federal sources (e.g., industry), creates a particularly strong return-on-investment for the U.S. taxpayer. In particular, for every $100,000 in federal dollars invested, Berkeley Lab creates approximately two U.S. jobs, $102,000 in worker compensation, and $276,000 in total output.[3]

Because Berkeley Lab is primarily funded through federal sources, the economic impacts quantified herein have historically been relatively stable and less subject to the vicissitudes of the private sector business cycle. Additionally, a significant percent of all contract dollars awarded go to small businesses (54 percent or $68 million in FY 2018) while over half of all procurement is from California businesses.[4]

Figure 4. Combined Effect of Berkeley Lab Activities on Total Jobs by Geography

Expenditure Category	Bay Area	California	United States
Operations	6,140	7,003	11,400
Capital and Construction	432	504	1,228
Startups	3,480	4,177	6,950
Total Jobs	**10,052**	**11,684**	**19,578**

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems



3 These estimates were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.
4 Of the Berkeley Lab $907 million in total costs in FY 2018, about $429 million was for procurement (consisting of $394 million in purchase orders and $34.8 million in direct purchases of goods, services from outside entities). Of this amount $224 went to California businesses while $68 million of the contracts were awarded to small business.

2. Overview of Berkeley Lab

Background and Mission

LAWRENCE BERKELEY NATIONAL LABORATORY (Berkeley Lab) is a U.S. Department of Energy (DOE) Office of Science national laboratory addressing critical national mission needs in discovery science, energy security, environmental sustainability, and international innovation competitiveness. DOE's Office of Science is the nation's largest funder of the physical sciences.

Founded in 1931 by Nobel Prize Winner Ernest Orlando Lawrence, Berkeley Lab has been managed since its inception by the University of California – without taking a profit, leveraging and augmenting the 10 UC campus system and three national laboratories to create scientific productivity greater than the sum of its parts.

University of California Radiation Laboratory Staff in 1938
Caption: Ernest O. Lawrence along with other Radiation Laboratory staff, including Nobel prizewinners Edwin McMillan and Luis Alvarez.

Advanced Light Source (ALS) Staff in Present Day

INVESTING IN SCIENCE EDUCATION

In addition to supporting graduate and post-doctoral research, Berkeley Lab seeks to engage students of all ages and backgrounds in the world of science.

K-12 STEM Education and Outreach Program

Berkeley Lab's K-12 Science, Technology, Engineering, and Mathematics (STEM) Outreach Program includes a variety of initiatives built on relationships with local school districts, community organizations, and employers. Over 2,000 students are served through on- and off-site visits, career panels, virtual sessions and special programs, including:

- Berkeley Lab staff participation in STEM nights, festivals, science fairs and school visits.
- Tours of the lab, a virtual Science Series, Director's Apprenticeship Program, and the Science Accelerating Girls' Engagement in STEM summer camp.
- Annual one-day programs such as Bring A Kid to Work Day and Nuclear Science Day for Scouts (each hosting about 300 students per year).

Workforce Development and Education

- Berkeley Lab is in the top 5 of the largest national laboratory programs under the DOE Office of Science Workforce Development for Teachers and Scientists.
- Between 2014 and 2018, 468 mentors supported 638 undergraduate, post baccalaureate, graduate, and faculty internships.
- Berkeley Lab supports interns from 208 four-year universities, 42 two-year colleges, and represented 384 cities from 2014 to 2018.
- Over 25 percent of all participants from 2014 to 2018 were Underrepresented Minorities (URMs).

Berkeley Lab is located on a 200-acre campus in the hills of Berkeley, California overlooking the San Francisco Bay. The campus includes numerous offices, laboratories, meeting and conference space, overnight accommodations, as well as specialized equipment and facilities that continue to evolve to meet changing needs. Berkeley Lab also has space in west Berkeley that houses Biosciences researchers and Cyclotron Road startups and in the adjacent City of Emeryville that houses the Laboratory-led Joint BioEnergy Institute (JBEI).

The Berkeley Lab user facilities provide state of the art equipment and collaboration resources to scientists around the world to advance scientific discovery and practical applications, including an estimated 14,000 individuals in FY 2020.[5] The approximately 3,130 full time staff in FY 2018, including scientists, engineers, faculty, and other professionals, are joined by students, visiting scholars, and other collaborators who together drive technological growth and innovation. Berkeley Lab's approach is driven by a commitment to diversity and inclusion and a mission to accomplish the following:

- Solve the most pressing and profound scientific problems facing mankind
- Conduct basic research for a secure energy future
- Understand living systems to improve the environment, health, and energy supply
- Understand matter and energy in the universe
- Build and safely operate leading scientific facilities for the nation
- Train the next generation of scientists and engineers
- Become the premier research institution welcoming all backgrounds, cultures, disciplines, and approaches to solve problems together

5 Represents FY 2020 use of Lab User facilities by U.S. scientists (one user agreement can involve multiple users).

Team Science

Ernest Lawrence, whose development of the cyclotron won him the Nobel Prize, pioneered "team science"— the strategy of bringing together large interdisciplinary teams to solve the hardest research and technology challenges. Team science still drives Berkeley Lab today and is utilized across most fields of science around the world. Berkeley Lab's research areas boast a depth and breadth of expertise and tools rarely matched.

Major science and technology areas at Berkeley Lab include:

- **One of the world's most productive HIGH-PERFORMANCE COMPUTING ecosystems** leverages internationally recognized capabilities in supercomputing, artificial intelligence, mathematical modeling, data analysis, computer system architecture and software, and high-speed scientific networking to solve grand challenges for the nation across all fields of science.
- **DOE's largest BIOSCIENCES complex** advances sustainable energy solutions to convert waste streams such as forest and agricultural residues into bio-based fuels and products, as well as engineering biological systems for sustainable manufacturing.
- **Novel advanced MATERIALS AND CHEMICAL SCIENCES research** drives solutions to global energy-related challenges by building deeper understanding of the interactions between energy and matter, beginning at the atomic scale.
- **World leading EARTH AND ENVIRONMENTAL SCIENCES capabilities** enable sustainable stewardship and judicious use of the Earth's subsurface resources; develop low-cost water desalination technologies; and advance our understanding of climate change and impacts (e.g., wildfire and extreme weather).
- **Global leadership in ENERGY TECHNOLOGIES** advances solutions in areas such as energy efficiency; clean energy generation and storage, and protection of indoor and outdoor air quality.
- **Nobel Prize winning PHYSICAL SCIENCES research** embodies Berkeley Lab's historic role in exploring the fundamental forces and particles of matter from deep within the hearts of atoms to the farthest edges of the universe.

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3. Research, Innovation and Knowledge Transfer

BERKELEY LAB's economic contributions start with the cadre of top tier scientists and scholars as well as state of the art facilities and supporting staff that for almost 90 years have been the source of numerous innovations and scientific discoveries with practical applications across numerous fields. Given its core mission to advance science to solve pressing issues facing the country and world, Berkeley Lab regularly shares the results of its work with the broader scientific community and public at large. The Lab continually seeks to solve the pressing issues of the day as demonstrated by its ongoing contributions to addressing the Covid-19 pandemic (see page 12).

Research and Innovation

Berkeley Lab has played an outsized role within the United States' and the world's innovation ecosystems by delivering world leading, high quality peer reviewed science and by building sophisticated, singularly unique research tools and facilities to address big science and societal challenges. With an approximately $1.1 billion annual budget, Berkeley Lab ranks among the world's top research institutions that continue to shape the world in fundamental ways.[6] Since its founding, 14 Nobel Prizes have been awarded to researchers at Berkeley Lab.

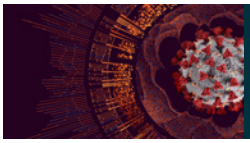
Knowledge Transfer

Berkeley Lab contributes to an immense amount of knowledge used by both academics and professionals to inform and advance various fields and applications. That said, knowledge transfer is a multi-dimensional process that can be relatively difficult to track, let alone quantify. Among other things, it often involves frequent interaction accomplished through both formal and informal channels and usually as part of on-going and collaborative relationships. As such, the metrics provided in subsequent chapters capture many of the outcomes of knowledge transfer from Berkeley Lab.

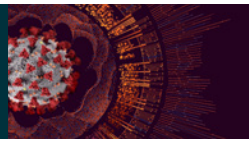
One of the more traditional and transparent forms of knowledge transfer occurs through publication of research, whether in peer reviewed journals, professional trade publications, stand-alone books, and / or conference proceedings. In 2015, DOE policy required that all national laboratory publications be made publicly available. The open access policy has allowed for publications by Berkeley Lab scientists to be accessed by more researchers, companies, and individuals, a trend that will likely expand in the years to come.

Based on available data, Berkeley Lab researchers and affiliated scientists consistently author over 2,000 publications per year.[7] Over the last 10 years (2009-2018), about one-fourth of all Berkeley Lab publications were in the physics and astronomy field, as illustrated in **Figure 5**. Other significant contributions include publications in the chemistry, materials science, engineering, and biochemistry/ genetics/molecular biology subject areas.

6 https://www.natureindex.com/institution-outputs/generate/All/global/government/score
7 Berkeley Lab Publications Management Database (2013-2019)



Berkeley Lab Contributes To COVID-19 SOLUTIONS



BERKELEY LAB's on-going work related to the coronavirus epidemic provides a "real time" lens into how it applies cross-cutting and collaborative science to address pressing issues facing humans and the environment.

With coronavirus research and development funds provided by Congress, the Department of Energy established the National Virtual Biotechnology Laboratory (NVBL), a consortium of National laboratories with core capabilities relevant to the threats posed by COVID-19.

Through support of the NVBL, the unique expertise and resources at Berkeley Lab are being deployed on multiple fronts and in collaboration with industry and scientists from other institutions to advance remedies, vaccines, detection, and other methods with potential to reduce the effect and spread of the virus.

While the work is in various stages of development, the Lab is focusing on areas in which its unique resources have the greatest impact, including:

- Supporting antiviral development with x-ray imaging and nanoscience
- Harnessing high-performance computing and high-bandwidth networking
- Scaling up potential antivirals, and leveraging bioengineering capabilities
- Improving COVID-19 testing capabilities

Industry Engagement – Industry is aggressively leveraging Berkeley Lab resources to speed the delivery of solutions to the coronavirus pandemic. For example, the Advanced Biofuels and Bioproducts Process Development Unit (ABPDU), a DOE Office of Energy Efficiency and Renewable Energy (EERE) bioproducts development facility, is helping two biotech companies ramp up production of potential COVID-19-fighting technologies to meet global demand. One is a highly accurate, easy-to-use testing platform that is much speedier than current diagnostic methods; and the other is a rapid approach for generating antibodies as a potential treatment for COVID-19 infections.

Berkeley Lab is also a part of the DOE Office of Technology Transitions Lab Partnering Service (LPS) that provides web resources and other tools for connecting industry to resources at the national labs. The Coronavirus Treatment Acceleration Program (CTAP) is an online portal of the LPS connecting United States companies with the people and resources at the 17 national laboratories that may be leveraged to deliver scientific advances and new technologies in the fight against the pandemic.

Other examples of important coronavirus research at Berkeley Lab include:

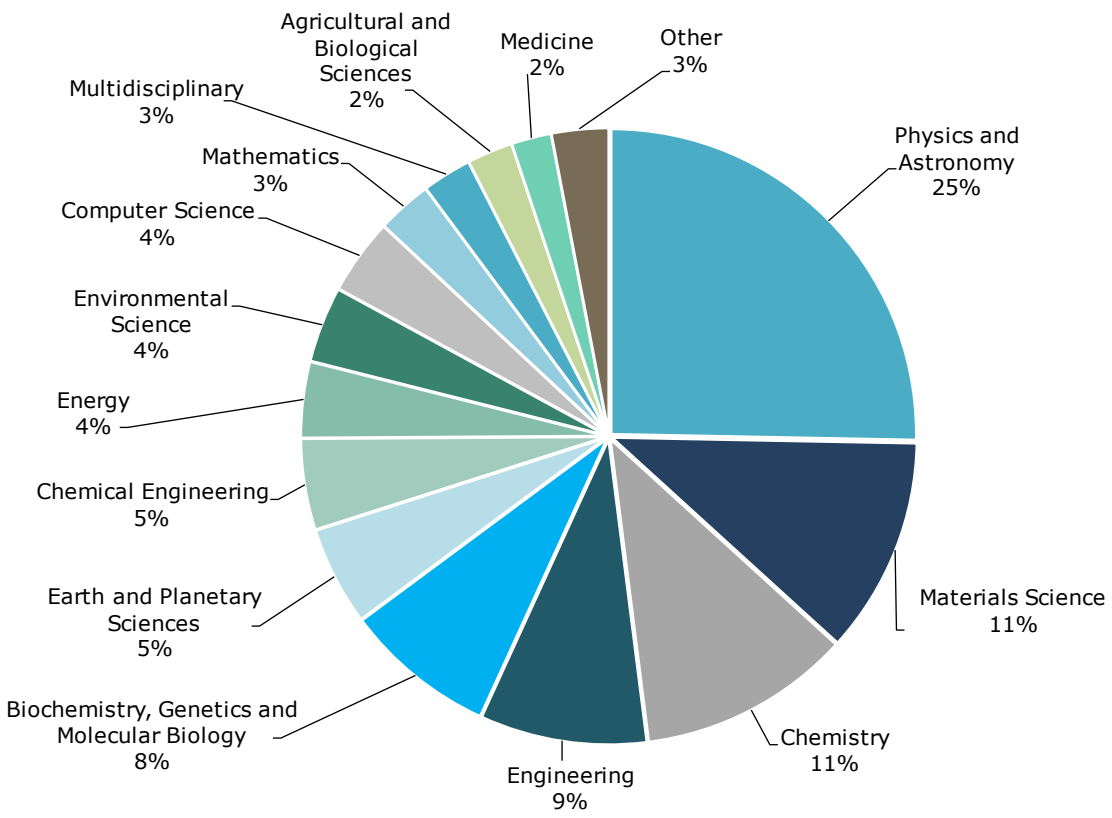
Evolutionary Patterns of SARS-CoV-2 – With the goal of developing computational approaches to study the evolutionary patterns of SARS-CoV-2, Joint Genome Institute (JGI) researchers analyzing over 80,000 coronavirus genomes. Knowledge gained through this research may provide the key to new diagnostics, vaccines, and possible treatments.

Understanding 55 Million Years of Coronaviruses – Berkeley Lab researchers are studying how SARS-CoV-2 fits into the history of coronavirus evolution, about 55 million years of diversification, to determine if it has characteristics similar to seasonal flu. If ancient coronaviruses have swapped genetic material frequently, there is good reason to believe that they will continue to do so. To do this, scientists are utilizing NERSC to computationally generate billions of possible histories then analyze these scenarios to determine which are most likely. The results so far are in line with the emerging scientific consensus: while recombination has taken place, it has not happened recently or often, and is unlikely to be a major factor in how SARS-CoV-2 adapts to human hosts.

Better Testing Capabilities – Lab scientists are leading teams focused on providing alternatives to the instruments and reagents used in current diagnostics. These efforts include (1) evaluating the performance of a digital microfluidic platform for COVID-19 detection, (2) developing computational approaches to optimize COVID-19 diagnostic tests, and developing structure-based protein design for diagnostics.

See: https://sites.google.com/lbl.gov/covid-portal/Berkeley-Lab-COVID-19-Research

Figure 5. Berkeley Lab Publications by Subject Area (2008-2019)



Source: SciVal, © 2020 Elsevier B.V.; Lawrence Berkeley National Laboratory, Economic & Planning Systems

Bibliometric Performance Indicators

So-called "bibliometric" performance indicators are a commonly used tool for measuring the success, merits and impact of published research.[8] Berkeley Lab's publication data is catalogued through several sources, each with slightly different collection protocols. The numbers presented herein are from Elements, Berkeley Lab's internal publications tracking system, and SciVal, a third-party web-analytics tool managed by Elsevier.

SciVal data used for comparison purposes tracks research performance from more than 17,900 research institutions and their associated researchers from 231 nations. It represents the largest abstract and citation database of peer-reviewed literature with more than 70 million publications. The publications data include journals, conference proceedings, trade publications, and stand-alone books.[9]

Based on a variety of metrics and sources, work published by Berkeley Lab scientists gain more views, citations, and are more impactful than other universities and institutions in California and the United States. For instance, the percentage of Berkeley Lab publications published in the past 10 years (2009-2018) in the top scientific journals is higher than for other research institutions on average in California and the

8 The term "bibliometrics" was coined by Alan Pritchard in his 1969 paper entitled "Statistical Bibliography or Bibliometrics?" in which he defined the term as "the application of mathematics and statistical methods to books and other media of communication." (Pritchard, 1969)

9 Most bibliometric techniques lack the ability to measure the impact of scholarly output in non-traditional avenues, such as blogs, Twitter, Facebook and other social media.

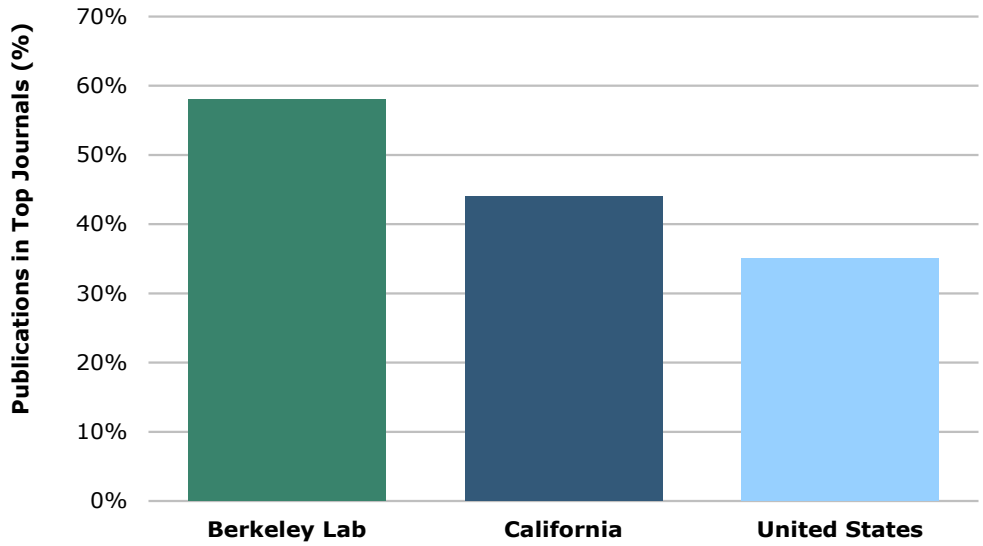
United States.[10] (See **Figure 6**.) Although difficult to quantify, the amount of articles published in top journals reflects high quality research that in turn helps attract additional funding.

A few of the user facilities also track publications by third-party users in high-impact journals as defined by DOE.[11] For example, the research conducted by Advanced Light Source users results in approximately 925 refereed publications per year, 20 percent of which are in DOE high-impact journals. Molecular Foundry users published over 1,000 publications in the three year period from FY 2016 to 2018, 36 percent of which were in DOE high-impact journals.

The following series of charts and graphs illustrate the influence of all Berkeley Lab's publications (not just top 10 percent) relative to other research institutions through a number of SciVal's publication metrics. Each metric includes year 2008 publications (as it often takes a number of years for articles to gain influence) as well as a longer timeline to demonstrate a trend.

As shown in **Figure 7** through **Figure 9**, Berkeley Lab's publications gained more views and citations per publication than other institutions in California and the United States. In other words, articles published by Berkeley Lab have a larger audience and are cited more frequently in papers written by other researchers as compared with the average institution in California or the United States. In addition, Berkeley Lab had a higher patent-citation per scholarly output.[12]

Figure 6. Comparison of Berkeley Lab Publications in Top Journals with Other Institutions



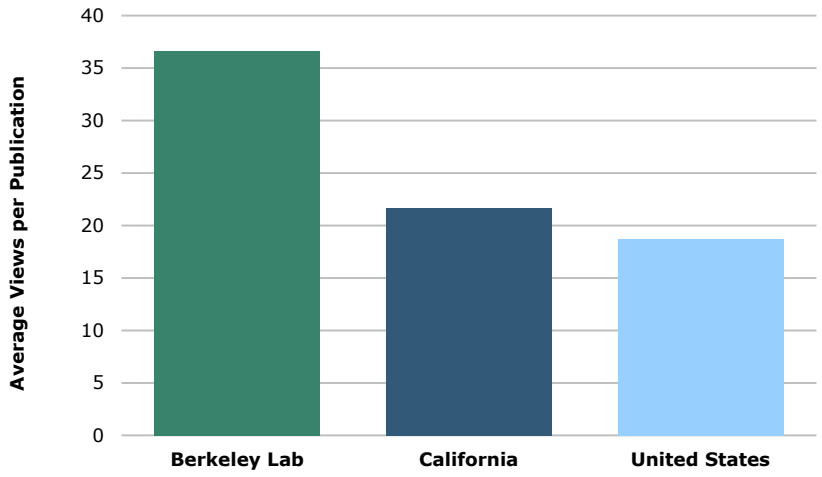
Source: Lawrence Berkeley National Laboratory, SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

10 Defined as the top 10 percent of journals by CiteScore. CiteScore Percentile indicates how a journal ranks relative to other journals in the same subject field.

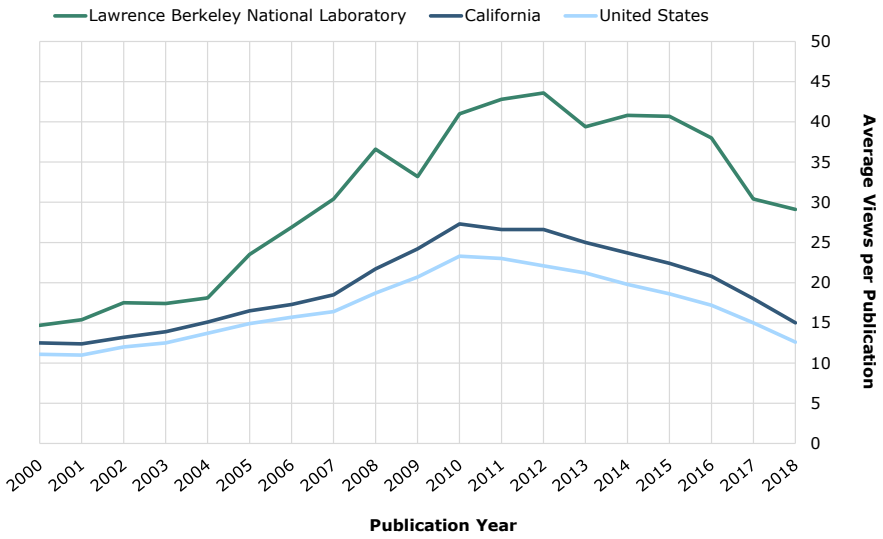
11 There are 20 journals that DOE considers high-impact journals, including Nature and Advanced Materials. The list of high-impact journals may vary for each user facility.

12 SciVal aggregates patents from the five largest patent offices: EPO (European Patent Office), USPTO (US Patent Office), UK IPO (UK Intellectual Property Office), JPO (Japan Patent Office) and WIPO (World Intellectual Property Organization).

Figure 7. Average Citations per Publication is 2008 and by Year

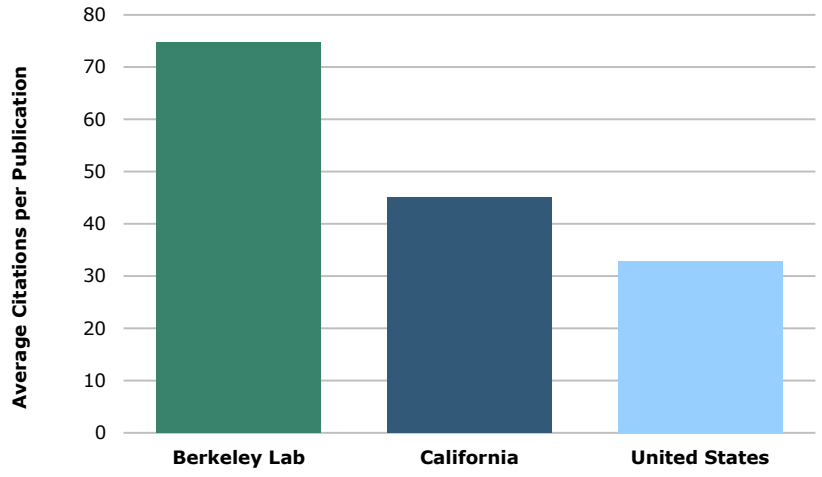


Source: Lawrence Berkeley National Laboratory, SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

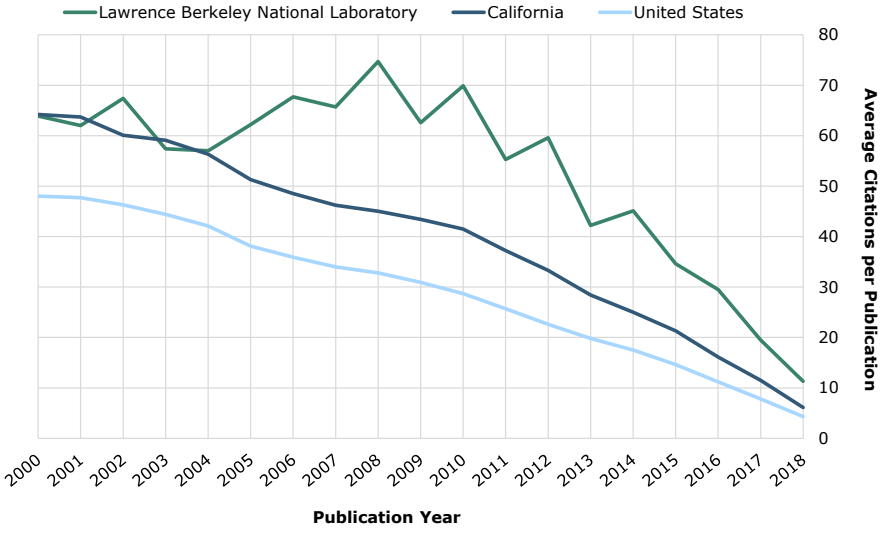


Source: SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

Figure 8. Average Views per Publication in 2008 and Through Time Year

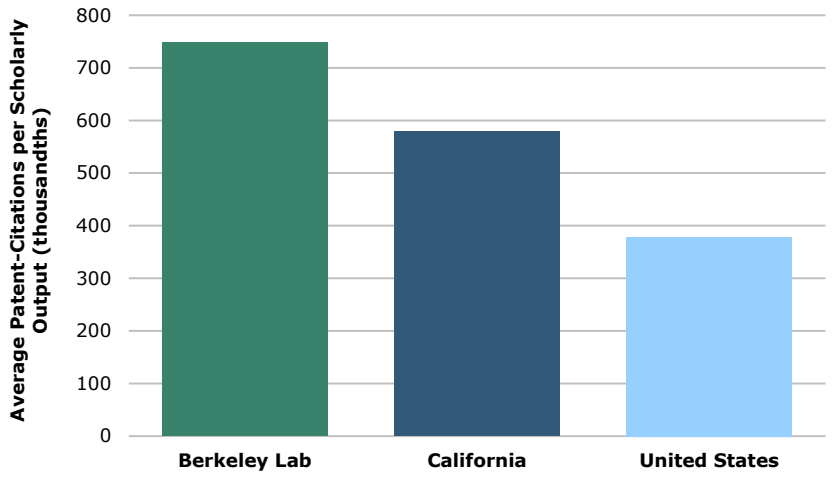


Source: Lawrence Berkeley National Laboratory, SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

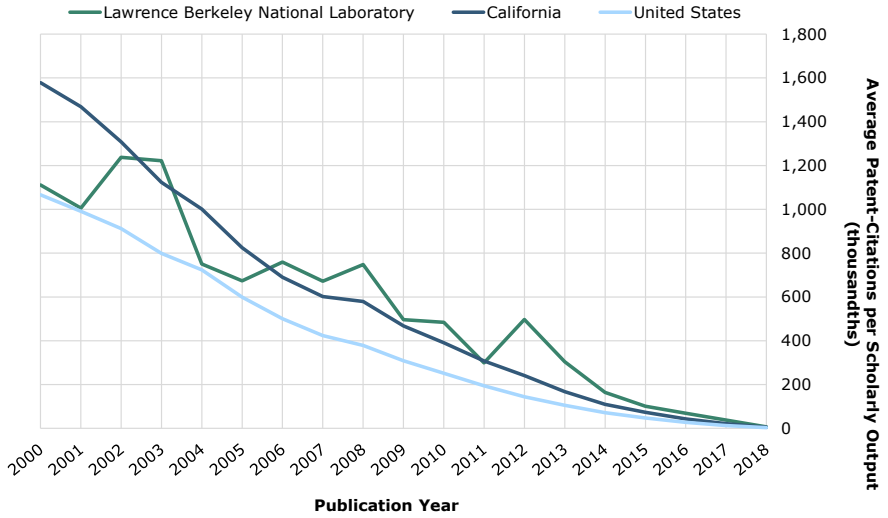


Source: SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

Figure 9. Average Patent-Citations per Scholarly Output in 2008 and by Year



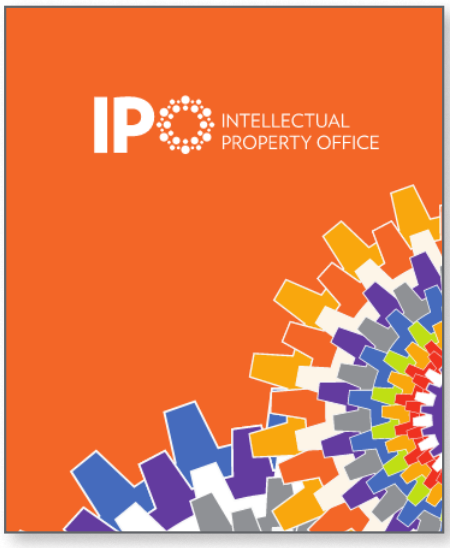
Source: Lawrence Berkeley National Laboratory, SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems



Source: SciVal, © 2020 Elsevier B.V.; Economic & Planning Systems

4. Commercialization and Firm Creation

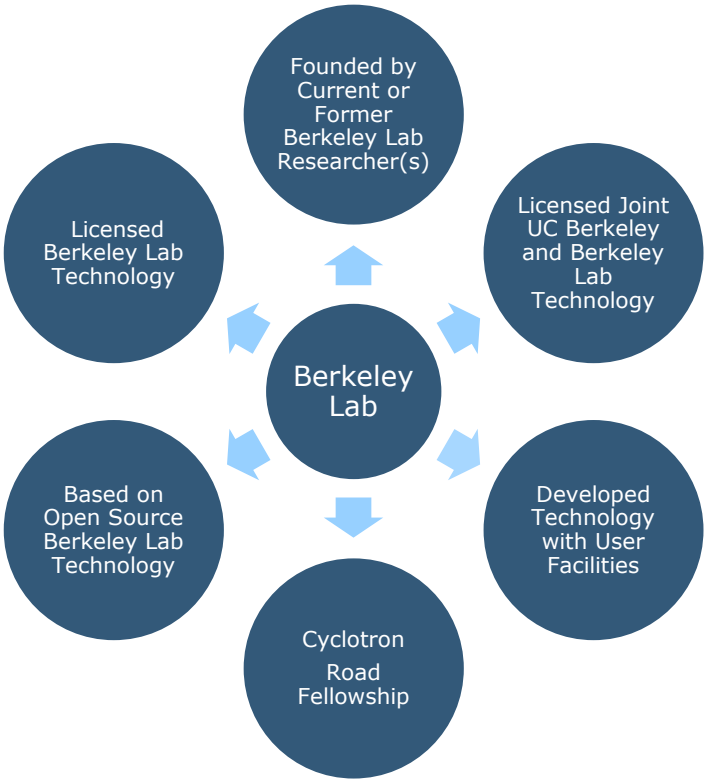
BERKELEY LAB supports a robust commercialization ecosystem as evidenced through its success in obtaining patents, generating licensing revenue, and supporting firm creation. Startups based on Berkeley Lab technology are tracked and involve a formal commercialization and licensing process through the Intellectual Property Office (IPO). Some startups become users of the Lab's scientific research facilities to further advance their technologies. Royalties earned from licensing are invested back into research, with the hope of making even more new discoveries.



Spin-off Firms

Figure 10 demonstrates the numerous ways spin-off firms affiliated with Berkeley Lab are formed. In many cases, Lab affiliated spin-off firms are affiliated with the Lab through more than one of the methods categorized. For example, a startup that licensed technology from Berkeley Lab could continue to use tools at the Molecular Foundry for research and development. Additionally, many firms originate from Berkeley Lab more indirectly, such as startups founded by former Lab researchers, based on collaboration between UC Berkeley (University of California, Berkeley) and the Lab, and / or based on the Lab's open source technology. In addition, numerous firms have originated based on Berkeley Lab programs (e.g., Cyclotron Road Fellowship) and resources (e.g., user facilities).

Figure 10. Berkeley Lab Spin-Off Firm Affiliation Map



Startups Based on Licensed Berkeley Lab Technology

The startups tracked by IPO were founded from 1990 to 2019 and span a wide number of industries including software, pharmaceutical, and battery technology. The tracked companies are those that have relied on licensed Berkeley Lab intellectual property (IP) rights. This list of companies does not include spin-off firms that have been created through the other methods as shown on **Figure 10**.

Of the total 55 Lab affiliated startups tracked by IPO, 55 percent are still active, 25 percent have been acquired by larger companies, and the remaining have either ceased operations or have a currently unknown status.

Figure 11 provides a list of active startup companies and **Figure 12** shows the percentage of Berkeley Lab startups that fall into each category as of 2019. It's worth noting that the percentage of successful startups is much higher for Berkeley Lab than the average startup. According to data from Forbes Magazine reports, about 90 percent of startups fail and 70 percent of tech startups fail within the first few years. In contrast, 80 percent of startups based on Berkeley Lab technology have been acquired or are still active.

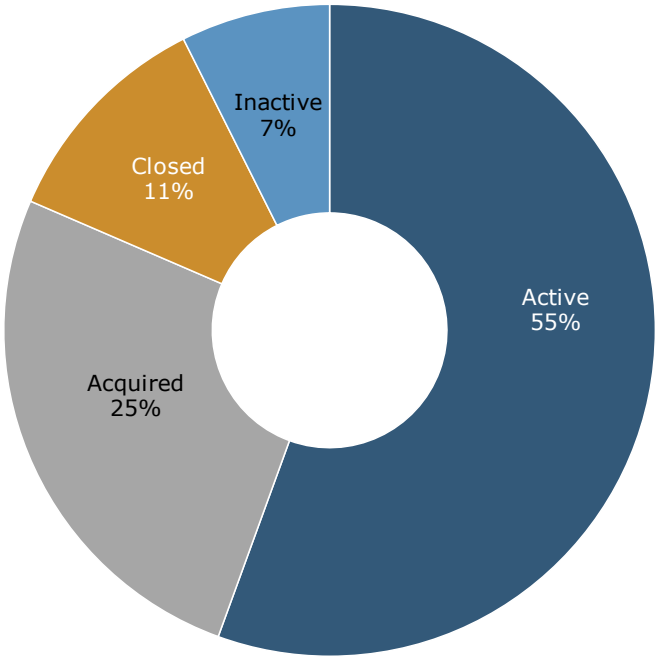
EPS analysis suggests that the 31 active, non-acquired Berkeley Lab startup companies employ approximately 1,866 workers. This estimate was derived based on the most recent data found on company websites, news releases, or crowdsourced employment data platforms (e.g., Owler, LinkedIn). Over three-fourths of jobs are located in the Bay Area, and of the remaining, the majority are located in other states such as Arizona, Texas, Massachusetts, and New Mexico (**Figure 13**).

Figure 11. Active Startups

Company Name	Region	Year Founded
Boost Biomes	Bay Area	2019
Scuba Probe	Bay Area	2019
GraphAudio	Bay Area	2018
EPIC Advanced Materials	CA	2018
Acepodia	Bay Area	2018
Green Light Labs	Bay Area	2018
Sepion	Bay Area	2018
NexTech Batteries	USA	2017
Whisker Labs (formerly Watts	USA	2015
Simple Water	Bay Area	2014
Optokey	Bay Area	2013
Heliotrope	Bay Area	2013
CinderBio (Cinder Biological)	Bay Area	2013
Seismos	USA	2013
Newomics	Bay Area	2013
Peptineo	USA	2013
Da Tung Hydrogen Energy	Bay Area	2013
TeselaGen Biotechnology	Bay Area	2012
Lygos	Bay Area	2011
Second Genome, Inc.	Bay Area	2010
Alphabet Energy	Bay Area	2010
View	Bay Area	2008
Siva Power	Bay Area	2008
Artery Therapeutics, Inc.	Bay Area	2006
Momenta Pharmaceuticals, In	USA	2002
Nanosys, Inc.	Bay Area	2002
Live Cell Assays	Bay Area	2002
Nanomix, Inc.	Bay Area	2001
Aeroseal, LLC	USA	1997
WaterHealth International	CA	1996
PolyPlus Battery Company	Bay Area	1990

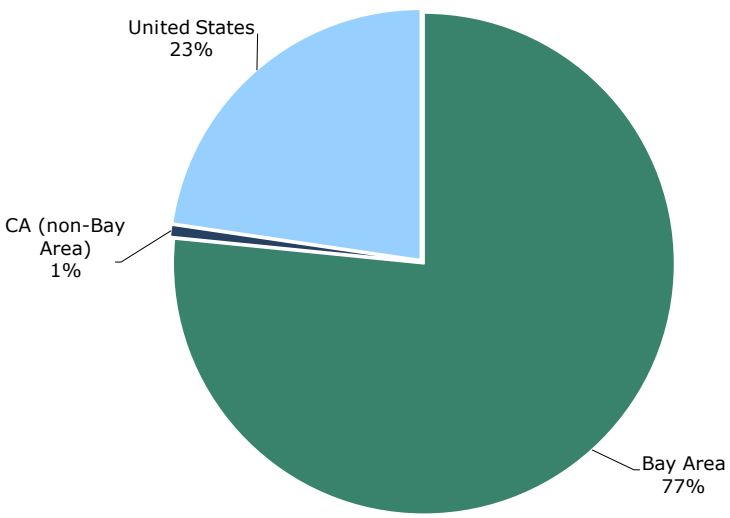
Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

Figure 12. Status of Startups Founded on Berkeley Lab Technology



Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems
Note: Inactive companies are those that are potentially closed but the exact status of the company is unconfirmed.

Figure 13. Berkeley Lab Startup Jobs by Geography



Source: Respective Company Websites and Job Sites (LinkedIn, Owler, AngelList); Lawrence Berkeley National Laboratory, Economic & Planning Systems

Other Startups Affiliated with Berkeley Lab

In addition to the IPO's list of 55 startups, other startups or spin-off firms are linked to the Lab in a variety of ways, including those founded by former employees, in collaboration with UC Berkeley, or based on open source software. The numerous startups that involve collaboration with UC Berkeley are managed by the latter as a joint license, with income shared proportionately.

For example, Berkeley Brewing Science (BBS) is based on research from UC Berkeley and JBEI. BBS sells customized yeast strains to brewers that allow beer to be produced more sustainably with less water, less energy, and fewer greenhouse gas emissions. As another example, the founder of Ansa Biotechnologies worked at a lab located both at UC Berkeley and Berkeley Lab. The company is now developing a DNA synthesis technology that will transform how biological research and engineering is conducted.

CYCLOTRON ROAD
FELLOWSHIP

The Cyclotron Road fellowship program aims to **support entrepreneurial scientists** as they move from research concept to viable first product. Cyclotron Road fills a gap in the existing research ecosystem by focusing on applied technologies that are still too risky or premature to attract private-sector investment.

In collaboration with the DOE Advanced Manufacturing Office, Berkeley Lab launched the program in 2014 to **support research and development in clean power and has expanded to include manufacturing and semiconductors**. Fellows stay at Berkeley Lab for two years to develop a technology project with potential to make a long-term global impact. During the fellowship, fellows have access to facilities at Berkeley Lab and expertise of Berkeley Lab staff scientists.

In addition to winning numerous awards, Cyclotron Road projects have **raised more than $150 million in funding** and **created more than 135 jobs** over the past five years. Today, Cyclotron Road receives funding and support from DARPA, foundations, the California Energy Commission and others.

Patents and Licenses

Berkeley Lab patents and licenses are another area that highlights third-party interest in and economic value of Berkeley Lab innovations and technology. A patent grants property rights to the inventor, issued by the U.S. Patent and Trademark Office. Licensing agreements and royalties are contracts and fee income associated with the use of the patents.

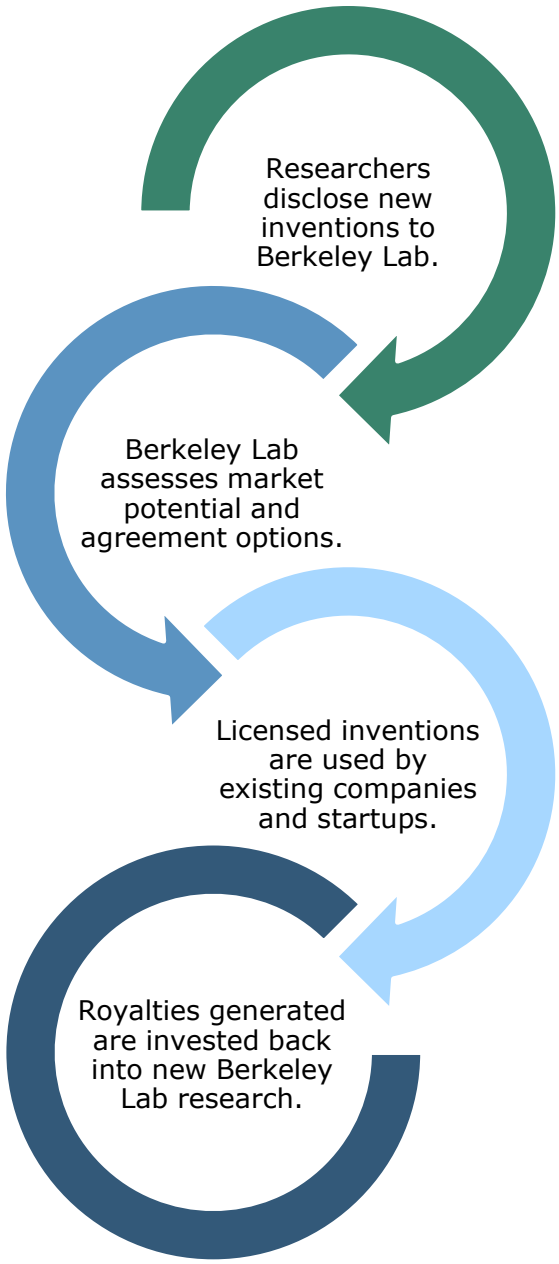
Figure 14 illustrates how the technology licensing process converts research disclosures and inventions into products and services used in the commercial marketplace.[13] At Berkeley Lab, the process begins with disclosures, which indicates the amount of unique inventions by Berkeley Lab researchers. In FY 2018, there were 153 invention and software disclosures and 77 patents were issued to Berkeley Lab and its researchers. Overall, as of April 2020, more than 80 Lab technologies, protected by more than 250 patents and patent applications, are being commercialized by the Lab's licensees.

Licensees range from startups to multinational companies to non-profits. Berkeley Lab's license agreements are set up in a way that is less expensive for academia and non-profits.

Recently licensed and optioned Lab technologies include:

- A portfolio of materials, structural design, and processes for the fabrication and manufacturing of solid oxide fuel cells licensed by Nexceris for use as a power extender in vehicles;
- A library of synthetic promoters to control gene expression in plant cells, optioned by BASF Plant Sciences; and
- A boron nitride (BN) portfolio, licensed by Epic Advanced Materials, offers a unique mix of properties to enable new material applications. These properties include mechanical strength, high thermal conductivity, and electrically insulating behavior.

Figure 14. Technology Licensing Economic Value Pipeline



Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

13 https://today.lbl.gov/2018/10/10/ipo-releases-2018-annual-report/

In addition to the impact on the economy, licensed technologies bring a financial reward to Berkeley Lab and participating scientists. For FY 2019, licensed inventions and copyrighted software and books earned royalties of more than $2,456,000. After patenting costs are reimbursed, 65 percent of net royalties are used to fund Berkeley Lab research through innovation grants and other initiatives, and 35 percent go to the researchers themselves. In FY 2019, 151 Berkeley Lab inventors and affiliates received a total of over $461,000 in royalties.

BERKELEY LAB
SOFTWARE

The majority of Berkeley Lab licenses are in software, including both open source and Lab proprietary software. Berkeley Lab's open source software has led to the creation of new companies and enabled technological innovation in many industries. Code that is selectively made open source (i.e., does not contain any proprietary materials) is available for any researcher to use without cost and can be altered to create new software used for different purposes.

Corelight is an example of a company based on open source software program called Zeek, created at Berkeley Lab. The company has created a tool used to track activity on networks and block cybersecurity attacks. Corelight and Zeek continue to collaborate with Berkeley Lab. The research addresses cybersecurity issues that governments, companies, and individuals face today.

One of Berkeley Lab's most impactful proprietary software creations is TOUGH (Transport of Unsaturated Groundwater and Heat). TOUGH is a suite of software used to model the transport of water and gases. It has wide-ranging applications from nuclear waste disposal to energy production and is used by universities, government organizations, and private industry.

TOUGH3, the latest simulator, is a popular software package used by academic institutions and for-profit companies. The software enables desktop simulations for predictive modeling of varying temperature and flow of gases or liquids, in fractured porous materials.*

* See more information at https://tough.lbl.gov/software/.

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5. Strategic Partnerships and Collaboration

BERKELEY LAB partners on a broad variety of research and technology development projects with industry, academia, state and local governments, foundations, research institutes, and other federal agencies. These partnerships, whether in the form of Strategic Partnerships Projects (SPPs), Cooperative Research and Development Agreements (CRADAs), or User Agreements (UAs), leverage the Lab's unique expertise and resources to not only advance the commercial and technical objectives of the partners, but also the mission imperatives of the Lab and DOE.

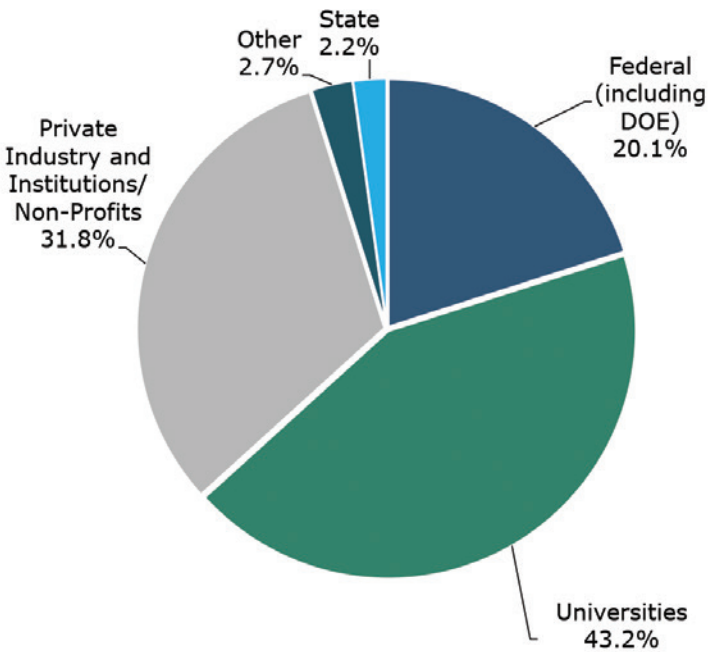
Although economically valuable intellectual property often arises from Berkeley Lab partnerships and collaborations, their impact goes well beyond the traditional metrics of technology transfer. In particular, the relationships are central to the Lab's mission and "team science" approach to addressing challenges. They also spur innovation from the cross-pollination of people and ideas, bringing to the partners a more diverse creation experience, with a myriad of new perspectives and novel approaches to problem solving. As further described below, these partnerships, collaborations, and user agreements offer a range of benefits to all participants and further demonstrate the value of the Lab's specialized fields of inquiry, scientific capabilities, and unique facilities.

Overview

R&D partnerships, collaborations, and user agreements at Berkeley Lab take a variety of forms and can last from a few weeks to several years, depending on the objectives of the Lab's partners. These collaborations with private and public sector partners are developed through the Lab's Strategic Partnerships Office (SPO). SPO supports the Lab's researchers in developing and managing these relationships, and also negotiates and executes the contracts required to formalize project scopes, deliverables and funding.

Overall, the Lab has initiated over 4,600 new agreements totaling about $1.2 billion from 2010 to 2019 (an annual average of 465 new agreements and $122 million). Since 2014, there have been more than 2,000 active agreements with separate organizations. In terms of the composition, slightly over 40 percent of these agreements are with universities while almost a third are with private or non-profit entities, as illustrated in **Figure 15**. Other federal agencies account for about 20 percent of the total.

Figure 15. Percent of Partnership Agreements by Entity Type

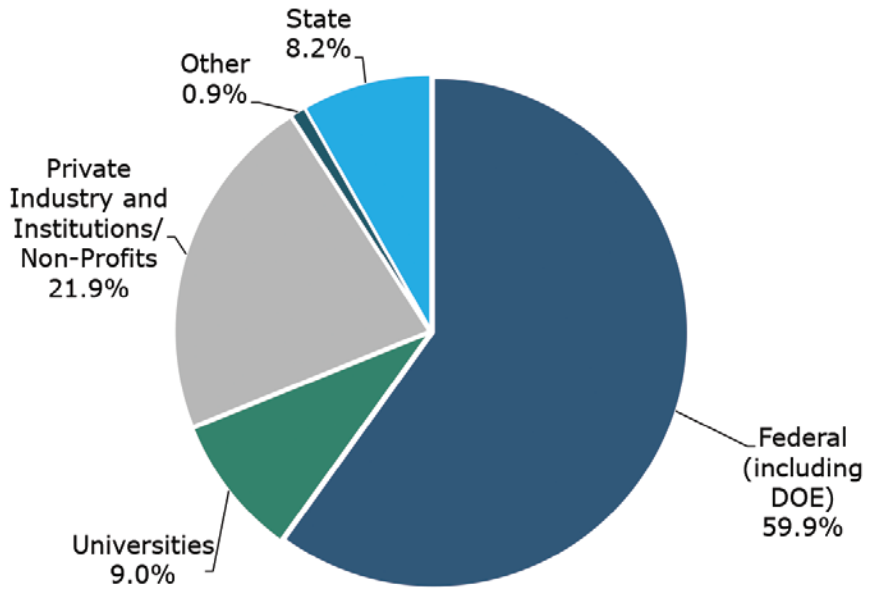


Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

The funding for Berkeley Lab partnerships and collaborations suggest a relatively broad and diverse base of support. While the federal government plays an important role, accounting for about 60 percent of total funding, significant contributions from private industry, non-profits, universities, and state governments demonstrate the value of Lab expertise and facilities to these outside parties (see **Figure 16**).

It is worth noting that the funding estimates understate the total value of contributions from outside entities since many of the agreements are not monetized. For example, participants often provide research support in the form of labor, equipment, or other services. Additionally, not all partnership types require entities to provide funding to Berkeley Lab, as discussed further under the user agreements section below.

Figure 16. Percent of Funding Received by Entity Type



Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

Industry-University-Lab Collaborations

One very productive way for the Lab to work with private sector partners is in joint collaboration with university teams. This enables industry partners to access the complementary capabilities and facilities of researchers with joint appointments and strong relationships with campus colleagues, as the following case study demonstrates.

- **Enhanced carbon capture technology** – Laboratory tests indicate novel materials called metal organic frameworks (MOFs) capture carbon dioxide emissions up to six times more effectively than conventional technology. ExxonMobil, Berkeley Lab, and UC Berkeley researchers demonstrated the ability to utilize MOFs to condense a surface area the size of a football field into just one gram of mass – about the size of a paperclip – to act as a sponge for CO2. The research successfully demonstrated that MOFs are highly selective and could capture more than 90 percent of the CO2 emitted from industrial sources. Not only did this project lead to a high profile publication in the journal Science, it has also set the stage for future development and collaboration.

Strategic Partnership Projects (SPP)

Berkeley Lab offers the option of an SPP to companies and other organizations that wish to harness the capabilities of Lab scientists to advance their research and market objectives. In the past 10 years, new SPPs have generated $451 million in funding through partnerships with private industry and account for 22 percent of all Lab partnerships.

Companies from startups to multinationals and Fortune 500 Companies rarely have either the scientific capabilities and facilities, or the collection of expertise across such broad areas of research as are found at the national laboratories. SPP projects at Berkeley Lab can help fill this gap. For example, the Advanced Biofuels and Bioproducts Process Development Unit (ABPDU) is providing a mixture of technical expertise and bioprocessing capabilities to three early-stage companies. This speeds up solutions to address the coronavirus pandemic – capabilities that would typically be cost prohibitive for these companies. In another example, the Lab's Molecular Biophysics and Integrated Bioimaging Division is working with both industry and academic partners to understand the structure and function of potential coronavirus therapeutics and vaccines (**Page 12** provides more information on the Lab's efforts to address the coronavirus pandemic). Other examples of SPP driven Lab-industry collaboration include:

- **Smog eating roof shingles testing with 3M** - Berkeley Lab researchers collaborated with 3M on the development of a new type of roof shingle that will help reduce air pollution. The shingles' photocatalytic granules, developed by 3M, were evaluated at the Lab to determine effectiveness and performance. The roof shingle granules, which were listed by TIME magazine as one of the best inventions of 2018, work by using sunlight to catalyze reactions that remove pollution from the air.
- **Lithium extraction to drive battery deployment** - Lithium is a key ingredient of most batteries and global demand for it is expected to skyrocket in coming years, growing tenfold by 2030. Sites in the United States, such as the Salton Sea in southern California, are some of the world's largest sources of lithium – however, the lithium is one of many substances in the water and not easily extracted. Working with two companies, Berkshire Hathaway Energy and Hell's Kitchen Geothermal LLC, Berkeley Lab researchers are evaluating and analyzing cutting edge lithium extraction technologies and capabilities to find cost effective and efficient means of separating the lithium. Both projects have recently been awarded grants from the California Energy Commission (CEC).
- **Developing better products with PepsiCo** - Global food and beverage giant PepsiCo utilized Advanced Light Source (ALS) x-ray capabilities to understand more about the chemical structure and behavior of its starch-based snack foods, with the goal of creating a new category of snacks. While most of PepsiCo's chips are cooked with traditional methods such as frying and baking, the company is currently exploring alternative heating methods to give its customers a broader selection of snacks with desirable texture and lower fat content. Using microtomography, an extremely high-resolution, 3D x-ray imaging technique, ALS scientists have been able to create real-time visualizations of proposed new cooking methods. PepsiCo is hopeful that its ALS research will move product development forward.

Cooperative Research and Development Agreements (CRADA)

A CRADA is another mechanism for research and technology development among Berkeley Lab and one or more partners. CRADAs allow the Lab and partners to more closely share resources and costs with even deeper collaboration and joint development than seen in most SPP initiatives and User Agreements. CRADAs are often structured to provide Lab partners the benefits or close collaboration at no cost except for their in-kind labor and material contributions. A CRADA requires any products resulting from the collaboration to be substantially manufactured in the U.S. unless the DOE grants a waiver.

Often focused on precompetitive research and development (i.e., scientific research not intended for protection through intellectual property rights), CRADA collaborations bring together companies that normally compete into close cooperation with one another and with Berkeley Lab to jointly tackle scientific and technological roadblocks or opportunities. The Lab also collaborates on applied and translational research and development projects to de-risk and mature technologies and processes. This allows an acceleration of the partners' commercialization timelines, market impact and growth.

In addition to CalCharge (see sidebar), some other examples of Lab CRADAs in key technology sectors include:

- **Building efficiency targeting tool for energy retrofits (BETTER)** – Developed under a CRADA between Berkeley Lab and Johnson Control, BETTER is a public-access, data-driven tool requiring minimal inputs and short run time to support more energy efficient buildings. The tool can quickly benchmark buildings against peers, quantify energy and cost savings, and recommend energy efficiency improvements. Inputs are minimal (basic building characteristics and utility bill data), resulting in an automatically-generated assessment report that quantifies potential cost savings for a single or entire portfolio of buildings and recommends optimal operational and technological improvements. Berkeley Lab partnered with Johnson Controls to automate and improve the energy analysis capabilities of the tool and create an open-source version for public use.
- **Energy efficiency in automotive painting** – Painting cars is one of the biggest energy expenditures in the U.S. As one of the world's largest paint manufacturers, PPG has a vested interest in increasing energy efficiency and is participating in a DOE program that fosters research partnerships between industry and national labs — High Performance Computing for

ACCELERATING CLEAN ENERGY TECHNOLOGY WITH A CRADA

In 2013, Berkeley Lab and CalCharge launched a CRADA that leverages both entities' resources to conduct **groundbreaking research in energy storage**. The CRADA is well aligned with Berkeley Lab's mission to **advance clean and efficient energy production**.

CalCharge is a consortium of private and public sector entities seeking to **advance the highly competitive field of energy storage**. Members include the California Energy Commission, UC San Diego, Bosch, and Toyota.

Advances in energy storage rely heavily on research and development, a costly process that can require specialized equipment. Through the standardized CRADA, CalCharge members can **swiftly access resources at the Lab's research areas and unique scientific facilities**.

Manufacturing (HPC4Mfg). PPG is now using a CRADA to collaborate with applied mathematicians in the Berkeley Lab Computational Research Division (CRD) to optimize paint design and applications that reduce energy consumption.

National User Facilities

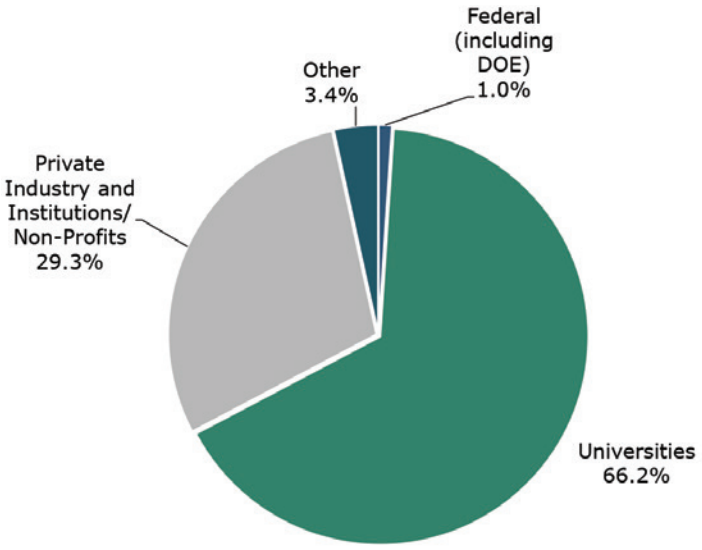
In addition to SPP and CRADA projects, approximately 14,000 individual researchers access Berkeley Lab resources through "User Agreements" (UAs).[14] These UAs provide the mechanism through which researchers utilize four of Berkeley Lab's five DOE National User Facilities: the Advanced Light Source (ALS), the Molecular Foundry, the Joint Genome Institute (JGI), and the National Energy Research Scientific Computing Center (NERSC). As DOE's high speed scientific network and a Berkeley Lab user facility, ESnet serves all researchers within the national laboratory complex.

Each of the five user facilities is designed to provide researchers and institutions access to the world's leading scientists and powerful scientific instruments. Because of the more cross cutting, collaborative, and often longer-term nature of the research activities at these user facilities, specific economic impact metrics can be more challenging to directly pinpoint (and there is no requirement that user benefits be systematically reported). Additionally, many of the metrics highlighted elsewhere in this study were at least partially attributable to work done at the user facilities.

Depending on the project and the facility, users can either work on-site with facility staff or access their capabilities remotely. Researchers access these facilities free of charge, provided they agree to publish their results. Proprietary UAs are available for a charge to researchers who choose not to make their results publicly available.

A UA can provide access for as short as a day, a week, or as long as 16 years, depending on the specific research needs. In the past 10 years, Berkeley Lab awarded 2,600 UAs (annual average of 260 UAs). A UA is associated with a larger entity such as a university and, in most cases, provides access for multiple individual researchers. Almost all of the UAs in the past 10 years were with non-federal entities, and only 5 percent were proprietary (see **Figure 17**). In other words, a large proportion of the users are conducting non-proprietary research, which encourages collaboration and improves access to knowledge. Additionally, the significant participation by universities (66 percent) and private or non-profit entities (about 30 percent) demonstrates the broad level of interest in Lab facilities.

Figure 17. Percent of User Agreements by Entity Type



Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

One good example of industry leveraging Berkeley Lab's user facilities is how the Molecular Foundry, a nanoscale science center, hosts roughly 50 companies each year. Estimates suggest that an average of 3.3 jobs are created and $1.9 million is raised by these companies as a result of each project. Other examples can be found in the **Appendix**.

14 Represents FY 2020 use of Lab User facilities by U.S. scientists (one user agreement can involve multiple users).

One advantage of having a variety of user facilities on site is that scientists at Berkeley Lab can utilize multiple user facilities for a single study. A study by the Molecular Foundry found that 40 percent of publications used at least one other Berkeley Lab user facility.

Recently, three user facilities were used for a study on flow batteries, a type of battery that has applications in energy grids, renewable energy, and electric vehicles. The study identified a cheaper, high-performing alternative for a component that could potentially reduce the cost of the batteries.

- **NERSC** supercomputers were used to simulate key structures
- **The Molecular Foundry's** instruments were used to synthesize novel materials
- **ALS**' x-ray instruments were used to image the molecular components of new materials and understand their characteristics

Figure 18 provides an overview of the Berkeley Lab User Facilities and selected metrics. A further description of each is provided in the **Appendix**.

Figure 18. User Facility Overview

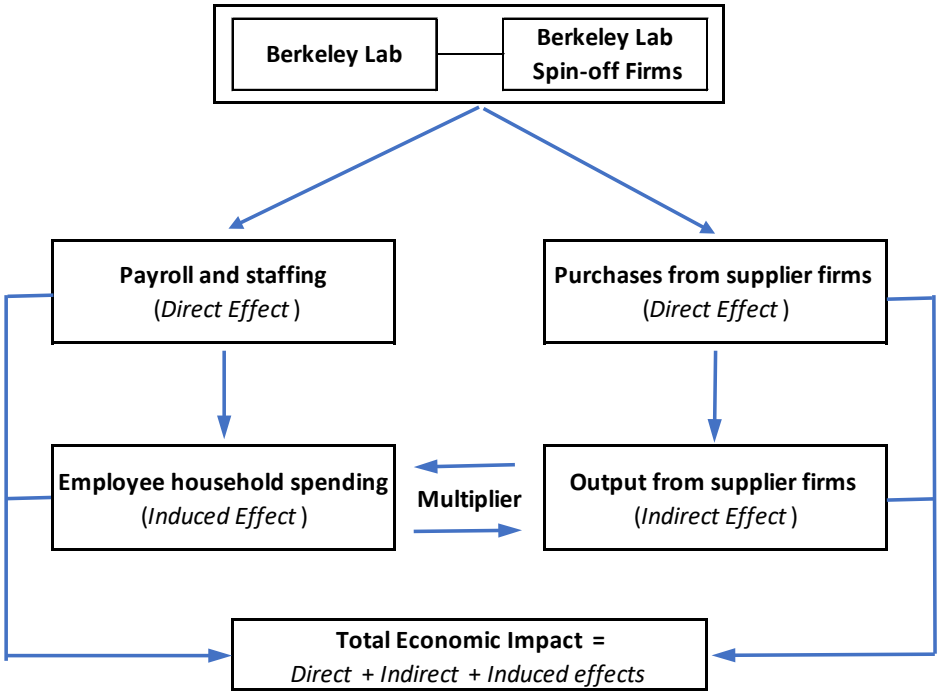
Advanced Light Source: *Specialized particle accelerator that generates bright beams of x-ray light through ≈40 beamlines to experimental end stations.*
• Hosts 50 to 100 on-site users at a time and 2,000 on-site and remote users annually (ranging from one hour to 10 days)
• 925 annual publications, 20% in "high-impact journals"
Energy Sciences Network (ESnet): *A high performance, unclassified network built to support scientific research and the entire DOE National Lab system.*
• Linked to more than 200 research and educational networks around the world
• Carries more than 90 petabytes a month or more than an exabyte per year
Joint Genome Institute: *Multi-disciplinary research in support of the Human Genome Project.*
• 2,000 unique users in FY 2020
• Generates ~300 human genome equivalents in plant and microbial DNA per day
• Generated 326 trillion letters of genetic code in 2019
Molecular Foundry: *State-of-the-art expertise, methods, and knowledge in nanoscale science and host to National Center for Electron Microscopy.*
• 1,500 users in FY 2020
• 150 users on-site daily (ranging from several weeks to over a year)
• Over 1,000 publications, 36% in high-impact journals from FY 2016-2018
National Energy Research Scientific Computing Center (NERSC): *The mission high performance computing facility for the DOE Office of Science.*
• Over 8,000 users annually
• 10,000 million computing hours every year
• Nearly 2,500 peer-reviewed publications involving computing at NERSC published in 2019

6. Payroll, Contracting, and Procurement

Spending on payroll, contracting and procurement by Berkeley Lab, and the startups founded through its technologies, generate "ripple" or "multiplier" effects in the local, regional, and national economy.[15] Due to successive rounds of spending, the total jobs, worker compensation, and economic output attributable to Berkeley Lab and its technologies are greater than the sum of its parts.

This analysis relies on IMPLAN (Impact Analysis for Planning) software, a Multi-Regional Input-Output (MRIO) model. MRIO analysis is premised on the concept that industries in a geographic region are interdependent and thus the total contribution of any one establishment is larger than its individual (direct) output and/or employment. This economic modeling framework is illustrated **Figure 19** and further described in the **Appendix**. Key input assumptions and results are described below.

Figure 19. Berkeley Lab Primary Economic Impacts Flowchart



15 This study takes into account Berkeley Lab's effect on the economy of the 9-County Bay Area, the State of California, and the United States. The 9-County Bay Area refers to the counties that surround the San Francisco Bay and includes San Francisco, Marin, Sonoma, Napa, Solano, Contra Costa, Alameda, Santa Clara, and San Mateo.

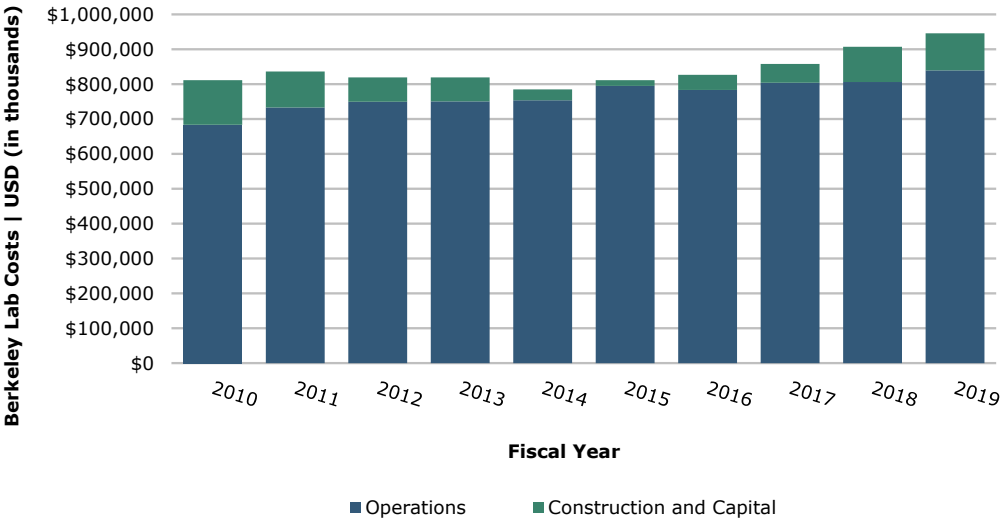
Impact from Berkeley Lab Spending

Berkeley Lab spending on staff, programs and projects has increased steadily over the last 10 years, with funding exceeding $1 billion in FY 2018.[16] As illustrated in **Figure 20**, the bulk of Berkeley Lab costs are associated with annual operations, most notably its on-going research and development programs and the staff needed to undertake them. Capital projects, such as the development of new facilities and sophisticated instruments have accounted for between 5 and 10 percent of the total budget.

The Fiscal Year 2018 Annual Financial Report and Annual Lab Plan identifies a workforce of 3,525 employees that include paid students, scientists, and a variety of operational and management positions with total operating cost of $805.8 million. Overall, about 80 percent of the funding is through the DOE, with the remaining 20 percent coming from other sources, including other federal agencies, the State of California, the private sector and other research organizations. These other sources help leverage the return on investment to taxpayers.[17]

Over the past 10 years (FY 2010 to 2019), Berkeley Lab's average construction and capital spending was approximately $78 million per year. In FY 2018, Berkeley Lab allocated over $100 million to construction and capital improvements, with about $44 million in new construction and $57 million in capital improvement.[18] Future spending (FY 2021 to 2026) is estimated to be around $95 million per year.[19]

Figure 20. Berkeley Lab Costs Over the Past 10 Years



Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

16 Funding for Berkeley Lab has exceeded actual costs in recent years due to forward funding of projects and time allotted for project preparation.
17 These estimates were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.
18 In this analysis the economic impact of capital and construction assumes $91 million, as a small portion of the total is in fact dedicated to operations and labor.
19 Future spending is based on current funding timelines and is discounted based on labor expenses covered in operational spending. Future spending is subject to Department of Energy budget requests and federal appropriations.

Newly Constructed Integrative Genomics Building

Several recent projects include the Advanced Light Source Upgrade, the Dark Energy Spectroscopic Instrument, and the recently completed Integrative Genomics Building, home to staff of the Joint Genome Institute, the DOE Systems Biology Knowledgebase, and the National Microbiome Data Collaborative.

Figure 21 shows the total economic impacts from Berkeley Lab's operation and capital spending by geography based on its direct employment and output. In particular, it illustrates the direct, indirect and induced economic impacts based on the spending patterns associated with the economic sectors most closely aligned with Berkeley Lab. For operations, the analysis is based on the "scientific research and development services" sector while construction also includes the "construction of commercial buildings" sector.

As shown, Berkeley Lab's 3,525 direct jobs from operations plus about 500 jobs associated with its capital projects generate about 6,570 Bay area jobs, 7,500 California jobs, and 12,630 jobs in the U.S. due to ripple or multiplier effects. This equates to total employee compensation of $627.8 million in the Bay Area, $697.2 million in California, and $920.4 million in the U.S. The total impact increases with larger geographies due to spending leakage.[20]

Figure 21. Total Economic Impact from Berkeley Lab Spending

Economic Impact	Employment	Employee Compensation	Value Added	Economic Output
Bay Area				
Direct Effect	3,813	378,700,000	573,300,000	860,100,000
Indirect Effect	1,190	134,300,000	203,500,000	297,900,000
Induced Effect	1,569	114,800,000	210,700,000	312,100,000
Total Impact	**6,571**	**$627,800,000**	**$987,500,000**	**$1,470,100,000**
California				
Direct Effect	3,819	379,600,000	574,600,000	862,200,000
Indirect Effect	2,019	197,100,000	300,100,000	460,900,000
Induced Effect	1,669	120,500,000	221,200,000	329,100,000
Total Impact	**7,507**	**$697,200,000**	**$1,095,900,000**	**$1,652,200,000**
United States				
Direct Effect	3,954	389,500,000	589,100,000	897,000,000
Indirect Effect	3,360	237,400,000	394,300,000	648,300,000
Induced Effect	5,314	293,500,000	569,100,000	927,800,000
Total Impact	**12,628**	**$920,400,000**	**$1,552,500,000**	**$2,473,100,000**

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems

20 These estimates were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.

Inclusion of Berkeley Lab Startups

As described earlier, Berkeley Lab tracks and supports business startups that originate from the Lab and license its technology, providing on-going technical expertise, access to facilities and equipment, and other services. The economic impact of the 30 active startups are estimated based on EPS research on the number of employees in each and the economic multipliers associated with their industry sectors. Overall, it is estimated that for every job created by a Berkeley Lab startup, an additional 2.7 jobs are created in the United States.[21]

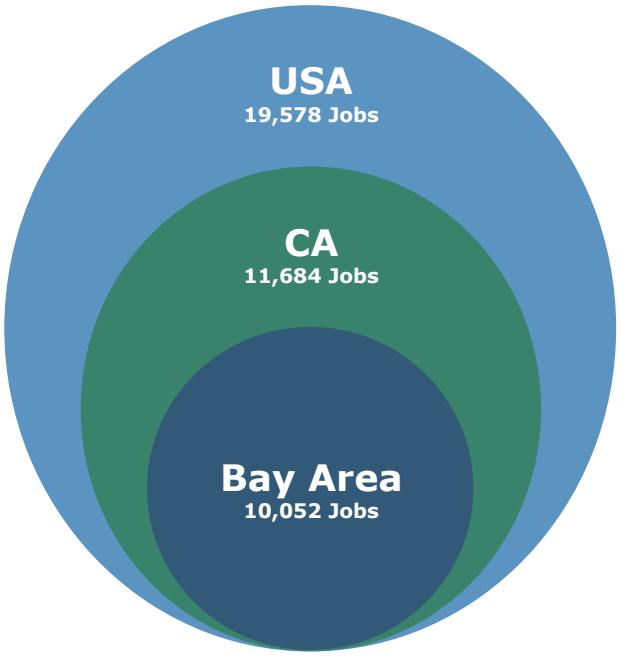
As illustrated in **Figure 22**, when the output and jobs from these firms is included, Berkeley Lab's ripple effects are even more significant at every geographic level. Specifically, the total employment attributable to Berkeley Lab increased by over 50 percent to about 10,000 in the Bay Area, 11,700 in California and close to 20,000 nationwide. In the Bay Area, one in every 500 jobs is represented in Berkeley Lab's primary economic impact. In California, around one in every 2,000 jobs is represented in Berkeley Lab's primary economic impact, and in the nation, one in every 10,000 jobs is captured by Berkeley Lab's primary economic impact.

The combined effect of these spin-off firms, and the fact that about 20 percent of Berkeley Lab's funding is leveraged through non-federal sources (e.g., industry), creates a particularly strong return-on-investment for the U.S. taxpayer. In particular, for every $100,000 in federal dollars invested, Berkeley Lab creates approximately two U.S. jobs, $102,000 in worker compensation, and $276,000 in total output.[22]

Figure 22. Combined Effect of Berkeley Lab Activities on Total Jobs by Geography

Expenditure Category	Bay Area	California	United States
Operations	6,140	7,003	11,400
Capital and Construction	432	504	1,228
Startups	3,480	4,177	6,950
Total Jobs	10,052	11,684	19,578

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems



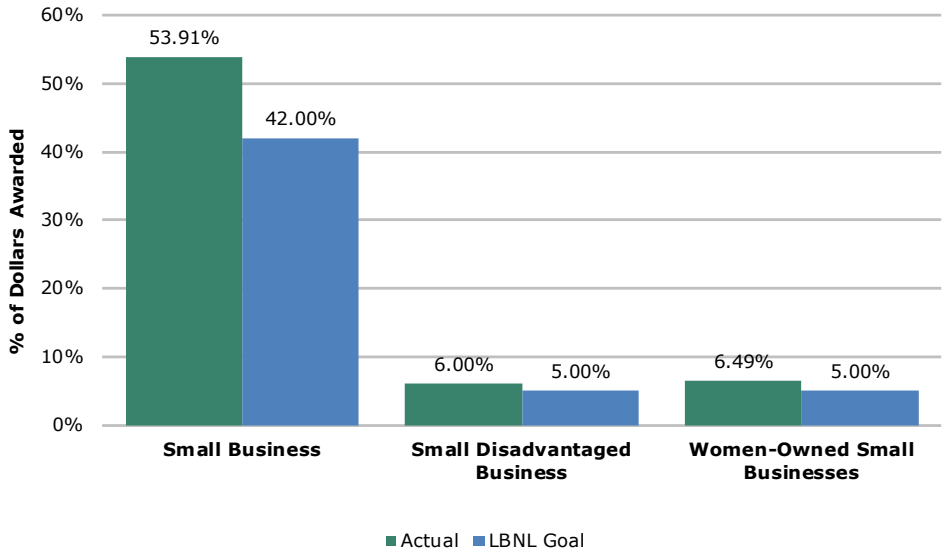
21 The economic impact of spin-off firms is based on IMPLAN default multiplier for the "scientific research and development services" sector. The multiplier differs slightly from the Berkeley Lab multiplier that is based on actual employment levels.
22 These estimates were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.

Small Business Procurement

Berkeley Lab's Small Business Program sets annual goals for the percentage of dollars awarded to small businesses, and has exceeded those goals each year (**Figure 23**). In FY 2018, 54 percent of all contract dollars awarded went to small businesses, exceeding the year's goal of 42 percent.

Goals were also set and exceeded for contracts awarded to small disadvantaged businesses and women-owned small businesses. The Small Business Program has been the recipient of numerous awards recognizing Berkeley Lab's continued commitment to sourcing from small businesses.

Figure 23. FY 2018 Small Business Procurement Goals



Source: Lawrence Berkeley National Laboratory 2018 Annual Report (Page 61), Economic & Planning Systems

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Appendix

BERKELEY LAB

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1: Overview of Study Approach

This Report documents the range of economic benefits generated by Berkeley Lab through its scientific endeavors and research facilities. Berkeley Lab has commissioned Economic & Planning Systems, Inc. (EPS) to conduct this study using well accepted methodologies and data sources. The results focus on quantifiable metrics, to the extent possible, but also includes anecdotal information to provide context.

This Report builds on a variety of on-going efforts to document and profile the scientific discoveries, innovations, and collaborations emanating from Berkeley Lab and associated commercial applications. By way of example, Berkeley Lab regularly provides information on its patents, licensing agreements, industry partnerships, and commercial spin-offs. Berkeley Lab also commissioned an economic impact study in March 2010. This new study builds on many of these previous and related efforts to provide a comprehensive and up-to-date look at all of Berkeley Lab's various programs and facilities in the context of California and the nation's current economy.

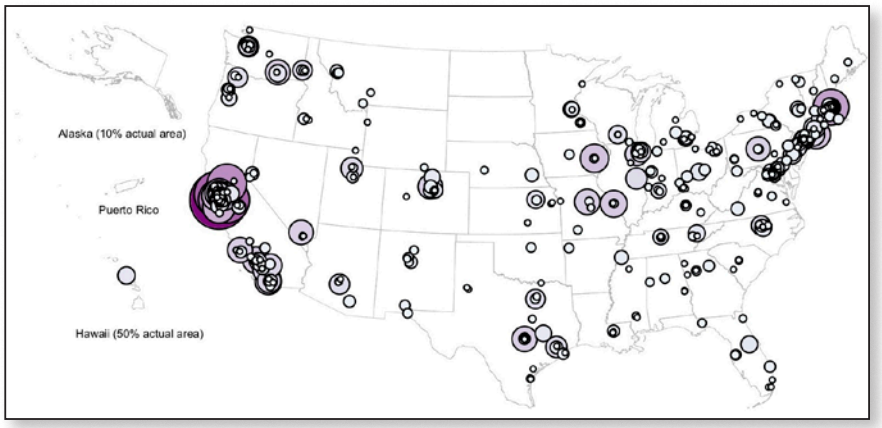
EPS research is based on existing Berkeley Lab reports and publications as well as numerous staff interviews starting in October 2019. For example, the Intellectual Property Office was able to provide resources and data on Berkeley Lab's commercialization and technology transfer activities. For data on Berkeley Lab's publications, EPS consulted with Berkeley Lab's Scientific Publications team.

Additionally, EPS met with representatives from various Berkeley Lab departments and User Facilities to discuss key milestones, on-going research and collaborations, and other activities with immediate real-world applications. Finally, EPS conducted additional follow up research using various online and vendor databases, such as Sci-Val.

The remainder of this **Appendix** provides further information on the study methodology, data, and supporting information.

2: Description of User Facilities

Figure A-1. ALS Users Across the United States (FY 2015-2017)



Advanced Light Source (ALS)[23]

The ALS is a specialized particle accelerator used by scientists to conduct research in fields such as materials science, biology, chemistry, physics, and environmental sciences. Bright beams of light generated by the accelerator, spanning wavelengths from the infrared through higher-energy x-rays, are directed down 40 beamlines to experimental endstations where research is conducted. The ALS' unique capabilities attract researchers from all over the U.S. as well as other countries.

Within the complex of five light source user facilities supported by the DOE Office of Science, the ALS's specialty is lower-energy, "soft" x-rays. Researchers from academia, industry, and government seek out the ALS to gain further insight into their research topic and gain access through a peer-reviewed proposal process. Approximately 7 percent of users are funded by industry and the majority of the remaining users are funded by federal government agencies (e.g., DOE, NSF). Typically, the ALS hosts 50 to 100 users at a time and over 2,000 per year, including those who use the facility remotely by shipping samples. An on-site user might stay anywhere from one hour to 10 days to conduct their research. The research conducted by ALS users results in nearly 1,000 refereed publications per year, 20 percent of which are in high-impact journals as defined by the DOE.

The ALS has contributed to fundamental knowledge and developments in diverse areas of science. Using ALS x-rays, drug discovery company Plexxikon was able to optimize its highly successful drug to treat metastatic melanoma, Zelboraf. In addition, the ALS's specialized "soft" x-rays have allowed researchers to track chemical reactions inside lithium-ion batteries in real time, learning how to avoid lithium-rich "hot spots" that shorten battery lifetime.

Energy Sciences Network (ESnet)[24]

This multi-100Gbps fiber optic backbone stretches across the country and beyond, interconnecting the DOE's national laboratory system and experimental facilities with more than 200 research and commercial networks around the globe. ESnet's high-speed interconnectivity enables tens of thousands of scientists to access data portals, transfer vast research data streams, and tap into remote instruments and sources—all in real time. It is 5,000 times faster than a typical home network and carries anywhere from 80 petabytes to one exabyte of data each month.

The integration of experimental, networking, and computational facilities is giving scientists the ability to make a giant leap forward in gaining insight from massive datasets. This is especially critical as the

23 https://newscenter.lbl.gov/2019/11/07/grid-battery-for-renewable-energy/
https://newscenter.lbl.gov/2009/03/03/synthetic-biology-can-help-extend-anti-malaria-drug-effectiveness/
24 http://es.net/news-and-publications/esnet-news/2019/the-technological-heavyweight-youve-probably-never-heard-of-esnet/

instruments they use become more sophisticated and data production increases exponentially.

Using the Linac Coherent Light Source (LCLS), bio-scientists are exploring the process of photosynthesis in exquisite detail to discover new types of renewable energy. In the Photosystem II experiment, they are merging advanced data science algorithms with the LCLS data to investigate the first link in the chain of photosynthesis that captures photons and uses energy to extract electrons from water molecules. Using ESnet's high-speed connection, scientists send 60 to 100 Gigabyte datasets from the LCLS to NERSC in under a minute, where supercomputers analyze the data and transmit the results back to Stanford Linear Accelerator Center (SLAC) in near real time. Future Photosystem II experiments at the LCLS-II will generate even larger datasets, that will need petaflops of available supercomputing resources to reconstruct this data. As another example, the Dark Energy Spectroscopic Instrument (DESI) that is currently being installed (described in Capital Expenditures) will rely upon ESnet to manage datasets.

Joint Genome Institute (JGI)

The Joint Genome Institute is committed to enabling the worldwide research community to advance the field of genomics in support of DOE missions related to renewable biofuels and bioproducts, and environmental characterization and cleanup, by generating, analyzing, and distributing publicly the DNA code of plants and microbes.

From the 1990s to the early 2000s, JGI played a key role in the Human Genome Project, which is one of the world's largest collaborative biological research initiatives. Subsequent studies indicated that the 13 year effort to map out the human genome generated almost $800 billion in global economic impact.[25]

BIOTECH INNOVATION AT JGI

Over thousands of years, the domestication of crop plants and livestock have enabled a system of agriculture that has fueled and fed vast populations. To serve the growing global population, the Joint Genome Institute has developed a new technology – "CRAGE" – that facilitates the rapid introduction of genes or entire complex biosynthetic pathways into microbial host strains so that they can serve as cellular factories for producing:

- Sustainable/renewable biofuels and bioproducts from plant biomass
- Biomaterials
- Agricultural products
- Pharmaceuticals
- Alternative foods

Strain engineering represents an emerging market currently valued at over $300 million/year and CRAGE is available for licensing opportunities across these diverse industry segments.

[https://www.prnewswire.com/news-releases/global-strain-gauges-market-2017-2023-market-to-grow-from-286-million-in-2016-to-346-million-by-2023-300573862.html]

Scientist Using DNA Sequencer
Source: Berkeley Lab

25 https://www.battelle.org/docs/default-source/misc/battelle-2011-misc-economic-impact-human-genome-project.pdf

JGI's contribution to genome research continues to pay dividends with the Lab generating about 326 trillion letters of genetic code from plants and microbes in 2019 alone. This is the equivalent of characterizing 300 human genomes per day or a city of over 108,000 in an entire year.

Every year, thousands of users benefit from the knowledge and tools hosted by the JGI. In FY 2020, JGI hosted just over 2,000 unique users. Users are defined as researchers competing for JGI resources through peer reviewed proposals submitted to JGI. In FY 2019, JGI hosted around 18,000 registered data users. Registered data users are those who access JGI data or use JGI computational tools.

Molecular Foundry

The Molecular Foundry provides state-of-the-art expertise, methods, and knowledge in nanoscale science. It is one of five nanoscale research centers funded by the DOE and hosts the National Center for Electron Microscopy.

From nanoscale imaging to nanofabrication and assembly, users at the Molecular Foundry gain access to cutting-edge instruments and expertise that are applied to a diverse array of sectors. For example, in 2017 Molecular Foundry and Magic Leap Inc. developed technology that would allow for advancements in augmented reality. The research was inspired by butterfly wings, which use nanoscale architecture to produce colors without pigments or dyes.

Through its review process, the Molecular Foundry grants user access to a diverse set of researchers. In FY 2016-2018, proposals were submitted from 46 states and 39 countries. Over 130 companies also submitted proposals, 90 percent of which were small businesses. Larger industry users included Intel, Seagate, ExxonMobil, and Hewlett Packard.

The Molecular Foundry Building

Depending on specific project needs, users may be on-site from anywhere from a few weeks to over a year. The average stay is about three months. On any given day, there are hundreds of active projects and around 150 users on-site. In FY 2020, the Molecular Foundry hosted over 1,500 users. From FY 2016-2018, over 1,000 publications resulted from research conducted at the Molecular Foundry, 36 percent of which were in high-impact journals as defined by DOE.

Of the industry users who embark on projects, the Molecular Foundry has measured the economic benefits of using its resources. In a 2018 survey, industry users reported an average of 1.2 pieces of intellectual property, 0.3 peer-reviewed publications, $1.9 million in funds raised, and 3.3 jobs created over the course of their respective projects at the Molecular Foundry. At the time of the survey, half of the projects were still ongoing and not yet completed.

National Energy Research Scientific Computing Center (NERSC)

The National Energy Research Scientific Computing Center (NERSC) is the primary scientific computing facility for the DOE Office of Science. Central to its mission is the ability to enable computational science at scale. Interdisciplinary teams of scientists are able to work on fundamental problems in science and engineering.

NERSC is a valuable resource for all non-defense related research projects requiring high performance computing. More than 8,000 scientists used NERSC in FY 2020 for a combined 10,000 million computing hours. The majority of users are from universities and DOE labs. In 2018, small businesses used 21 million hours and other industry users were provided 6 million hours. In the past 15 years, six scientists or projects affiliated with NERSC have been awarded the Nobel Prize.

Research conducted using NERSC often has significant scientific and economic impacts. NERSC is not a supercomputer, it is a supercomputing facility that deploys and maintains multiple supercomputers, such as Edison (which was decommissioned in 2019), Cori, and the next-generation Perlmutter system maximized for artificial intelligence. Perlmutter, debuting in 2021, is a Cray pre-exascale system based on the "Shasta" platform. It will be a heterogeneous system comprised of both CPU-only and GPU-accelerated nodes with a performance of 3 to 4 times that of Cori, NERSC's current platform. Perlmutter is designed to speed scientific productivity and will include a number of innovations designed to meet the diverse computational and data analysis needs of NERSC's user base. The new system derives performance from advances in hardware and software, including a new Cray system interconnect, code-named "Slingshot", which is designed for data-centric computing. Slingshot's Ethernet compatibility, advanced adaptive routing, first-of-a-kind congestion control, and sophisticated quality of service capabilities improve system utilization and performance scalability of supercomputing and AI applications and workflows. The system will also feature NVIDIA GPUs with new Tensor Core technology, direct liquid cooling, and will be NERSC's first supercomputer with an all-flash scratch filesystem. Developed by Cray to accelerate I/O, the 35-petabyte Lustre filesystem will move data at a rate of more than 5 terabytes per second. The next NERSC supercomputer system is deploying in early 2021.

MANUFACTURING RESEARCH AT NERSC

Research using NERSC resources has led to discoveries that could significantly reduce manufacturing costs for some of the largest industries in the United States.

In 2017, researchers at Berkeley Lab and Lawrence Livermore National Laboratory (LLNL) used NERSC supercomputers and related computational research algorithms to model the paper manufacturing process.

Using these models, scientists can study methods to save water and energy. Increasing paper dryness by 10 to 15 percent would lead to $400 million in reduced energy costs.

In 2018, researchers at the DOE's Pacific Northwest National Laboratory (PNNL) used NERSC computing power to conduct simulations of a "self-healing" cement with applications for the oil and gas industry, which typically spends over $1.5 million per well to repair cement cracks.

If applied, the cement-polymer combination would repair itself in a few hours and could dramatically decrease the cost of energy production.

At the same time NERSC is expanding its high performance computing capabilities, it is also attracting more users by dedicating significant effort towards educating the next generation of scientists through its programs. NERSC is also at the center of DOE's top priorities in science, including artificial intelligence, exascale computing, and quantum computing.

Figure A-2. Nobel-Prize Winning NERSC Users

3: Input-Output Analysis Framework

Model Overview

To measure the economic impact of spending on payroll, contracting and procurement by Berkeley Lab, and the startups founded through its technology, EPS relies on IMPLAN (Impact Analysis for Planning) software, a Multi-Regional Input-Output (MRIO) model. The model and software draw on data from several state and federal sources, including the Bureau of Economic Analysis, Bureau of Labor Statistics (BLS), and the Census Bureau. Results reflect the most current data available from IMPLAN (2018).

MRIO analysis is premised on the concept that industries in a geographic region are interdependent and thus the total contribution of any one establishment is larger than its individual (direct) output and/or employment. Specifically, an establishment's economic activity has a "multiplier" effect that generates successive rounds of spending and output in other economic sectors in and beyond a particular region.

The analysis begins with an estimate of the initial economic injection associated with Berkeley Lab expenditures on operations, capital investment, and construction. This initial round of spending is referred to as the direct effect. Next, the model quantifies the impacts associated with the ripple or multiplier effects that result from Berkeley Lab's expenditures. The ripple effects are categorized as indirect or induced effects. Indirect effects represent economic impacts on suppliers while induced effects represent economic impacts on household income and spending.

In this Report, direct, indirect, induced, and total effects are defined as follows:

- The **Direct Effect** is a measure of the economic value of the initial injection of spending into the economy that is made by Berkeley Lab and its employees.
- The **Indirect Effect** is a measure of the economic value of "upstream" industry-to-industry transactions that supply inputs to the production of goods and services consumed by Berkeley Lab and its employees.
- The **Induced Effect** is a measure of the economic value of labor income that recirculates in the economy as a result of the initial expenditures made by Berkeley Lab and its employees.
- The **Total Impact** is the sum of the direct, indirect, and induced effects. The total impact measures the overall impact of Berkeley Lab activities on the economy.

This Report measures economic significance using common economic metrics, including employment, employee compensation, output, and value added, as defined below.

- **Employment** is equivalent to jobs, a headcount that includes part-time and full-time workers.
- **Employee Compensation** represents payments to labor in the form of both income and fringe benefits paid by the employer (e.g., health, retirement).
- **Value Added** represents a contribution to gross regional product and equals the market value of the final goods and services produced within a particular region. Value added is equal to economic output, as defined below, less the value of intermediate goods and services.
- **Economic Output** represents a measure of economic activity, calculated as production value including intermediate inputs (i.e., the goods and services used in the production of final products). Output includes spending on employee compensation as well as the production value of each intermediate input, such as equipment, supplies, insurance, rents, utilities, communication services, printing, and other goods and services.

Berkeley Lab Operating Cost Impacts

Figure A-3 illustrates Berkeley Lab funding by source. As shown, total operating cost was $805.8 million in FY 2018, with about 80 percent funded through the DOE. Within the DOE-funded project costs, approximately 64 percent of projects are funded by the Office of Science. Additional DOE funding has been provided by the offices of Energy Efficiency and Renewable Energy and Environmental Management. Meanwhile, about 20 percent of Berkeley Lab's budget is funded by other sources, including the private sector and research organizations.

Figure A-4 shows the total economic impacts from Berkeley Lab's operations by geography based on its direct employment and output. In particular, it illustrates the direct, indirect and induced economic impacts based on the spending patterns associated with the "scientific research and development services" sector. By way of example, the 3,525 direct jobs create an additional 2,615 jobs in the Bay area economy, 3,478 in the State, and 7,875 in the U.S. due to ripple or multiplier effects. This equates to total employee compensation of $237 million in the Bay Area, $301 million in California, and $482 million in the U.S. The total impact increase with larger geographies due to spending leakage.[26]

Figure A-3. Operating Expenditures by Source

Funding Source	FY2018 Costs	% of Total
Department of Energy		
Administrator for National Nuclear Security Administration	$8,956,000	1.11%
Advanced Research Projects Agency - Energy	$4,392,000	0.55%
Assistant Secretary for Electricity Delivery & Energy Reliability	$7,671,000	0.95%
Assistant Secretary for Energy Efficiency & Renewable Energy	$78,272,000	9.71%
Assistant Secretary for Environmental Management	$16,187,000	2.01%
Assistant Secretary for Fossil Energy	$9,134,000	1.13%
Assistant Secretary for Nuclear Energy	$2,417,000	0.30%
Assistant Secretary for International Affairs	$3,374,000	0.42%
Office of Energy & Threat	$147,000	0.02%
Office of Energy Policy & Systems Analysis	$641,000	0.08%
Office of Environment, Health, Safety and Security	$42,000	0.01%
Office of Legacy Management	$141,000	0.02%
Office of Science	$517,636,000	64.24%
Office of the Chief Information Officer	$81,000	0.01%
Subtotal	$649,093,000	80.55%
Other Sources		
Other Federal Agencies	$46,674,000	5.79%
Other[1]	$110,100,000	13.66%
Subtotal	$156,723,000	19.45%
TOTAL	**$805,816,000**	**100%**

[1] Other includes Non-Federal Sponsors, Cooperative Research and Development Agreements, DOE Integrated Contractors

Source: Lawrence Berkeley National Laboratory, Economic & Planning Systems

26 The estimates in Figure A-4 on the following page were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.

Figure A-4. Berkeley Lab Operations Impact by Geography

Economic Impact	Employment	Employee Compensation	Value Added	Economic Output
Bay Area				
Direct Effect	3,525	$353,300,000	$540,300,000	$805,800,000
Indirect Effect	1,134	$128,600,000	$194,600,000	$283,200,000
Induced Effect	1,481	$108,400,000	$198,900,000	$294,600,000
Total Impact	**6,140**	**$590,300,000**	**$933,800,000**	**$1,383,600,000**
California				
Direct Effect	3,525	$353,300,000	$540,300,000	$805,800,000
Indirect Effect	1,909	$187,400,000	$284,900,000	$434,600,000
Induced Effect	1,569	$113,400,000	$208,100,000	$309,500,000
Total Impact	**7,003**	**$654,000,000**	**$1,033,400,000**	**$1,549,900,000**
United States				
Direct Effect	3,525	$353,300,000	$540,300,000	$805,800,000
Indirect Effect	3,052	$215,600,000	$359,300,000	$582,600,000
Induced Effect	4,823	$266,400,000	$520,100,000	$842,000,000
Total Impact	**11,400**	**$835,300,000**	**$1,419,700,000**	**$2,230,400,000**

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems

Capital / Construction Cost Impacts

In FY 2018, Berkeley Lab allocated over $100 million to construction and capital improvements. This includes $44 million in construction spending and $57 million in capital improvement spending. For capital improvement spending, $47.2 million out of the $57 million is attributable to procurement spending on significant projects. The majority of the remainder are labor costs included as employee compensation in operations costs. The resulting $91 million figure of construction and capital procurement spending is used to determine the economic impact of capital and construction spending.

BERKELEY LAB CAPITAL PROJECTS

Integrative Genomics Building (IGB)

The Integrative Genomics Building (IGB), completed in November 2019, is a 77,000 gross square foot, four-story research and office building located on the Berkeley Lab Campus. The new building accommodates approximately 300 occupants and is home to staff from DOE research programs of the Joint Genome Institute (JGI), Systems Biology Knowledgebase (KBase) and a new initiative, the National Microbiome Data Collaborative (NMDC). These programs include research initiatives in bioenergy, carbon cycle, biogeochemistry, and systems to promote computer modeling of gene and protein functions.

The Advanced Light Source Upgrade (ALS-U)

The ALS is one of the world's most powerful tools for soft x-ray science and one of five DOE user facilities at Berkeley Lab. The ongoing upgrade of the ALS is designed to enhance its capabilities, enabling transformative science, with applications in energy storage, computing, and more, that cannot be performed on any existing or planned light source in the world.

(*continued*)

Figure A-5 shows the total economic impacts from Berkeley Lab's FY 2018 capital and construction spending by geography based on its direct employment and output. In particular, it illustrates the direct, indirect and induced economic impacts based on the spending patterns associated with the *"construction of commercial buildings"* sector for construction spending and *"scientific research and development services"* for capital spending.[27]

Figure A-5. Berkeley Lab Construction and Capital Spending Impact by Geography

Economic Impact	Employment	Employee Compensation	Value Added	Economic Output
Bay Area				
Direct Effect	288	$25,400,000	$33,000,000	$54,300,000
Indirect Effect	56	$5,700,000	$8,900,000	$14,700,000
Induced Effect	88	$6,400,000	$11,800,000	$17,500,000
Total Impact	**432**	**$37,500,000**	**$53,700,000**	**$86,500,000**
California				
Direct Effect	294	$26,300,000	$34,300,000	$56,400,000
Indirect Effect	110	$9,700,000	$15,200,000	$26,300,000
Induced Effect	100	$7,100,000	$13,100,000	$19,600,000
Total Impact	**504**	**$43,100,000**	**$62,600,000**	**$102,300,000**
United States				
Direct Effect	429	$36,200,000	$48,800,000	$91,200,000
Indirect Effect	308	$21,800,000	$35,000,000	$65,700,000
Induced Effect	491	$27,100,000	$49,000,000	$85,800,000
Total Impact	**1,228**	**$85,100,000**	**$132,800,000**	**$242,700,000**

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems

27 These estimates were developed by EPS based on data from the 2018 Annual Financial Report. EPS consulted the Budget Office on the methodology for all estimates not directly contained in the Financial Report. The Budget Office is not the source of these calculations.

BERKELEY LAB CAPITAL PROJECTS

Dark Energy Spectroscopic Instrument (DESI)

Described as the most ambitious galaxy-mapping project ever by Nature Research, DESI will enable astronomers to search for answers to fundamental cosmology questions. According to the DESI team, "over its 5-year observing lifetime, DESI will measure the spectra of more than 30 million galaxies and quasars covering 14,000 square degrees. The instrument will provide unprecedented multi-object spectroscopy incorporating a novel design. The long-awaited instrument is designed to explore the mystery of dark energy, which makes up about 68 percent of the universe and is speeding up its expansion."

Future Projects

Significant projects slated for future years include the ESnet6 implementation, which is described as the next-generation network for the research community. The update is expected to be completed in 2023 and will include new equipment, eight times the capacity of ESnet5, and advanced cybersecurity capabilities. In addition, NERSC's next supercomputer system is expected to be delivered in 2021. Named "Perlmutter" in honor of Saul Perlmutter who shared the 2011 Nobel Prize in Physics, the new exascale-era system is designed to leverage cutting-edge GPU and CPU processors and software services.

By way of example, the $91 million in direct capital and construction spending generates an estimated 144 jobs in the Bay area economy, 210 in the State, and 799 in the U.S. after accounting for ripple or multiplier effects. This equates to total employee compensation of $12 million in the Bay Area, $17 million in California, and $49 million in the U.S. Again, the total impact increases with larger geographies due to spending leakage.

Startup Spending Economic Impacts

Figure A-6 shows a summary of FY 2018 economic impacts generated by startups founded on Berkeley Lab technology. The results are driven by the number of employees that the 30 active startup companies collectively have and are shown for the Bay Area, California, and United States.

Based on the employees located in each geography, the Berkeley Lab startups generate over $1 billion in economic output in the Bay Area, $1.2 billion in the State, and over $1.4 billion nationwide. For every job created by a Berkeley Lab startup, an additional 2.7 jobs are created in the United States.[28, 29]

Figure A-6. Berkeley Lab Startup Impact by Geography

Economic Impact	Employment	Employee Compensation	Value Added	Economic Output
Bay Area				
Direct Effect	1,429	$295,600,000	$434,900,000	$600,300,000
Indirect Effect	847	$96,100,000	$145,400,000	$211,700,000
Induced Effect	1,204	$88,100,000	$161,700,000	$239,500,000
Total Impact	**3,480**	**$479,800,000**	**$742,100,000**	**$1,051,500,000**
California				
Direct Effect	1,443	$297,800,000	$438,100,000	$605,300,000
Indirect Effect	1,448	$141,600,000	$215,500,000	$329,100,000
Induced Effect	1,286	$92,800,000	$170,300,000	$253,400,000
Total Impact	**4,177**	**$532,200,000**	**$823,900,000**	**$1,187,700,000**
United States				
Direct Effect	1,866	$213,300,000	$304,500,000	$541,000,000
Indirect Effect	2,049	$144,800,000	$218,300,000	$391,100,000
Induced Effect	3,035	$167,700,000	$296,300,000	$529,900,000
Total Impact	**6,950**	**$525,700,000**	**$819,100,000**	**$1,461,900,000**

Source: IMPLAN, Lawrence Berkeley National Laboratory, Economic & Planning Systems

28 The economic impact of spin-off firms is based on IMPLAN default multiplier for the "scientific research and development services" sector. The multiplier differs slightly from the Berkeley Lab multiplier which is based on actual employment levels.
29 These estimates were developed by EPS based on data from IPO. EPS consulted IPO on the methodology for all estimates not directly provided. IPO is not the source of these calculations.

4: Acronyms and Abbreviations

ABPDU

Advanced Biofuels and Bioproducts Process Development Unit

ALS

Advanced Light Source

ALS-U

Advanced Light Source Upgrade

Berkeley Lab

Lawrence Berkeley National Laboratory

BES

Department of Energy Office of Basic Energy Sciences

BLS

Bureau of Labor Statistics

CRADA

Cooperative Research and Development Agreements

DESI

Dark Energy Spectroscopic Instrument

DOE

Department of Energy

ESnet

Energy Sciences Network

EPS

Economic & Planning Systems, Inc.

IGB

Integrative Genomics Building

IMPLAN

Impact Analysis for Planning

IPO

Intellectual Property Office

I/O

Input/ Output

JGI

Joint Genome Institute

JBEI

Joint BioEnergy Institute

KBase

DOE Systems Biology Knowledgebase

LCLS

Linac Coherent Light Source

NASA

National Aeronautics and Space Administration

NERSC

National Energy Research Scientific Computing Center

NIH

National Institutes of Health

NMDC

National Microbiome Data Collaborative

NSF

National Science Foundation

MRIO

Multi-Regional Input-Output

SLAC

Stanford Linear Accelerator Center

SPP

Strategic Partnership Project