University of Colorado
Boulder

April 2018
Version 1.3

A case study of the Biochemistry Cell Culture Facility at the University of Colorado Boulder: avoided costs and other benefits resulting from shared equipment in collaborative research space

Christina Greever
CU Green Labs Program Assistant

Theresa Nahreini
Cell Culture Facility Manager

Kathryn Ramirez-Aguilar, PhD
CU Green Labs Program Manager

CU Green Labs is jointly funded by the Environmental Center and Facilities Management

University of Colorado
Boulder

Table of Contents

I. Abstract

With scientists experiencing intense competition for federal biomedical research funding, efficiency and cost-saving measures are powerful tools to maximize the impact of those research dollars (1, 2). The large environmental footprint of laboratory research facilities and equipment (3, 4, 5, 6), coupled with growing awareness of climate change, also points to laboratory resource efficiency as a contributing critical goal for the future of our planet. This case study examines a progressive approach to cell culture research that is highly efficient, resulting in substantial cost avoidance and a smaller environmental footprint. The Biochemistry Cell Culture Facility (BCCF) at the University of Colorado Boulder (CU Boulder) is a shared scientific resource utilized by 16 labs from three departments. Studying the comparative costs to build and operate the BCCF shared-space versus a hypothetical scenario where 16 labs are built to conduct cell culture in individualized spaces allows us to understand the avoided costs for campus scientists and their institutions made possible through streamlining in this shared facility. The BCCF is providing a cost avoidance of $253,000 per year to CU Boulder with $195,000 per year of those avoided costs realized directly by scientists and the Biochemistry Division, and the remaining $58,000 per year realized by Facilities Management and building management. Through a projected cost analysis, we estimate that new construction of the BCCF would cost $804,000 less than the hypothetical scenario mentioned above; renovation of existing laboratory space to create the BCCF would cost $274,000 less than the hypothetical scenario. Furthermore, a cost avoidance of $288,000 is realized for the purchase of new, shared equipment for the BCCF since it requires less equipment than the hypothetical scenario. Based on square footage of the BCCF as compared to the hypothetical scenario, the shared facility provides a space savings of 30 percent. Additional components of this case study include a brief history of the BCCF, a phone survey of biosafety officers at peer institutions, a BCCF end-user survey, and a cost analysis of the number of labs required for effective implementation of a shared facility. This case study demonstrates that a shared cell culture facility can provide qualitative benefits and significant avoided costs to scientists and their academic institutions. Moreover, integrating shared research assets into grant proposals as a best practice would demonstrate prudent use of grant funding, thus strengthening proposals.

II. Introduction

The Biochemistry Cell Culture Facility (BCCF) of the Biochemistry Division, Department of Chemistry and Biochemistry at the University of Colorado Boulder (CU Boulder) is a successful example of shared equipment in collaborative research space at a large research institution. Besides being a more efficient use of equipment, research space, and numerous other qualitative benefits, the facility provides cost avoidance each year for CU Boulder and the scientists utilizing this resource. All values, data, and pricing represented in this case study are from 2015-2016 unless otherwise noted.

The BCCF is not a fee for service core. There are 70 active users from 16 laboratories that use the Biosafety Level 2 facility, and most labs have multiple users in the facility each day. These users represent three departments: the Biochemistry Division of the Department of Chemistry and Biochemistry; Chemical and Biological Engineering; and Molecular, Cellular, and Developmental Biology. The BCCF is 1,554 square feet of shared research space located in the

LEED Platinum Jennie Smoly Caruthers Biotechnology Building (JSCBB) completed in 2012. The facility accommodates scientists who wish to conduct general cell culture as well as primary, viral, insect, and large-scale cell culture. It also supports research involving bacterial invasion of mammalian cell hosts. Much of the existing equipment has been donated over the years by faculty who either use the facility themselves and are willing to share the equipment with other users or who no longer have use for the equipment in their own labs.

The BCCF is supervised by one full-time Facility Manager who ensures the facility is in operational order for its many users. Among other duties, the Facility Manager prepares approximately 1,200 liters of cell culture media in-house each year, provides training to new facility users, and orders and stocks supplies. Though a designated Facility Manager is not necessarily required for a shared facility to be a success, having one significantly increases a favorable outcome and is highly beneficial to all users.

There are many benefits to labs sharing both specialized and general lab equipment as well as research space. For example, sharing equipment contributes to more efficient use of research funds, can attract new talent to a department by showcasing equipment resources available to potential candidates, promotes collaboration, reduces laboratory plug loads, can save a department funds in the form of offering smaller startup packages, and is in compliance with the Code of Federal Regulations (7, 8, 9) which are the rules published in the Federal Register by the executive agencies of the Federal Government. Sharing equipment also leads to more efficient use of laboratory space, which is one of the most expensive types of facilities on any campus to build and maintain (5, 10). Currently at 100 percent capacity, there is high demand to join the BCCF. Since 2012, seven different labs at CU Boulder and two external companies have requested to become users of the facility but have been turned away due to lack of space, thus demonstrating the success of this model and the untapped potential to develop more shared cell culture space in this building and on our campus.

III. Biochemistry Cell Culture Facility: Past to Present

The BCCF was formed around 1990 by three Principal Investigators (PIs) from the Biochemistry Division in the Department of Chemistry and Biochemistry who pooled their resources to create a shared facility. It began with a microscope, two incubators, and two biosafety cabinets, all donated by the three PIs involved. Together, the initiating PIs hired a technician and student helper to support the facility with media preparation, serum testing, biosafety cabinet maintenance, and training of new users. They each contributed equally to support 25 percent of salary and benefits for the staff, and divided the remaining 75 percent based on the number of users of the facility per laboratory. Even though the Biochemistry Division and department initially contributed no funds toward the development of the BCCF, as new faculty were hired, more PIs found a need to use cell culture in their research and benefitted from the availability of the facility. When the number of investigators in the BCCF grew to approximately ten labs, the shared facility was formalized and became partially supported by the Biochemistry Division (11), as it remains today.

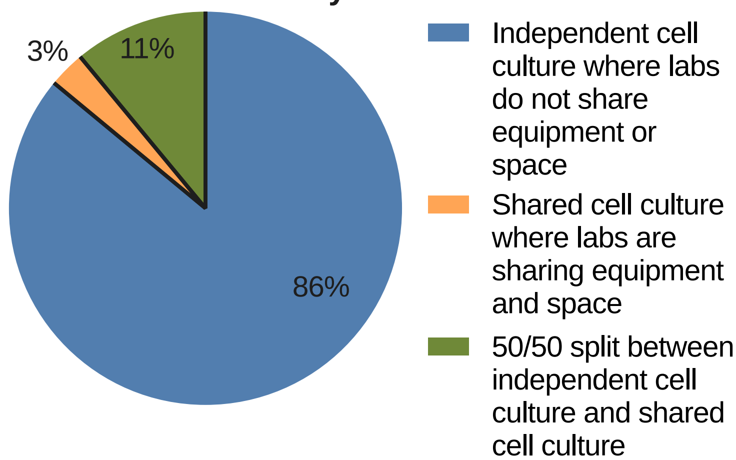
The success of the BCCF can be attributed to the willingness of faculty within the Biochemistry Division to pool their instrumentation and share these resources with others, including researchers from other departments. The establishment of the BCCF in the 1990s set a precedent for how new shared facilities and cores were developed within the Biochemistry Division. Besides the BCCF, the Biochemistry Division faculty have created several cores and shared facilities which are used by many departments across CU Boulder including core resources in Biomolecular X-ray Crystallography, Mass Spectrometry (Central Analytical Laboratory), Proteomics, Light Microscopy, NMR Spectroscopy, Single Molecule Detection, and a Biochemistry Shared Instrument Pool. In most cases, the cores were initially developed as shared resources among a handful of users within the Biochemistry Division. As the number of labs using each core increased to approximately five, the faculty of the Division voted to provide partial support for the facilities. This practice has been in place since 2005 (11).

In the BCCF, half of the salary and benefits for the Facility Manager are contributed by the Biochemistry Division. The other half is paid from research grants, where each PI pays a percentage based on the number of their lab members who use the facility. This percentage is also used to calculate a PI's contribution toward yearly biosafety cabinet certification and equipment maintenance or repair. These percentages are re-evaluated each year. The Facility Manager purchases cell culture supplies in bulk, and as labs use these supplies, their total use is calculated and charged to individual accounts. There is no mark-up cost on any item. New equipment has always been addressed in an ad hoc fashion, and in many cases faculty that use the facility have made generous donations to place new equipment in the BCCF. Some equipment in the facility is second hand from other labs. The BCCF provides a way for faculty who currently have more funding to indirectly support their colleagues with less funding when new equipment is needed by the BCCF.

IV. Prevalence of Shared Cell Culture Facilities Among AAU Schools

Examples of shared cell culture facilities can be found at CU Boulder's peer institutions, but independent cell culture spaces are far more common. To better understand the format of cell culture research at other institutions, the authors conducted a phone survey of biosafety officers at peer institutions within the Association of American Universities (AAU). Figure 1 below shows the distribution of the most prevalent type of cell culture space among the 35 institutions surveyed. Eighty-six percent reported that the most prevalent cell culture arrangement on their campus was independent cell culture whereas only one institution (3 percent) reported shared cell culture as the most prevalent.

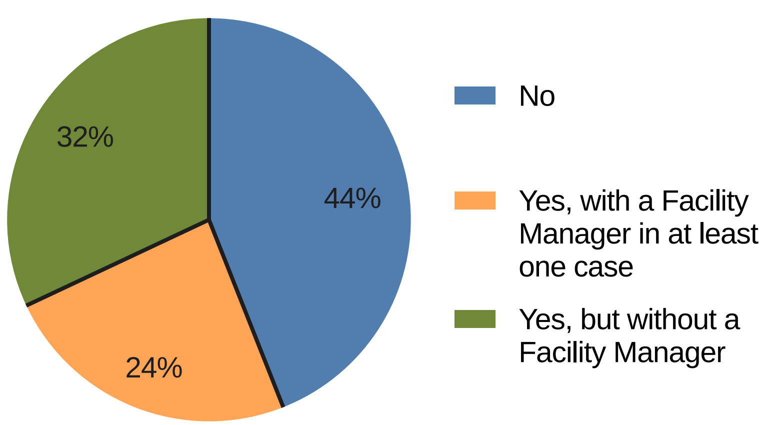
Figure 1. Most prevalent cell culture arrangement among the 35 institutions surveyed



While independent cell culture spaces were the most common scenario of the institutions surveyed, several interviewees indicated that new construction on their campuses often includes shared cell culture space and that institutions are shifting toward promoting this shared approach. Based on these conversations it appears that shared research spaces for cell culture as well as other instrumentation are becoming more prevalent at large research institutions.

Figure 2 below shows the distribution of institutions that had examples of shared cell culture spaces utilized by multiple departments as in our BCCF example. Of these, institutions that had a paid Facility Manager or not were fairly evenly divided (24 percent versus 32 percent). Note that only 34 institutions were surveyed for Figure 2 as one institution was unable to answer this particular question. For a full description of the AAU school survey and additional results, see Appendix 1.

Figure 2. There is at least one example on campus of three or more labs from multiple departments that share lab space and equipment for cell culture research. 34 institutions surveyed

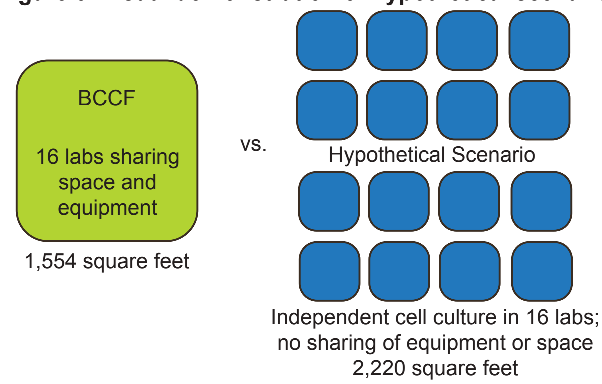


V. Financial Cost Avoidance

A. A Hypothetical Scenario to Estimate Cost Avoidance

To estimate whether a shared cell culture facility is more financially beneficial to CU Boulder and scientists than individual cell culture spaces, we compared the features of the BCCF with a hypothetical laboratory arrangement in the same building where 16 labs would conduct cell culture research independently without sharing space or equipment (Figure 3 at right). The BCCF occupies 30 percent less square footage than the hypothetical scenario described in this case study based on differences in equipment needs (see floor plans in Appendix 2).

Figure 3. Visual demonstration of hypothetical scenario



Square footage of the BCCF was determined by measuring all rooms and corridors within shared portions of the facility. Equipment in the BCCF was also measured. The space necessary for a single lab to conduct cell culture was estimated for the hypothetical scenario by placing one of each essential or most commonly used piece of equipment into a room with a single door using dimensions of the equipment from the BCCF. By placing equipment side by side with the least amount of excess space, we estimated the square footage required for a single lab to do cell culture. Four of the sixteen labs utilizing the BCCF require two biosafety cabinets for their research so the square footage of these four hypothetical cell culture spaces was increased accordingly (Appendix 2). The difference in square footage between our hypothetical scenario of 16 labs conducting cell culture in individual spaces (2,220 square feet) and the BCCF (1,554 square feet) is 666 square feet.

B. Upfront Cost Avoidance via New Construction or Renovation

i. Cost Avoidance with Building New Cell Culture Space – over $800,000

First we wanted to compare the cost of new construction for a shared cell culture facility versus the hypothetical scenario of 16 individualized cell culture spaces. At CU Boulder in 2016, the cost for new construction as a part of a large building project (more than $2 million) was $575 per gross square foot (GSF) plus 25 percent in soft costs, and a 5 percent project contingency cost on top of that (12). Designers and architects distinguish between gross square feet and assignable square feet (ASF) for buildings as follows: GSF is the footprint of the entire building including wall depth, hallways, and other interstitial spaces whereas ASF is the usable space within a footprint such as the area of a lab. We measured the ASF for the BCCF and multiplied that by a factor of 1.6 (12) to determine the cost of building new space in terms of GSF. According to Facilities Planning at CU Boulder (12), a GSF factor of 1.6 should be used for biomedical/clinical labs, and a factor of 1.8 should be used in wet labs with many fume hoods. See Table 1 for relevant calculations. To build the BCCF as it is currently structured at 1,554 ASF in 2016 dollars would cost CU Boulder approximately $1,876,455. However, to build individual cell culture space for 16 labs at 2,220 ASF like in our hypothetical scenario would cost $2,680,650. Therefore, the upfront avoided cost to build a shared facility instead of individual cell culture spaces is over $800,000, or $804,195.

Table 1. Cost avoidance to build the BCCF as new construction instead of building space for 16 labs to conduct cell culture independently as outlined in this case study's hypothetical scenario.

	New Construction	
	BCCF	**Hypothetical Scenario**
ft^2 (ASF)	1554	2220
ft^2 (GSF) [ASF x 1.6]	2486.4	3552
Hard costs $575/$ft^2$	$1,429,680	$2,042,400
Soft costs (25% of hard costs)	$357,420	$510,600
Subtotal	$1,787,100	$2,553,000
Project contingency required by state (5% of subtotal)	$89,355	$127,650
Total Cost	$1,876,455	$2,680,650
Cost Avoidance	$804,195	

ii. Cost Avoidance to Renovate Cell Culture Space - $274,285

Next we compared the cost to renovate lab space to build the BCCF versus a renovation for 16 independent cell culture rooms. Renovation costs at CU Boulder in 2016 were $288 per ASF plus 30 percent in soft costs, with a 10 percent project contingency imposed by the state on top of those totals (see Table 2 below) (12). A renovation with a total finish upgrade with limited HVAC and plumbing changes would be about half the cost of new construction: $575/2 = $288. For reference, a total renovation would cost about 90 percent of new construction costs for the same space, or $518 (12). The authors have chosen to use a more conservative cost per square foot value for renovation because often there are small rooms off laboratories in the JSCBB that could be converted into cell culture space with minimal renovation if needed. Renovation of existing laboratory space to create the BCCF at 1,554 square feet would cost CU Boulder $640,000, whereas renovation to 16 individual cell culture spaces would cost $914,285. Therefore, renovating current laboratory space into a shared cell culture facility instead of 16 individual cell culture rooms results in a cost avoidance of $274,285.

Table 2. Cost avoidance to renovate lab space to build the BCCF instead of renovating lab space for 16 labs to conduct cell culture independently as outlined in this case study's hypothetical scenario.

	Renovation	
	BCCF	**Hypothetical Scenario**
ft^2 (ASF=GSF in a renovation)	1554	2220
Hard costs $288/$ft^2$	$447,552	$639,360
Soft costs (30% of hard costs)	$134,266	$191,808
Subtotal	$581,818	$831,168
Project contingency required by state (10% of subtotal)	$58,182	$83,117
Total Cost	$640,000	$914,285
Cost Avoidance	$274,285	

iii. Cost Avoidance from the Purchase of New Equipment - $288,344

Equipment sharing reduces the quantity of equipment required to meet researcher needs resulting in upfront cost avoidance from fewer purchases and long-term cost avoidance on maintenance and certifications. The basic items necessary for a lab to conduct cell culture include one of each of the following: internally vented biosafety cabinet, vacuum pump, carbon dioxide incubator, carbon dioxide tank, tabletop centrifuge, microcentrifuge, refrigerator/freezer combo unit, water bath, vortex, inverted microscope, cryo-freezer, liquid nitrogen tank, a sink, and space for storage of supplies. The authors requested quotes from Fisher Scientific, VWR, and Baker in July 2016 for CU Boulder pricing for the equipment pieces among the items mentioned above. In Table 3 below, only quantities and prices of the essential cell culture equipment in the BCCF and that would be required for our hypothetical scenario were included. It would cost only $215,560 to establish the existing BCCF with brand new equipment to serve 16 labs and more than 70 users, and $503,904 to place one of each essential piece of cell culture equipment in 16 different labs. That is an avoided cost of $288,344 to provide the BCCF with new equipment instead of the hypothetical scenario.

Table 3. Cost avoidance from using shared equipment in collaborative research space by providing new essential equipment to the BCCF instead of the hypothetical scenario. See Appendix 3 for full calculations of the values in this table and additional information.

	BCCF	Cell Culture for a Single Lab	Cell Culture for 16 Individual Labs (Hypothetical Scenario)
Cost of new equipment	$215,560	$29,408	$503,904**
Cost avoidance as a result of providing the BCCF with new equipment instead of the hypothetical scenario	$288,344		

** As noted in Appendix 2 and 3, four of the 16 labs currently using the BCCF would need two biosafety cabinets to conduct cell culture in their own labs instead of just one due to the nature of their work and number of users. Therefore, the number of biosafety cabinets and vacuum pumps has been increased here to two each for four of the 16 labs.

The annual ongoing cost of carbon dioxide, liquid nitrogen, and certification of biosafety cabinets is comparable between the BCCF and our hypothetical scenario. When we also consider these expenses, the cost avoidance provided by the BCCF is $291,480 (Appendix 3).

C. Ongoing Annual Cost Avoidance

i. Annual Cost Avoidance from Maintenance, Operations, and Utilities - $57,842/year

To determine the difference in operating costs between the BCCF and our hypothetical scenario, we sought estimates from Real Estate Services at CU Boulder for the cost to maintain and operate lab space in JSCBB, the building where the BCCF resides. Several factors go into that cost per square foot including the long-term debt interest for the building for FY 2017, deferred maintenance and capital costs, operations and maintenance (O&M), the cost of utilities (including electricity, water, sewer, and natural gas), and a General Administrative and Infrastructure Recharge which is an "overhead charge that the university levies on self-supporting operations...which benefit from central campus services and support" (13). According to Real Estate Services, the cost to maintain and operate space in JSCBB for fiscal year 2017 is $86.85 per year per assignable square foot. Therefore, it costs $134,965 per year to operate and maintain the BCCF, and it would cost $192,807 per year to operate and maintain the 2,220 square feet of space in our hypothetical scenario. If we assume JSCBB would have been built 666 square feet larger to accommodate individual cell culture spaces for 16 labs if the BCCF didn't exist, then this has led to a cost avoidance of $57,842 per year for the university to operate and maintain the BCCF instead of individual cell culture spaces.

ii. **Annual Cost Avoidance Due to Reduced Plug Loads - $8,300/year**
Utilities are already included in the maintenance, operations, and utilities costs above, but we include this calculation here because we wanted to show the specific cost avoidance provided by the fact that there is less equipment in a shared cell culture facility. By using a combination of metering data, information from manufacturers, data from a 2012 report by Kathy Ramirez-Aguilar for the State of Colorado Department of Public Health and Environment (14), and data from the CEEL Market Assessment (6), we estimated the energy consumption of common lab equipment required for cell culture research. See Appendix 4 for full details on energy consumption of individual equipment and the cost to run the equipment per year based on CU Boulder's rate for electricity. Table 4 below summaries Appendix 4, indicating the electrical cost avoidance made possible by less total equipment needed to serve the BCCF compared to our hypothetical scenario.

Table 4. Annual electrical cost avoidance due to differences in laboratory plug loads. The values below are based on several sources of metering data, an estimate of the number of hours per year that equipment is on in the BCCF, and the cost of electricity for CU Boulder which is $0.1189 per kWh for fiscal year 2016 and 2017. See complete details for this calculation in Appendix 4 of this report.

	Cost
Annual electricity cost for equipment in the Hypothetical Scenario	$14,404
Annual electricity cost for equipment in the BCCF	$6,104
Cost avoidance due to reduced plug loads in the BCCF	$8,300

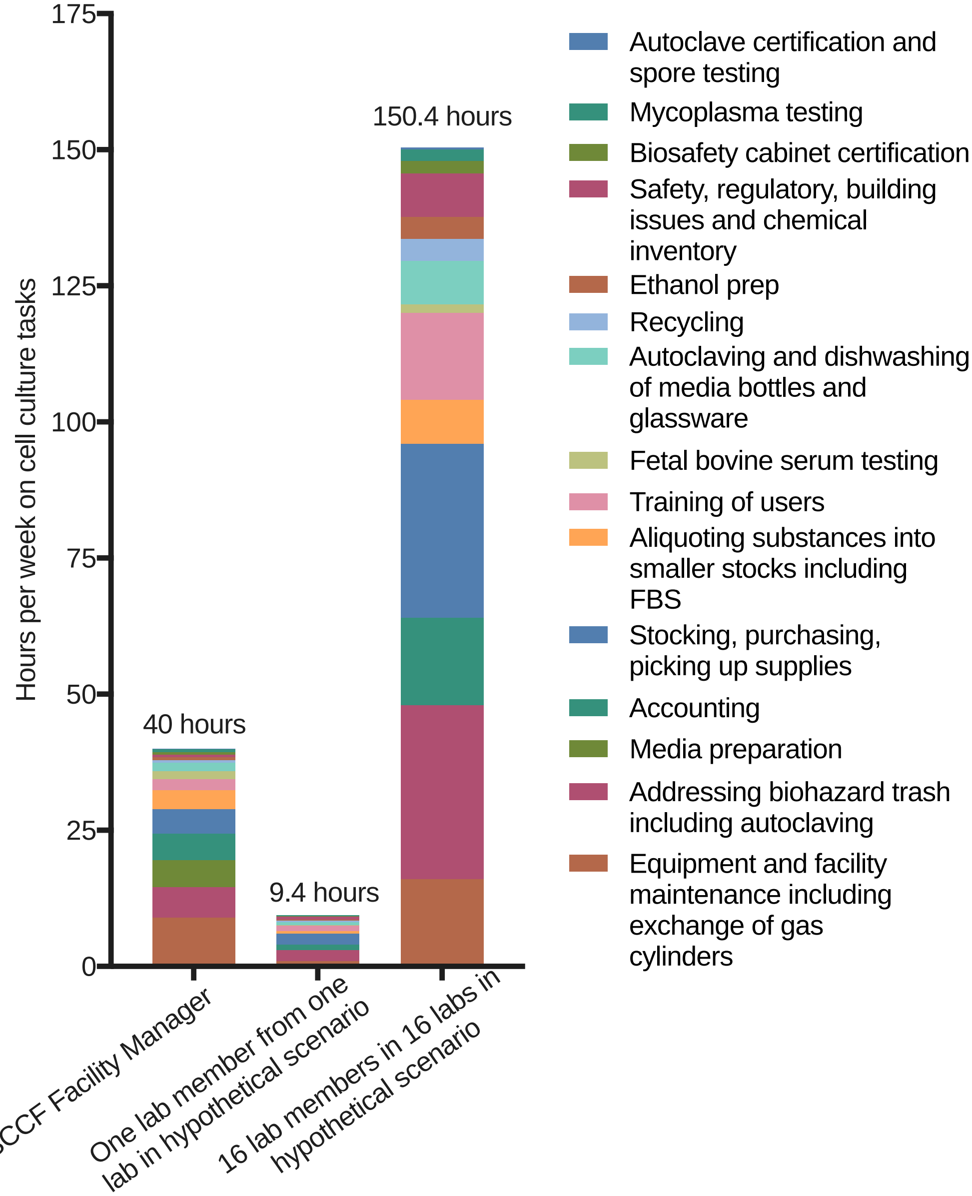
iii. **Annual Cost Avoidance from Building Ventilation - $4,964/year**
Avoided costs from ventilation differences between the hypothetical scenario and BCCF are also rolled up into the maintenance, operations, and utility values mentioned above but laid out here separately to better understand the impact of ventilation. Laboratory ventilation systems (LVS) consume 50 to 75 percent of a lab building's total energy (15, 16), and in some cases excess airflow or inefficient systems may account for 50 percent

of LVS energy being wasted (15). Therefore, ventilation is an important factor to consider for this case study. To understand the full picture of the cost difference between a shared facility versus individual cell culture rooms, we examined the ventilation costs associated with these various spaces. CU Boulder Mechanical Engineering with Facilities Management calculated the cost per cubic foot per minute-year (CFM/year) to ventilate the BCCF and 16 individual lab spaces to be just over $7/CFM/year based on the horsepower required to provide supply and exhaust air to and from these spaces as well as the heating and cooling needs for the required supply and exhaust airflows. This value is consistent with other estimates of the cost per cubic foot per minute-year to ventilate laboratory spaces (15, 17). By taking into consideration the cost per cubic foot per minute-year mentioned above, airflow rate, and the volume of air in each of our scenarios, the cost to ventilate the BCCF is $10,909 per year and the cost to ventilate our hypothetical scenario of 16 individual cell culture spaces is $15,873 per year. See Appendix 5 for these calculations. This is a cost avoidance of $4,964 per year assuming that JSCBB would have needed to be built 666 square feet larger if the BCCF didn't exist to accommodate cell culture needs.

iv. Time Savings (150 hours/week) and Annual Salary Cost Avoidance ($127,896/year)

Laboratories at CU Boulder save significant time by having a Facility Manager coordinate efforts in the BCCF. Without a Facility Manager, labs would need to ask a graduate student, professional research assistant, or other lab member to fulfill these support tasks that are critical for cell culture. Values in Figure 4 and Appendix 6 show the amount of timer per week that the BCCF Facility Manager spends on each cell culture-related task. Based on her expertise, Figure 4 and Appendix 6 also show best-guess estimates for the amount of time per week it would take a single lab to complete the same tasks. For example, the BCCF Facility Manager spends roughly five hours per week preparing media, but labs in our hypothetical scenario spend no time on this because the assumption is that they would be purchasing pre-made media instead. In another example, the Facility Manager will have a much larger volume of biohazard trash to autoclave and dispose of each week with 70 active users of the facility, so this will take them 5.5 hours whereas an individual lab might spend only two hours per week on that task. Several factors were considered when making these estimates, such as the number of pieces of equipment for which the lab or the Facility Manager are responsible, the number of users involved in the facility, the volume of media, ethanol, or biohazard trash used or produced, etc. Based on these estimations, the labs utilizing the BCCF are each currently saving approximately 9.4 hours per week and 150.4 hours per week combined because of everything the Facility Manager does on their behalf. That is 150 additional hours per week that labs are able to focus on their research instead of doing necessary cell culture-related tasks. Therefore, there are significant time savings to scientists by having a Facility Manager accomplish in 40 hours what would take 16 lab members 150 hours.

Figure 4. Hours per week required for a variety of tasks necessary for cell culture

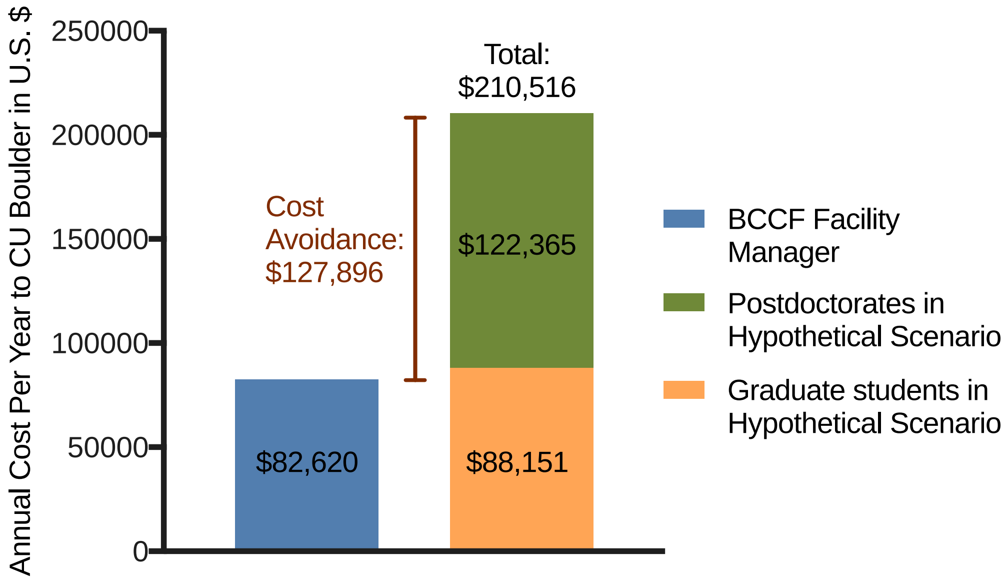


Of the 70 users of the BCCF, roughly 40 percent are graduate students and 40 percent are postdoctoral researchers. The other 20 percent of users are professional research assistants, undergraduates, and faculty. We calculated the cost avoidance scientists benefit from as a result of time saved from having a Facility Manager of the BCCF (Figure 5 below) by using the standard salary, benefits, and overhead of graduate students and postdoctoral researchers at CU Boulder since they are the majority users of the facility. For this comparison, we used the pay rate of a second-year postdoctorate on an NIH Kirschstein-NRSA award (18) and a Biochemistry Division post-comprehensive exam graduate student, and compared that to the median salary of a Senior Professional Research Assistant within the College of Arts and Sciences at CU Boulder, which is the same job title of the current BCCF Facility Manager.

Even though graduate students are technically a 50 percent appointment, once they are past their comprehensive exams, they are effectively doing research 100 percent of the time. Pay per hour was calculated based on a 40-hour work week instead of a 20-hour work week for Figure 5 below. It was assumed that for the 16 labs conducting cell culture independently in our hypothetical scenario, half of the 150.4 hours of cell culture-related tasks would be conducted by graduate students, and the other half by second-year postdoctoral researchers.

The median salary of the same job class as the BCCF Facility Manager is $60,000 per year. The Biochemistry Division pays an additional 37.7 percent to cover fringe benefits for the Facility Manager, bringing the total cost of this position to $82,620 per year. A second-year postdoctoral researcher on a NIH Kirschstein NRSA Award for fiscal year 2016 makes $47,268, also with a 37.7 percent fringe benefit rate, bringing the total cost of that position to $65,088 per year. The graduate student in our case study makes $31,709 per year, with a 13.7 percent fringe benefit rate and $10,836 in tuition costs covered, bringing the total cost of this position to $46,889 per year. In most cases postdoctorate and graduate student fringe benefits are paid from awards granted to their Principal Investigator, though CU Boulder subsidizes the cost of medical coverage and the non-residential tuition differential for graduate students. Because the Facility Manager spends 40 hours per week on necessary cell culture tasks, it costs their full salary plus fringe benefits, or $82,620 per year, for that individual to run the BCCF. For comparison, if we assume that eight postdoctorates and eight graduate students would need to fulfill necessary cell culture tasks in our hypothetical scenario, each would be spending 9.4 hours per week (Appendix 6) doing this work, or 75.2 hours per week for the postdoctoral researchers and 75.2 hours per week for the graduate students. This translates to $122,365 per year for eight postdoctorates and $88,151 per year for eight graduate students to do cell culture tasks for a total of $210,516 per year. Therefore, there is a cost avoidance of $127,896 per year for the BCCF to have a Facility Manager versus the manpower that would be required for 16 labs to conduct cell culture independently as described in our hypothetical scenario. See Figure 5 below for a summary of this cost avoidance. For further details, see Appendix 7.

Figure 5. The annual salary and benefits cost for the Facility Manager of the BCCF to work 40 hours per week on necessary cell culture tasks compared to eight graduate students and eight postdoctoral researchers in our hypothetical scenario spending a combined 150.4 hours per week on necessary cell culture tasks



v. Cost Avoidance with Cell Culture Media – over $33,000/year

Another avoided cost for labs using the BCCF is through lower costs for cell culture media. The Facility Manager prepares three kinds of media for a fraction of the cost of purchasing pre-made media from suppliers. The cost per liter of the in-house media is between $3.79 and $9.13 (2015 rates) versus $27 to $46 per liter for Gibco media purchased from Thermo Fisher Scientific. If labs were not using the BCCF, the additional hours researchers would need to commit to operations and maintenance of their own space and equipment might motivate them to purchase pre-made media at higher costs rather than spend the time to make it in-house. The Facility Manager prepared approximately 1,200 liters of media in 2015 for a total re-charge cost of $6,592 to all labs using the facility. Based on the volume of each of the three types of media prepared in 2015, the Facility Manager facilitated a cost avoidance of $33,781 for scientists by preparing media in-house. This is probably a conservative estimate as the avoided costs noted here do not include the cost of shipping pre-made media to campus.

vi. Cost Avoidance with Fetal Bovine Serum - $10,000 to $26,400/year

Fetal bovine serum (FBS) is a required media supplement providing growth factors necessary for cell propagation (19) and the price varies dramatically due to market cycles. Purchasing FBS in bulk is one of the ways the BCCF Facility Manager is able to avoid additional costs for CU Boulder scientists. The BCCF requires roughly 200 500-milliliter bottles of FBS per year. In 2015 the Facility Manager was able to get a price of $168 per 500-milliliter bottle for a total cost of $33,600, even though the average market cost was $300 per 500-milliliter bottle that year. She was able to secure the $168 per bottle price for all 200 bottles of FBS purchased in 2015 and had them delivered at various times throughout the year. This is evidence of the buying power when a large group of users need a product but can also guarantee a large sale for a vendor. In total, bulk purchasing of FBS in 2015 led to a cost avoidance of $26,400 for CU Boulder researchers. 2015 may have been a particularly expensive year for the purchase of FBS, but even if the average market rate for FBS was just $50 more than the 2015 price the Facility Manager was able to procure, this would have been a cost avoidance of $10,000 for CU Boulder scientists.

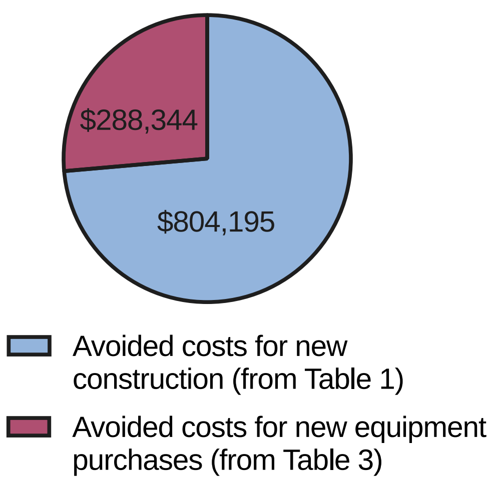
vii. **Cost Avoidance with Promotional Products and Reused Ethanol - $6,700/year**
In 2015 alone the BCCF received approximately $5,000 in free promotional supplies from scientific equipment manufacturers and suppliers including pipets, pipet controllers, and filters. The scientists using the BCCF directly benefited from those promotional supplies. In addition, the BCCF participates in an ethanol recycling program that led to an avoided cost of $1,700 for the facility in 2015. Humidified, uncontaminated ethanol that has only been used for cold trap purposes by CU Boulder's Institute of Arctic and Alpine Research is given to the BCCF and diluted to 70 percent ethanol for decontamination of materials and work surfaces.

D. Summary of Financial Cost Avoidance for the BCCF

i. Total Cost Avoidance for New Construction ($1,092,539) or Renovation ($562,629)

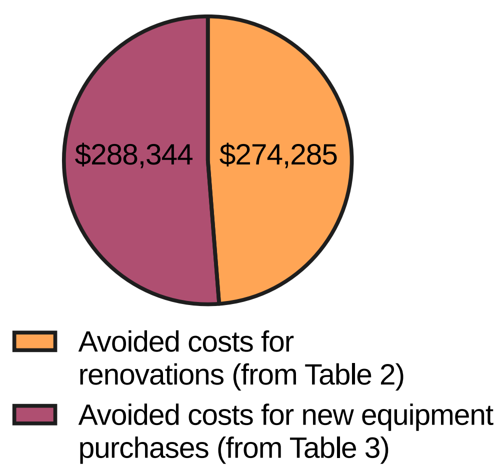
This is the upfront cost avoidance that could be realized if an institution established a shared cell culture facility such as the BCCF instead of 16 individual cell culture spaces for labs. Also included is the equipment cost avoidance mentioned above in Table 3 because new equipment would likely need to be purchased to outfit a newly constructed or renovated facility.

Figure 6. Avoided costs by creating the BCCF on a new build instead of the Hypothetical Scenario



Total= $1,092,539

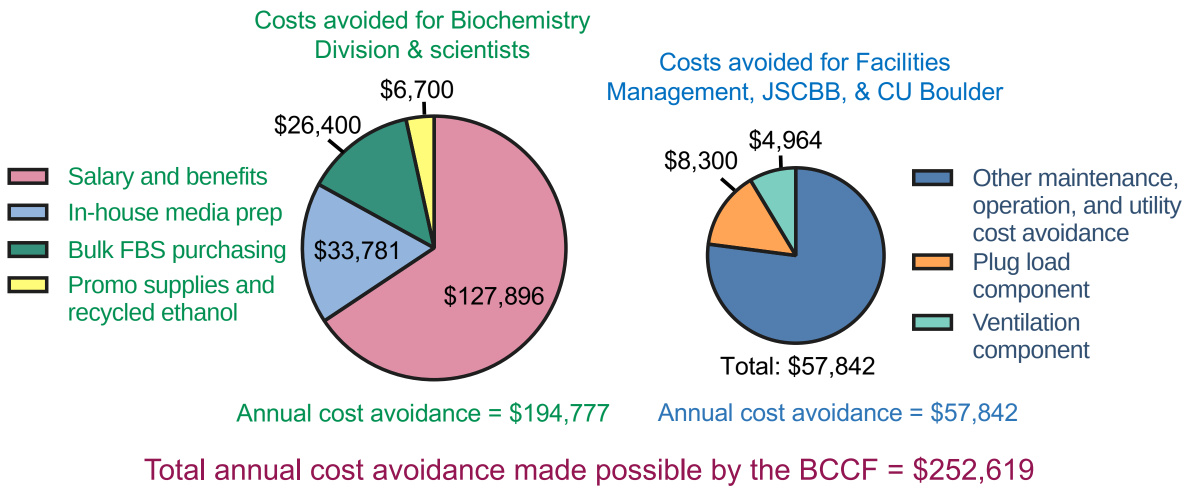
Figure 7. Avoided costs by creating the BCCF as a lab building renovation instead of the Hypothetical Scenario



Total= $562,629

ii. **Ongoing Annual Cost Avoidance made possible by the BCCF - $252,619/year**
Comparing costs associated with the BCCF versus our hypothetical scenario allows us to estimate the cost avoidance the BCCF provides to CU Boulder annually. Figure 8 below shows the breakdown of annual cost avoidance made possible for the a) Biochemistry Division and the scientists using the facility, and b) Facilities Management, JSCBB Building Management, and the CU Boulder administration. In total, the BCCF is providing CU Boulder with a cost avoidance of $252,619 a year by avoiding the need for 16 individual cell culture spaces.

Figure 8. Annual cost avoidance made possible by the BCCF



VI. Qualitative Benefits

Having a Facility Manager benefits the labs using the BCCF. For example, basic training for cell culture work is standardized for all individuals that use the facility. The Facility Manager places an emphasis in training on how to prevent contamination by practicing proper technique and using biosafety cabinets correctly. Furthermore, during initial training she is able to emphasize proper safety procedures. Beyond training, the Facility Manager provides several other invaluable services for the users of the BCCF. She tests cell lines regularly for mycoplasma, which are bacteria resistant to most antibiotics that are routinely supplemented in cell culture media (20, 21). This important testing process allows labs to know if their research may be compromised by the presence of mycoplasma. Individual labs may not be as thorough with mycoplasma testing on their own due to time or monetary constraints. The Facility Manager also provides testing of fetal bovine serum lots to ensure their compatibility with cell lines currently in use by labs. These services have been invaluable in saving researcher time and grant funds, and they also provide a level of quality assurance that scientists may not have the resources to provide when doing cell culture independently.

Another benefit of the Facility Manager is the ability to connect individuals from different labs who may be able to aid each other in their research through ideas or expertise, thereby creating a collaborative community. Having 16 labs from three departments sharing the same space allows for useful interactions and more opportunities to brainstorm, troubleshoot, and discuss experimental design. Furthermore, the Facility Manager can offer expertise and years of experience to the labs that use the facility by answering questions and helping to determine if samples are contaminated. If scientists take vacation or sick leave, the Facility Manager is available to take care of cell lines for those individuals. Alternatively, she can connect that person with someone else (possibly from a different lab) using the same cell line to take care of their samples while they are away. Having a shared facility allows for more community cooperation and creates a larger network of scientists with varied experience who can assist one another. Another example of this is when equipment goes into alarm in the BCCF, even on the weekend, the many users of the facility ensure this will not go unnoticed for long since people are coming and going every day of the week. Finally, for scientists who are a part of the BCCF, the Facility Manager takes care of all equipment maintenance, certifications, and repairs so that they can focus on their research.

A benefit of the BCCF is that the facility does not over-purchase consumables since so many labs are utilizing the various plastic wares and other consumables provided in the facility. One fact of research is that it can quickly change direction for a lab. In the BCCF, if a lab needs the Facility Manager to order a specialized consumable and then decides that the product is not necessary for their research after all, a different lab will likely need to use the same specialized consumable before it expires. In an individual lab such as in our hypothetical scenario, specialized items purchased and then deemed not useful may sit on a shelf for years for possible future use and then expire. This not only leads to an inefficient use of these resources, but also takes up valuable laboratory space. Given that it costs about half as much to construct storage space compared to the construction cost of laboratory space, it is better value to avoid using labs for storage of equipment and consumables (12).

Not only does the BCCF provide more equipment than just the essentials for culturing cells, but all this equipment is heavily utilized. Placing only currently needed, heavily utilized equipment into the BCCF helps prevent the accumulation of abandoned equipment in the lab space which can occur in individual labs when a lab’s research changes direction. A lab partially filled with unused lab equipment does not create a positive work environment for lab members. Maintaining a pleasant workspace in the lab can help with retention of talent, promote efficient work, and help foster a team culture (22) which is critical to scientific endeavors.

Lastly, in our discussion concerning the time and cost required to take care of essential cell culture tasks (Figure 4 and Figure 5), the values do not consider the time it would take a new lab to set up independent cell culture at CU Boulder. There would likely be months of waiting involved as equipment is delivered, biosafety cabinets are certified, and all the necessary supplies are gathered to begin. If the BCCF was not at capacity, having it available to faculty when they move to CU Boulder would save many additional hours of valuable research time. Faculty could get started right away once their personnel were trained instead of waiting weeks or even months to set up cell culture space in their lab.

VII. End User Survey Results

In November 2016, CU Green Labs designed and conducted an end user survey at the BCCF. The survey captured responses from 43 out of 70 active facility users, or 61 percent. The predominant method of gathering responses was for CU Green Labs student assistants to sit at the entrance of the BCCF during heavy use times and asking those entering or exiting if they had taken the survey yet and if not, asking them to take our brief two-minute survey on an iPad. We also emailed the survey link to specific people who said they were too busy to take the survey in person at that moment but would respond on their own time. Overall, the survey results show that users overwhelmingly appreciate the function and accessibility of the BCCF and would prefer this model over independent cell culture space with the understanding that in an individualized cell culture scenario, the end user would be required to do some of the tasks currently taken care of by the BCCF Facility Manager. Figures of the survey results are included in Appendix 8.

Of those that responded to the survey, 58 percent are graduate students and 23 percent are postdoctoral researchers or Research Associates. The majority of respondents (70 percent) have been doing cell culture work for two years or less while 30 percent have done cell culture for three years or longer. The BCCF is a busy lab area with 37 percent of users in the facility one or two days per week, 35 percent of users in the facility three or four days per week, and 23 percent in the facility five days a week or more. Of the twelve options given in the survey, the top benefit of the BCCF was that the Facility Manager prepares media in-house as well as orders and stocks supplies in bulk, saving labs money and time. There were also four other benefits that were selected by more than 75 percent of the respondents (Appendix 8) including 1) that the Facility Manager consolidates, autoclaves, and disposes of biohazardous waste, 2) equipment maintenance and repairs are coordinated by the Facility Manager, 3) the Facility Manager provides standardized training to new users of the facility, and 4) that users have access to more (or more specialized) equipment than their lab would otherwise be able to use.

The most commonly selected disadvantage or dislike was that the facility does not have enough space (49 percent of respondents). For all the other disadvantages listed in the survey, none were selected by more than 32 percent of respondents. In an effort to better understand the background of those surveyed, we asked whether users had prior experience doing cell culture at other institutions. The majority of those surveyed had no other cell culture experience except in the BCCF, or they had worked in a different facility used by one or two labs that did not have a Facility Manager. The majority of the 43 individuals surveyed (77 percent) would prefer to utilize the BCCF instead of doing cell culture in their own lab if doing cell culture independently in their own lab meant that they would have to take care of some of the essential tasks the Facility Manager currently takes care of for them. Overall, 70 percent of the users surveyed responded with a “5” and 25 percent of users responded with a “4” on a 1-5 scale with 5 being the most satisfactory opinion of the BCCF. After hearing from more than half of the BCCF users, it is encouraging to see that many scientists would choose the same arrangement if given the choice between the existing shared facility and doing cell culture independently in their own lab space.

VIII. Addressing and Overcoming Concerns

Some commonly expressed concerns regarding shared cell culture facilities may hinder scientists, biosafety officers, or institutions from considering their feasibility, but the BCCF has found ways to circumvent these issues successfully. Most cell culture facilities will experience contamination issues whether the facility is shared or not, but there are steps that can be taken to minimize risk. With all cell culture, it is vital to understand sterile technique and how to properly work within a biosafety cabinet both for the sake of personnel safety and sample integrity. This requires high-quality training for new personnel, something that a skilled Facility Manager could provide. Taking the time to consistently train researchers on proper technique will go a long way toward minimizing contamination in a shared facility. Though the BCCF has occasional contamination issues, these can mostly be traced back to user error through issues such as improper biosafety cabinet technique.

Thoughtful lab design and equipment placement can help reduce contamination risk further. Placing biosafety cabinets in locations where there is less foot traffic such as at the back of narrower rooms can minimize miscellaneous air currents as has been done in the BCCF (23). Contamination is not a pervasive issue in the BCCF. Proof of this fact is that there are 16 labs preferentially using this facility. If contamination was a systemic issue in the BCCF, this facility would not have grown over the past 25 years and labs would be seeking other options. Similarly, there has been a shared cell culture space at UC Berkeley for over 30 years with shared biosafety cabinets, other shared equipment, and training provided by Facility Managers in addition to a fee for service core. They currently have two shared biosafety cabinets with 30 regular users (24). Boston University has also moved in the direction of shared cell culture, with a stem cell culture facility established in their Center for Regenerative Medicine (CReM) in 2013 utilized by five labs, and they now have seven active labs using the space. The CReM has a Facility Manager that provides consistent training to new users, 20 biosafety cabinets, and 45 active users (25). The longevity of the BCCF along with these other institutions' shared facilities is a great indication that this model for cell culture can work well if the personnel and resources are devoted to it.

Running a shared facility requires coordination and diligence on the part of the users to clean up the space they use so it is ready for the next person to follow. In the BCCF, current practice is that each individual sterilizes their biosafety cabinet before and after use. This practice is redundant because theoretically the biosafety cabinet is cleaned twice before each new user, but the result also lowers risk of contamination between users. Another challenge to be aware of is that when users become unconcerned for others and others' research, this can lead to a lack of trust between parties as well as uncomfortable and possibly unsafe situations. The Facility Manager can support the success of a shared cell culture facility by helping scientists be good neighbors with their fellow facility users. Whether through the help of a Facility Manager or not, increasing communication and understanding between the different lab groups utilizing the shared facility, including getting everyone on the same page about procedures and the type of research taking place, can help avoid miscommunication and aid everyone to see the value in each other's research. Lastly, early communication between the campus biosafety officer and the faculty or staff planning for a shared cell culture facility is essential for success (23).

IX. Number of Labs Required for Cost Effective Implementation

Even with all these benefits described, it may still seem daunting to consider forming a shared cell culture facility. While this case study describes a facility with 16 labs sharing, it is not necessary to have that many labs to make this model feasible. After all, the BCCF itself had its beginnings with just three labs 25 years ago. In addition, there is no reason why a single Facility Manager could not serve multiple small shared facilities in nearby buildings.

Based on the BCCF model, how many labs must be involved to make a shared cell culture facility financially viable? Figure 9 below shows that a shared cell culture facility with much fewer than 16 labs would be cost effective. Analyses 1-3 in Figure 9 were developed with the understanding that a Facility Manager would be working full-time on cell culture-related tasks in a shared facility serving multiple labs whereas a single graduate student or single postdoctoral researcher would be doing cell culture-related tasks in their individual lab for 9.4 hours per week as laid out in the hypothetical scenario of this case study.

Analysis 1 in Figure 9 below only considers the salary, benefits, and time involved to do cell culture-related tasks for a Facility Manager, graduate students, and postdoctoral researchers. With just these factors considered, it becomes cost effective to form a shared cell culture facility with six to eight labs involved that would otherwise do cell culture independently. This is a much more manageable number of labs to bring together to form a shared cell culture facility than 16.

Analysis 2 in Figure 9 below builds on Analysis 1's parameters but also includes 30 percent of the cost avoidance ($20,064 per year) from preparing media in-house, bulk purchasing of FBS, promotional material benefits, and ethanol reuse that the BCCF provides to CU Boulder. Thirty percent of this cost avoidance is included in Analysis 2 because even a smaller shared facility would receive some of the benefits the BCCF experiences from having more cost-efficient media preparation and bulk purchasing. The $20,064 per year in cost avoidance a shared facility would experience partially offsets the cost of a Facility Manager's salary and benefits. With these factors considered in Analysis 2, it is cost effective to develop a shared cell culture facility with just five or six labs involved.

Analysis 3 below is a further extension of Analysis 2 by also including a portion of the maintenance, operations, and utilities cost avoidance described in this case study. This additional cost avoidance of $14,460 is included because even a smaller shared facility would save on square footage, and therefore maintenance, operation, and utility costs, as opposed to those labs doing cell culture independently. The cost avoidance due to reduced lab space maintenance costs in a shared facility for this case study is $57,842. That divided by 16 labs is a cost avoidance of $3,615 per lab, so for four labs the cost avoidance is $14,460. Analysis 2's $20,064 plus $14,460 is $34,524. Analysis 3 below highlights that it would be cost effective for four or five labs to form a shared cell culture facility together if the avoided costs that come from reduced square footage are also taken into account.

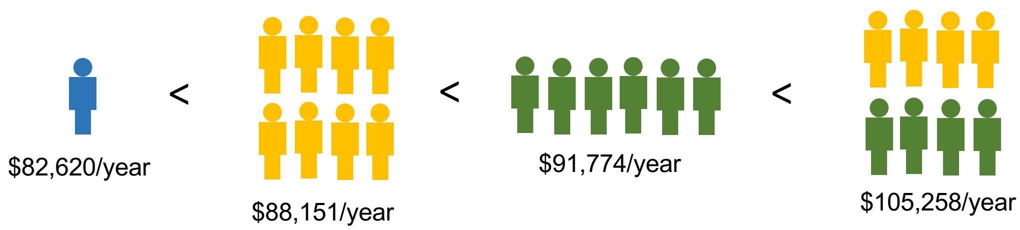
Figure 9. Cost Analyses

Below are comparisons of the salary and benefits cost of the BCCF Facility Manager conducting cell culture related-tasks compared to graduate students and postdoctoral researchers in the hypothetical scenario conducting cell culture-related tasks for roughly 9 hours per week each as outlined in Figure 4 above. Based on these cost analyses it is possible to understand the thresholds at which it is more cost effective to pay a full-time Facility Manager to coordinate efforts in a shared facility instead of continuing to support individualized cell culture as described in our hypothetical scenario. There are three different analyses below.

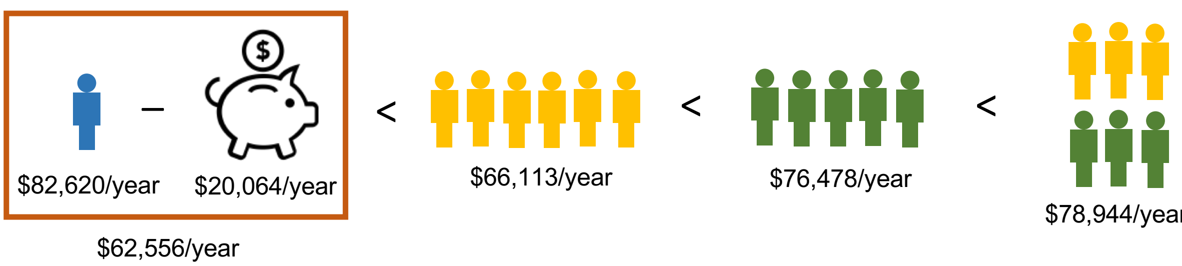
KEY

BCCF Facility Manager	Postdoctoral Researcher	Graduate Student
serving 16 labs	serving a single lab	serving a single lab
Salary & Benefits: $82,620/year	Salary & Benefits: $65,088/year	Salary & Benefits: $46,889/year
40 hours per week for cell culture	9.4 hours per week for cell culture	9.4 hours per week for cell culture

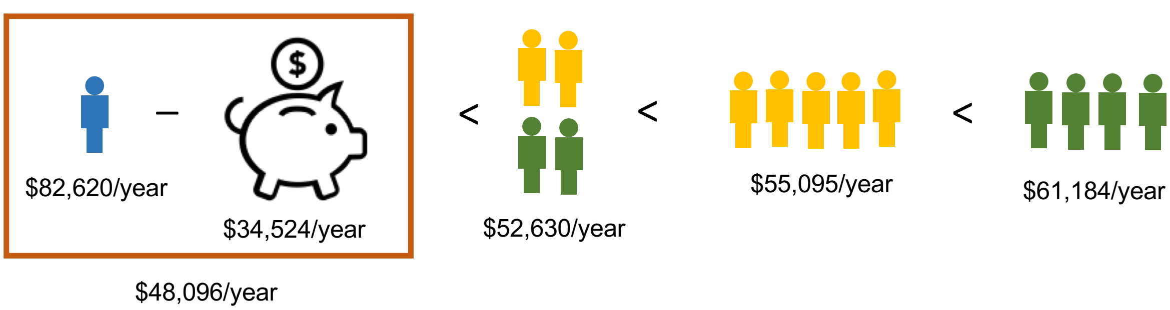
ANALYSIS 1: Cost analysis based solely on salary, benefits, and time spent on cell culture-related tasks.



ANALYSIS 2: Cost analysis based on factors considered in Analysis 1 above plus 30% of the cost avoidance described in this case study from preparing media in-house, bulk purchasing of FBS, promotions, and ethanol reuse ($20,064/year). These additional avoided costs are included because even a smaller shared facility would receive some benefit from bulk purchasing and in-house media preparation which would offset the cost of a full time Facility Manager's salary and benefits.



ANALYSIS 3: Cost analysis based on all factors considered in Analysis 2 above including the $20,064 cost avoidance from in-house media preparation and bulk purchasing of FBS plus a cost avoidance of $14,460 as a result of four labs participating in a shared facility together. The cost avoidance due to reduced lab space maintenance, operation, and utility costs in a shared facility for this case study is $57,842. That divided by 16 labs is a cost avoidance of $3,615 per lab, so for four labs the cost avoidance is $14,460. With four labs conducting cell culture in a shared facility together, there would be modest savings from reduced lab space maintenance, operation, and utility costs.



X. Broader Implications

At research institutions across the nation, sharing naturally occurs for expensive research assets such as NMRs, mass spectrometers, and electron microscopes because it is too cost prohibitive not to. However, there is extensive untapped potential to share more general-use, less expensive laboratory equipment and, as shown in this case study, it can be cost effective to do so. A key ingredient is a manager to keep equipment well-maintained, train new users, and allow scientists to remain focused on science. Managed, shared equipment saves research funding and promotes efficiency in four ways: 1) by keeping scientist time focused on research rather than the logistics of maintaining equipment and other associated tasks (tasks that can be consolidated and more efficiently handled by a manger), 2) by avoiding the need to purchase multiple pieces of equipment, and thus also avoiding the need to support multiple equipment assets (with space, utilities, service contracts and repairs), 3) by enabling volume purchases (at reduced rates) of needed materials and supplies for use with equipment, and 4) by avoiding the accumulation of abandoned equipment in individual labs which can be a product of a lab's research changing direction. Even with the need to pay for a manager's salary and only taking into consideration 1-3 above when making calculations, this case study shows significant cost avoidance to research by having shared equipment, a shared facility, and a manager for cell culture. Cost avoidance is not only in terms of direct costs (researcher time, equipment-related costs, and supplies) typically paid by researchers from sponsor-funded grants, but also in terms of indirect (a.k.a. overhead) costs both paid by grant sponsors and covered by institutions.

At times such as these when the NIH is looking for ways to spread grant funding among more scientists (1), this case study provides a suggestion of how this could be done by promoting managed, shared equipment in collaborative spaces. Using this case study as an example, much of the $194,777 per year in cost avoidance from reduced salary costs and reduced cost of materials (Figure 8 above) is positively impacting grant funding from NIH and Howard Hughes Medical Institute (HHMI) which fund nearly all of the research in the BCCF (about ~80% and ~20%, respectively). Efficient use of funding in the BCCF is helping to maximize the research potential of grant dollars while minimizing the amount of funding necessary to conduct research. Keeping in mind that this case study has only assessed the financial benefit of 16 labs sharing cell culture space—just a small subset of NIH- and HHMI-funded labs across the U.S.—imagine the beneficial impact to finances and the environment if managed, shared cell culture was practiced on a much larger scale. Now imagine the impact if managed, shared equipment expanded beyond cell culture to also include other equipment types that, like cell culture equipment, are outside that cost-prohibitive category and are often less commonly shared at research institutions. Another study will be needed to measure how extensive the impact could be but based on observations of the Green Labs community at various research institutions across the nation, the cost avoidance potential is expected to be large not only in direct costs but also indirect (overhead) costs particularly when the costs connected with space utilization are also considered.

Laboratory space is one of the most expensive spaces to build and maintain at research institutions. Federal funding often contributes toward building new laboratory buildings. Space is also a very important factor in determining the facilities portion of the indirect (overhead) cost rate (a.k.a. Facilities and Administrative (F&A) Rate) for academic research institutions. The more space connected with sponsor funded research, the higher the calculated facilities portion of the F&A rate will be for that research institution. Higher overhead costs than necessary such as those associated with inefficient use of lab space are not beneficial to the pool of funding available for scientific research on a national scale, nor are they beneficial to research institutions which end up cost-sharing overhead costs with sponsors since insufficient funding is received from sponsors to truly cover these costs. Federal granting agencies such as NIH do not control how the F&A rate is calculated, but funding to support indirect costs comes from their budget. Granting agencies could consider encouraging efficiency actions in their grant funding process that minimize not only direct costs, but also overhead costs in support of research. After all, it is common to find science departments at research institutions where each principal investigator (PI) has their own equipment in their own individual research space. Because research focuses of individual PIs often change directions over time, and thus the equipment needs also change, laboratory space in departments utilizing an individualized culture can partially become storage space for underutilized or unused equipment waiting to be needed again. Not only does this lead to inefficient use of equipment resources, but it also leads to inefficient use of lab space which results in higher overhead costs and adds pressure to build new lab buildings which are hundred-million-dollar investments.

Federal policy requiring equipment sharing and avoidance of duplication already exists in the Code of Federal Regulations (7). These CFRs are not well known since they have not been regularly promoted by the federal government but efforts by research institutions to advance equipment sharing such as the example in this case study would benefit compliance with these CFRs. The federal government does promote equipment sharing through certain major equipment grants such as the NIH Shared Instrumentation Grant Program and the NSF Major Research Instrumentation Program.

Lastly, there is an effort through the International Institute for Sustainable Laboratories called Bringing Efficiency to Research (BETR) Grants working to encourage PIs and institutions to include descriptions of efficient practices and shared facilities into grant proposals (26). The core of BETR Grants is to connect efficiency and sustainability with research funding. By including mention of equipment sharing, efficient space utilization, and energy and water conservation in grant proposals, this sends a signal to sponsors that certain research groups and institutions are trying to conserve resources and conduct science in a more efficient way.

XI. Conclusions

The National Institutes of Health recently considered plans to spread funding among more scientists for the purpose of “optimizing stewardship of taxpayer dollars” (1). As discussed previously, another way to accomplish this same goal is through more efficient use of research dollars, an action of great importance during these times of intense competition for biomedical federal research funding. The BCCF at CU Boulder is an example of efficiency for cell culture, both in terms of financial cost avoidance and a smaller environmental footprint. The facility also saves scientists time and provides many qualitative benefits to research that we cannot assign value to here for this case study. The BCCF would not function as it does without a qualified manager at the helm, ensuring that the users of the facility are able to focus their energy on their experiments. It is interesting to note that as this case study was nearing completion, a new 0.5 full time equivalent (FTE) assistant for the BCCF was hired to enable the facility to expand the number of users it serves and the services it can provide. Six-foot-long biosafety cabinets may be replaced with four-foot-long biosafety cabinets in the BCCF to enable more bench and biosafety cabinet space, and the Facility Manager and 0.5 FTE will likely do more cell sorting in the future. These examples demonstrate the ongoing and growing value this shared facility provides to our campus.

As shown in this case study, the vision of faculty in the Biochemistry Division as well as their promotion and development of a sharing culture is benefiting the university with ongoing avoided costs and efficient use of laboratory space through the BCCF. It should be noted that although the BCCF serves three departments, 50 percent of salary support for the Facility Manager comes from the Biochemistry Division alone. Therefore, the Biochemistry Division subsidizes the financial costs of providing this shared cell culture resource to researchers in other departments. Subsidies such as these are not uncommon in shared facilities led by individual departments and can result in some departments closing off access to others. With the difficult competition for funding that scientists are facing and the benefits to science that can come from well-managed, shared equipment facilities, now is an opportune time to encourage resource sharing between scientists while minimizing equipment duplication and inefficient use of laboratory space. Help in the form of partial funding from the institution to contribute toward covering operational costs and management of shared facilities would greatly benefit the use and creation of shared facilities on university campuses, as well as the sustainment of shared facilities. This financial support could encourage movement away from the individual equipment in individual space approach, help break down barriers that may prevent sharing between departments, and could benefit the ability to offer competitive pay for a high-quality manager. Other institutional help could come in the form of administrative support such as online scheduling and billing systems or the institution could provide a pool of funding to address equipment needs such as new equipment to further campus research potential or emergency repairs that researchers or their department may not be able to cover.

Shared equipment facilities have immense inherent value for creating new research opportunities for investigators, which in turn can impact their ability to obtain more research funding. This is especially true in expanding the ability of researchers to conduct interdisciplinary research for members of a lab with no hands-on knowledge of a new technology. These individuals can take advantage of the training and technological capabilities that the shared facility provides. Therefore, support of shared facilities can overcome difficult barriers that stand in the way of allowing researchers to access cutting edge technologies and to conduct research in new or different areas. In developing new shared equipment facilities, it is important to “peer over the horizon to see how science is changing”, as noted by Dr. Natalie Ahn, one of the early PIs using the BCCF. The development of shared equipment facilities must be strategic, directed by faculty who are entrenched in the science and committed to the technology.

The BCCF allows for more efficient research to take place at CU Boulder by resource sharing and allowing the facility users to be unhindered by many of the tasks required to make cell culture a success. The Facility Manager is able to provide those skills and services to the BCCF user base. Efficient research often leads to the ability to do more research with existing resources, which in turn can lead to more research opportunities. The fact that the BCCF is a more efficient use of research funds than our hypothetical scenario is beneficial to our research scientists, our university, and research sponsors. This case study demonstrates that sharing more common, lower cost laboratory equipment and fostering collaborative research space at research institutions not only impacts those scientists using these resources today, but also has the potential to benefit the national science grant funding climate and help maximize the impact of sponsored research funding if there is widespread adoption of these practices across the U.S.

XII. Acknowledgments

The following individuals have been instrumental to the success of this case study and provided consultation and assistance to the authors: Natalie Ahn, Sesha Pochiraju, Ziyu Liu, Helina Ayalew, Sarah Vander Meulen, Wayne Northcutt, Rebecca Fell, Otha Barrow, Pamela Williamson, David Jacobs, Thomas Smith, Pieter Diebold, Jeremy Johnson, Shannon Horn, Stephanie Preo, Kate Daugherty, Holly Gates-Mayer, Mark Lapham, Joshua Lindenstein, Ellen Edwards, Theresa Siefkas, Joe Dragavon, Gretchen O'Connell, and Brenda Petrella.

XIII. References

1. **Collins, Francis S.** New NIH Approach to Grant Funding Aimed at Optimizing Stewardship of Taxpayer Dollars. *National Institutes of Health, The NIH Director.* [Online] May 2, 2017. [Cited: May 23, 2017.] 1. https://www.nih.gov/about-nih/who-we-are/nih-director/statements/new-nih-approach-grant-funding-aimed-optimizing-stewardship-taxpayer-dollars.
2. **Lauer, Michael.** Implementing Limits on Grant Support to Strengthen the Biomedical Research Workforce. *Extramural Nexus, Open Mike, National Institutes of Health.* [Online] May 2, 2017. [Cited: May 23, 2017.] https://nexus.od.nih.gov/all/2017/05/02/nih-grant-support-index/.
3. **Hafer, Moira.** Inventorying Plug Load Equipment and Assessing Plug Load Reduction Solutions on a University Campus. *Sustainable Stanford.* [Online] October 2015. [Cited: May 31, 2017.] http://sustainable.stanford.edu/sites/default/files/resource-attachments/Plug%20Load%20White%20Paper%20FINAL.pdf.
4. *Adding efficiency to general lab equipment.* **May, Mike.** s.l. : Science/AAAS Custom Publishing Office, April 28, 2016, Science. DOI: 10.1126/science.opms.p1600104.
5. **DeCrappeo, Anthony P.** Council on Governmental Relations. *Proposed Modifications to the Utility Cost Adjustment Methodology.* [Online] November 15, 2015. [Cited: May 31, 2017.] http://www.cogr.edu/sites/default/files/COGR_Adjust_UCA_Nov13_2015.pdf.
6. **Paradise, Allison.** Center for Energy Efficient Laboratories. *Market Assessment of Energy Efficiency Opportunities in Laboratories.* [Online] March 12, 2015. [Cited: May 31, 2017.] http://www.etcc-ca.com/sites/default/files/reports/ceel_market_assessment_et14pge7591.pdf.

7. **U.S. Government Publishing Office.** 2CFR §200.318 d and CFR §200.313 c2. *Code of Federal Regulations.* [Online] 2/9/2017. [Cited: June 5, 2017.] https://www.gpo.gov/fdsys/search/home.action.
8. *Shared Support: Centralized laboratories offer an alternative for researchers with a predilection for the latest technology.* **Gould, Julie.** March 2015, Nature, Vol. 519, pp. 495-496.
9. *A Framework for Managing Core Facilities within the Research Enterprise.* **Haley, Rand.** September 2009, Journal of Biomolecular Techniques, Vol. 20, pp. 226-230.
10. **Lawrence Berkeley National Laboratory Center for Building Science Applications Team.** *A Design Guide for Energy-Efficient Research Laboratories.* [PDF] July 1996. Vols. LBNL-PUB-777. https://eetd.lbl.gov/sites/all/files/evam_mills_-_a_design_guide_for_energy-efficient_research_laboratories.pdf.
11. **Ahn, Natalie.** *Professor in the Department of Chemistry and Biochemistry and Investigator with the Howard Hughes Medical Institute.* [interv.] Kathy Ramirez-Aguilar Christina Greever. March 16, 2017.
12. **Northcutt, Wayne.** Architect-Facilities Planner at the University of Colorado Boulder. *personal communication.* September 2016.
13. **University of Colorado Boulder.** General Administrative and Infrastructure Recharge (GAIR). *Budget & Fiscal Planning.* [Online] May 4, 2016. [Cited: June 5, 2017.] http://www.colorado.edu/bfp/budget/misctopics/gair/gair.html.
14. **Ramirez-Aguilar, Kathryn A.** *CU Green Labs Audit and Conservation Program: MCD Biology Department Pilot Study, Final Report for Pollution Prevention Mini-Grants for Greening of State Government.* Environmental Center/Facilities Management, University of Colorado Boulder. 2012. https://www.colorado.gov/pacific/sites/default/files/CU%20Green%20Laboratory%20Audits%20and%20Conservation%20Program%20Final%20Report.pdf.
15. *Managing and Maintaining High Performance Laboratory Ventilation Systems (slide 6).* **T.C. Smith of Exposure Control Technologies, Inc.** 2016. Presentation given at the International Institute for Sustainable Laboratories National Conference 2016.
16. *Optimizing Laboratory Exhaust Systems: How New Technologies, Such as Variable Air Volume Controls, Can Provide Significant Energy Savings.* **Neuman, Victor.** 3, April 2013, Lab Manager, Vol. 8, pp. 32-34. http://photos.labmanager.com/magazinePDFs/2013/LMM-Apr-2013.pdf .
17. *Laboratory Design Fundamentals (slide 47).* **Don MacDonald of Phoenix Controls.** 2016. Presented at ASHRAE Madison Chapter on March 14, 2016. http://ashraemadison.org/images/ASHRAE_Madison_Lab_Fundamentals_03_14_2016.pdf
18. **National Institutes of Health.** Ruth L. Kirschstein National Research Service Award (NRSA) Stipends, Tuition/Fees, and Other Budgetary Levels Effective for Fiscal Year 2016. *NOT-OD-16-047.* [Online] January 20, 2016. [Cited: June 5, 2017.] https://grants.nih.gov/grants/guide/notice-files/NOT-OD-16-047.html.
19. **Biological Industries.** Introduction to Fetal Bovine Serum Class. [Online] [Cited: February 15, 2017.] http://www.bioind.com/support/tech-tips-posters/introduction-to-fetal-bovine-serum-class/.

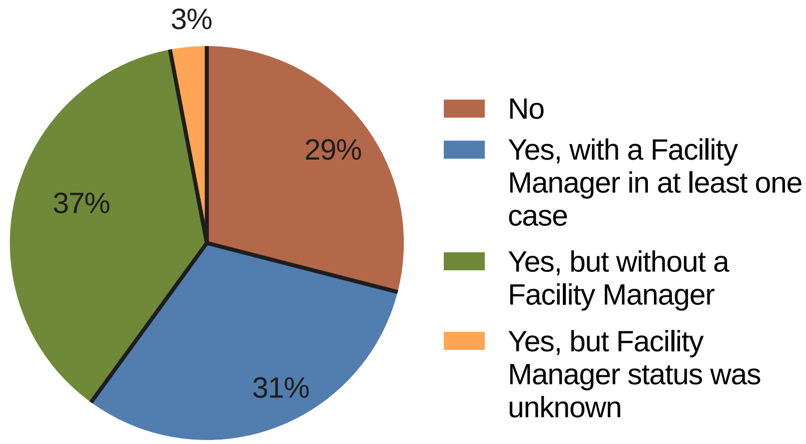
20. *Assessing the prevalence of mycoplasma contamination in cell culture via a survey of NCBI's RNA-seq archive.* **Anthony O. Olarerin-George, John B. Hogenesch.** 5, February 24, 2015, Nucleic Acids Research, Vol. 43, pp. 2535-2542. doi: 10.1093/nar/gkv136.
21. *Prevention and Detection of Mycoplasma Contamination in Cell Culture.* **Laleh Nikfarjam, Parvaneh Farzaneh.** 4, December 22, 2011, Cell Journal (Yakhteh), Vol. 13, pp. 203-212. PMCID: PMC3584481.
22. *Improving Your Lab's Workplace Culture.* **Muenz, Rachel.** 1, February 2017, Lab Manager, Vol. 12, pp. 34-37.
23. **Gates-Mayer, Holly.** Biosafety Officer at the University of Colorado Boulder. [interv.] Christina Greever. *personal communication.* April 14, 2017.
24. **Killilea, Alison.** Scientific Recharge Facilities Manager at University of California Berkeley. [interv.] Christina Greever. *personal communication.* April 27, 2017.
25. **Miller, Greg.** Lab Manager of CReM at Boston University. [interv.] Christina Greever. *personal communication.* May 22, 2017.
26. **Bringing Efficiency to Research (BETR) Grants.** Home. [Online] [Cited: October 26, 2017.] https://betrgrants.weebly.com/
27. **Association of American Universities.** Who We Are. [Online] [Cited: April 17, 2017.] https://www.aau.edu/who-we-are.

Appendix 1. Shared Cell Culture Facilities Among AAU Schools

In order to determine how common shared cell culture facilities are at large research institutions in the United States, the authors conducted a phone survey of biosafety officers at peer institutions within the Association of American Universities (AAU). CU Boulder is a member of these “62 distinguished institutions in the United States and Canada that continually advance society through education, research, and discovery…[earning] the majority of competitively awarded federal funding for academic research…” (27). The phone surveys were conducted over a period of several weeks in March and April 2017 by one of the authors. Though an attempt was made to contact biosafety officers at all 60 of the U.S. AAU institutions, only 35 Biosafety Officers were available for interview. The interview questions focused on whether there were any instances on their campus of shared cell culture facilities, individualized “independent” cell culture facilities, what cell culture arrangement was most prevalent, and the academic departments that utilize shared cell culture facilities. Twenty-two public U.S. institutions and 13 private U.S. institutions were surveyed.

As indicated in Figure 1 above, independent cell culture facilities were the most prevalent scenario for the majority of institutions interviewed. Biosafety officers at four of the 35 institutions surveyed indicated that independent cell culture spaces and shared cell culture spaces were equally prevalent on their campus. Only one institution indicated that shared cell culture was the most prevalent scenario on their campus. One hundred percent of the institutions interviewed had at least one example of independent, individualized cell culture. While independent cell culture spaces were the most common scenario of the institutions surveyed, several interviewees indicated that new construction on their campuses often includes more shared cell culture spaces, and that institutions are shifting towards promoting these shared resources. Based on these conversations, it appears that shared research spaces for cell culture as well as other instrumentation are becoming more prevalent at large research institutions. Figure 2 from the case study as well as Figure 10 below show that the majority of institutions interviewed had at least one example where three or more labs were sharing space and equipment for cell culture. Whether or not the shared cell culture facility had a paid Facility Manager was fairly evenly divided (Figure 10, 31 percent versus 37 percent).

Figure 10. There is at least one example on campus of three or more labs within a single department that share lab space and equipment for cell culture research.
35 institutions surveyed



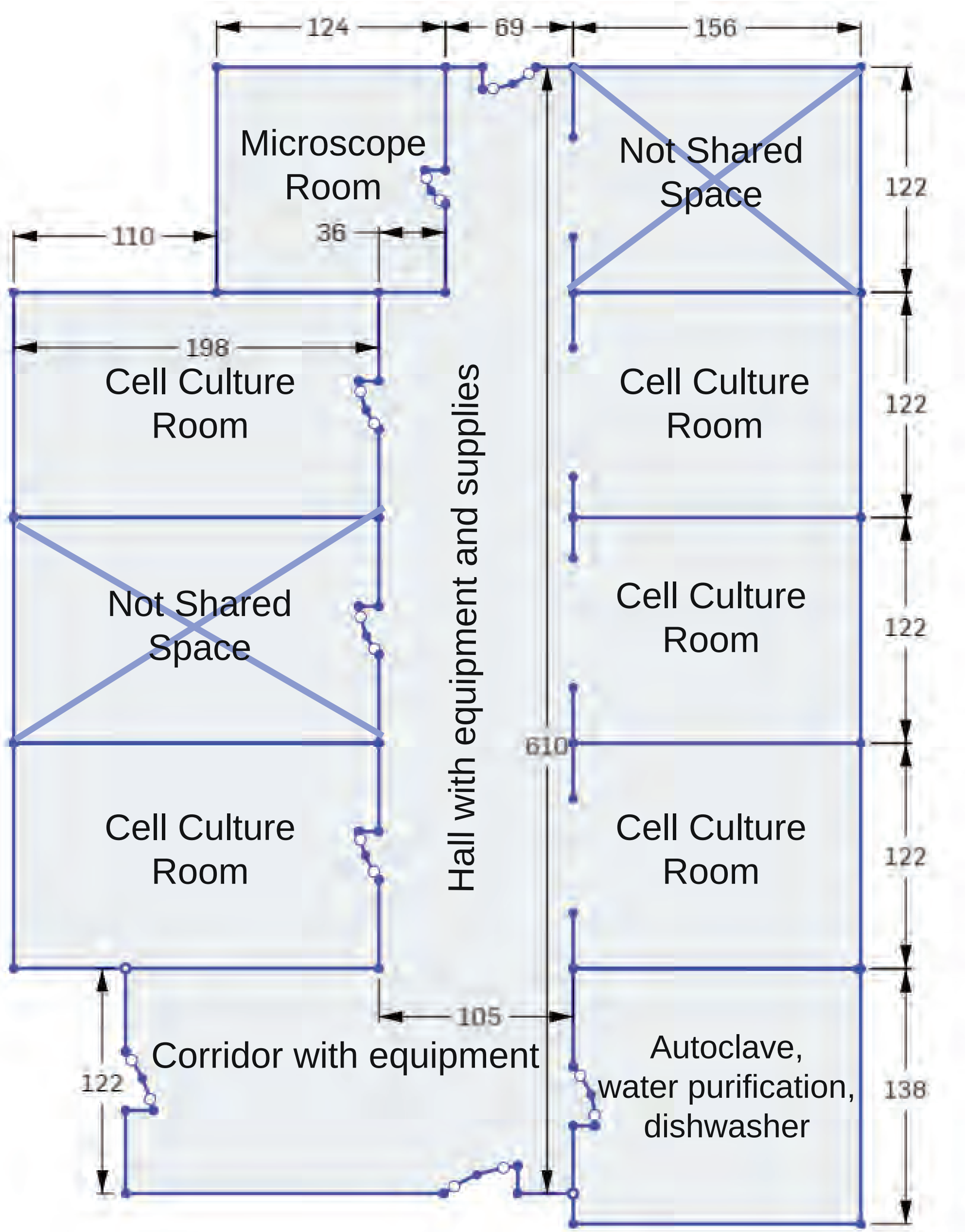
The reasons labs conduct cell culture in individualized spaces are not solely a factor of them working with higher risk hazards. In fact, some BSL-3 facilities at these institutions are the sole example of shared cell culture on the campus. The general opinion of biosafety officers was that scientists tend to prefer their own space for cell culture if it is an option. Other driving factors that lead to a lab doing cell culture independently are whether funding is available to purchase the necessary equipment or renovate space, whether the faculty member has the prestige or power to request their own space, and whether the research building was originally designed to facilitate individualized cell culture. Many older buildings were designed so that labs had their own cell culture space, but as mentioned above, the trend for newer buildings is for more shared cell culture spaces.

Finally, there were a wide variety of responses to the question of which academic departments had shared cell culture:

- At six institutions, basic science departments were the only ones with shared cell culture facilities.
- At two institutions, medical or veterinary departments were the only ones with shared cell culture facilities.
- At 14 institutions, both basic science departments and medical/veterinary departments had shared cell culture facilities.
- At one institution, both the basic science and veterinary departments had shared cell culture facilities.
- At three institutions, the biosafety officers did not know which departments were represented in their shared cell culture facilities.
- At nine institutions, there was no form of shared cell culture.

Appendix 2 BCCF Floor Plan

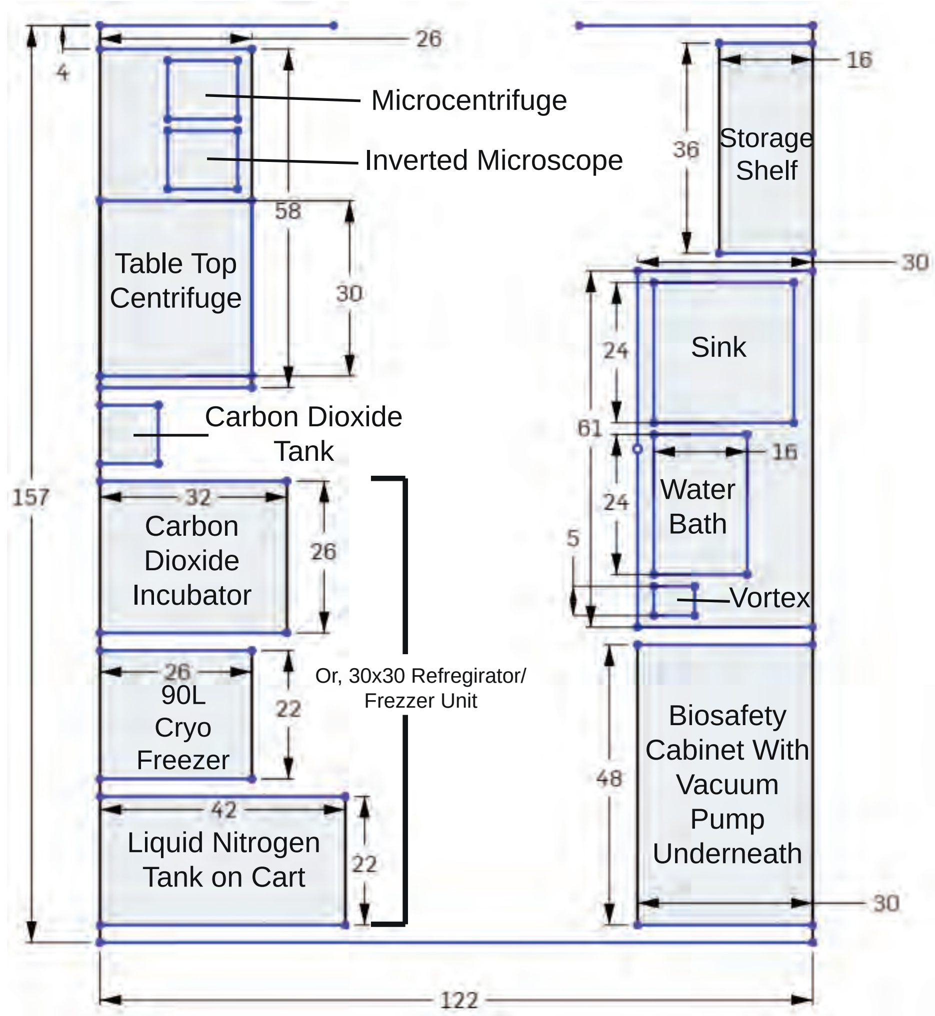
Floor plan of the BCCF. All dimensions are in inches.



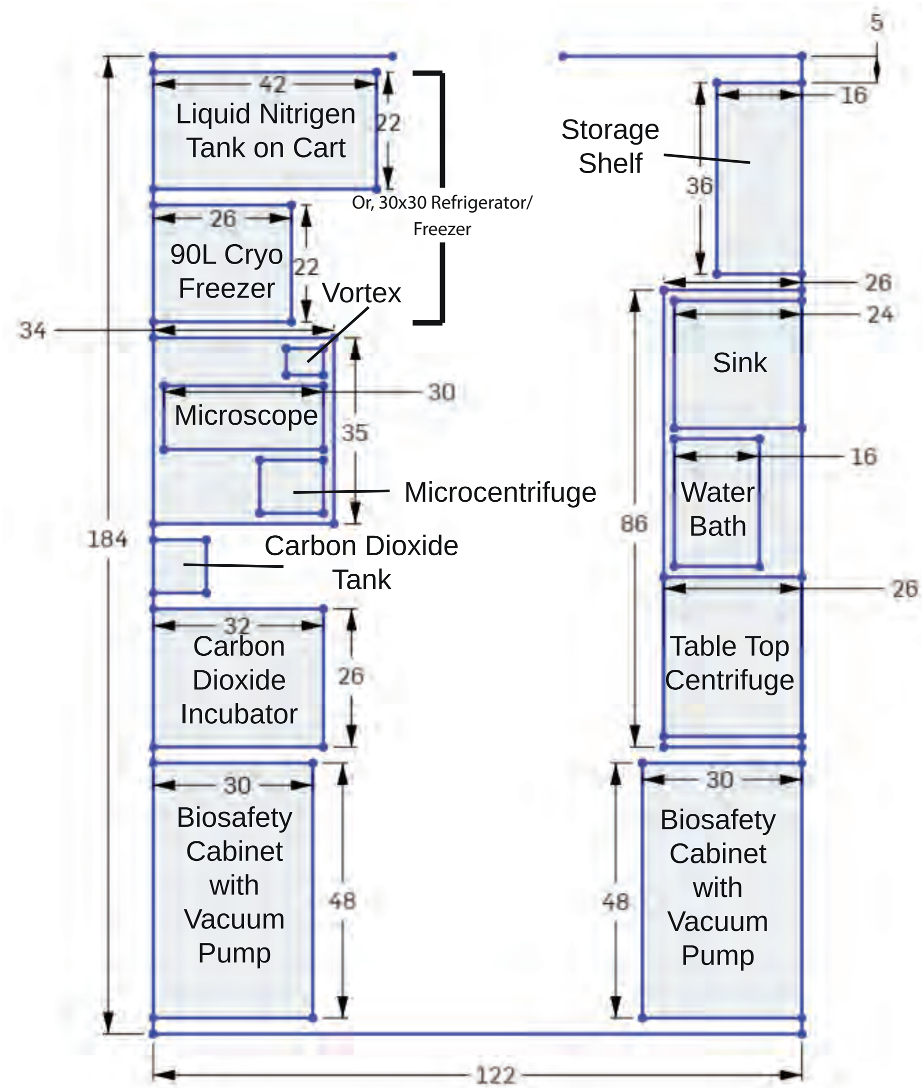
Biochemistry Cell Culture Facility, 1554 ft²

Appendix 2 Hypothetical Scenario Floor Plans

Floor plans of the hypothetical scenario individual cell culture spaces. All dimensions are in inches. Unless noted otherwise, all gaps between tables and equipment that would sit on the floor are three inches wide. All gaps between equipment on table tops are two inches wide.



Hypothetical Scenario
Individual Cell Culture Space with one biosafety cabinet
12 labs would have this floor plan
133 ft²



Hypothetical Scenario
Individual Cell Culture Space with two biosafety cabinets
4 labs would have this floor plan
156 ft²

$(133\ ft^2 * 12) + (156\ ft^2 * 4) = 2{,}220\ ft^2$

Square footage of Hypothetical Scenario is $2{,}220\ ft^2$

Appendix 3. Equipment required for cell culture

	Biosafety Cabinets (BSC)	Vacuum Pump	Carbon Dioxide Incubator	Carbon Dioxide Tank	Centrifuge	Microcentrifuge	Refrigerator/Freezer Combo Unit	Water Bath	Vortex	Inverted Microscope	Cryo-storage Freezer (200 L for BCCF, 90 L for 16 ind. labs)	Liquid Nitrogen Tank	Sinks	*(-)20 °C Freezer*	*4 °C Refrigerator*	*Autoclave*	*Dishwasher*	*Insect cell shaker*	*Low temperature incubator for insect cells*	*Maxi pipettman controller*	*Millipore water purifier*	Total Cost
Equipment in the Biochemistry Cell Culture Facility (BCCF)	10	10	15	5	3	1	4	3	1	3	2	2	6	1	3	1	1	1	1	12	1	*Equipment in gray was not included in subsequent calculations but provided here for informational purposes*
2016 pricing for single unit of equipment	7850 ⁑	496†	4815*	—	6572*	2272*	2210*	408†	320*	1967*	7992 for 90L*, 10801 for 200L*	—	—	**BCCF**								
Estimated cost if new equipment were purchased for BCCF at 2016 pricing	78500	4960	72225	—	19716	2272	8840	1224	320	5901	21602	—	—	**New Equipment Cost**								**215560**
Annual cost of gases and BSC certification for BCCF	1850 ☆	—	—	2068	—	—	—	—	—	—	—	9040	—	**Annual gases and BSC certification**								**11108**
														Total								**226668**
Equipment required for one lab in Hypothetical Scenario	1	1	1	1	1	1	1	1	1	1	0.31❖	0.31❖	1	**Hypothetical Scenario (one lab)**								
Estimated cost of equipment for one lab	7850	496	4815	—	6572	2272	2210	408	320	1967	2497.5	—	—	**New Equipment Cost**								**29408**
Annual cost of gases and BSC certification for one lab	185	—	—	106	—	—	—	—	—	—	—	553	—	**Annual gases and BSC certification**								**844**
														Total								**30252**
Equipment required for 16 labs in Hypothetical Scenario	20◆	20◆	16	16	16	16	16	16	16	16	5	5	16	**Hypothetical Scenario**								
Estimated cost of equipment for 16 labs	157000	9920	77040	—	105152	36352	35360	6528	5120	31472	39960	—	—	**New Equipment Cost**								**503904**
Annual cost of gases and BSC certification for 16 labs	3700	—	—	1696	—	—	—	—	—	—	—	8848	—	**Annual gases and BSC certification**								**14244**
														Total								**518148**
														Difference in new equipment cost alone between BCCF and Hypothetical Scenario								**288344**
														Difference in new equipment cost plus annual gas and BSC certification needs between BCCF and Hypothetical Scenario								**291480**

⁑ quote from Baker Company for BSC, model SG404

†quote from VWR

*quote from Fisher Scientific

** Based on actual cost of gases for BCCF in 2015

*** Estimated costs based on pricing for CO_2 and LN_2 in 2015

☆ Though BCCF has 6 internally vented BSCs that cost $185 per year to certify and 4 externally vented BSCs that cost $250 to certify, all estimates above are for internally vented BSCs only.

❖Five 90 L cryofreezers are required in order to provide the equivalent sample storage that the BCCF currently has (400 L). Even in our hypothetical scenario, labs would share liquid nitrogen storage. Five 90 L cryostorage freezers divided by 16 labs is 0.31 cryostorage units per lab.

◆ Four of the sixteen labs currently utilizing the BCCF would need two BSCs instead of just one to conduct cell culture in their own labs spaces due to the nature of their work and number of users. Therefore, the number of BSCs and vacuum pumps has been increased to two each for four labs. A hypothetical lab with one BSC would be 133 ft^2, and a lab with two BSCs would be 156 ft^2.

Appendix 4. Plug Loads in the BCCF versus Hypothetical Scenario

				BCCF			Hypothetical Scenario			
Equipment	**Use Assumptions**	**Source of Data**	**kWh/day**	**Units of Equipment in BCCF (Appendix 3)**	**kWh/year**	**Cost/year at $0.1189/kWh**	**Units of equipment in 16 labs conducting cell culture independently (Appendix 3)**	**kWh/year**	**Cost/year at $0.1189/kWh**	**Savings** (difference between BCCF and Hypothetical Scenario)
Internally-Vented BSC	on 24 hrs/day, 5 days/week	CU metering data	12.00	10	31200.0	3709.7	20	62400.0	7419.4	3709.7
Vacuum Pump	on 8 hrs/day, 5 days/week	CU metering data & CEEL Market Assessment (6)	2.20	10	5720.0	680.1	20	11440.0	1360.2	680.1
CO_2 Incubator	on 24/7/365	Thermo Fisher Scientific's Peter Diebold; HeraCell 150i incubator (5-8 cubic feet) consumes 51 watts.	1.22	15	6679.5	794.2	16	7124.8	847.1	52.9
Table Top Centrifuge	on 24/7/365	CEEL Market Assessment (6)	4.30	3	4708.5	559.8	16	25112.0	2985.8	2426.0
Microcentrifuge	on 24/7/365	CDPHE study (14)	0.25	1	91.3	10.8	16	1460.0	173.6	162.7
Refrigerator/Freezer Combo	on 24/7/365	Home Depot	1.10	4	1606.0	191.0	16	6424.0	763.8	572.9
Water Bath at 37 °C	on 24/7/365	CU metering data	0.46	3	503.7	59.9	16	2686.4	319.4	259.5
Vortex	on 24/7/365	CU metering data	0.02	1	7.3	0.9	16	116.8	13.9	13.0
Inverted Microscope	on 24/7/365	CU metering data & CEEL Market Assessment (6)	0.75	3	821.3	97.6	16	4380.0	520.8	423.1
Cryo-storage Freezer on LN_2	on 24/7/365	Thermo Fisher Scientific's Peter Diebold	0.00	2 (200 L)	0	0	5 (90 L)	0	0	0
				Electricity cost per year:		**6104**	**Electricity cost per year:**		**14404**	
							Annual cost avoidance for electricity as a result of fewer plug loads in the BCCF:			**8300**

Appendix 5. Ventilation Calculations

Calculation 1. The cost per year to ventilate the BCCF. The BCCF is 15,540 cubic feet, air changes per hour (ACH) used is six, and the cost to ventilate the BCCF is $7.02 per cubic foot per minute-year (CFM/year) based on the horsepower required to provide supply and exhaust air to and from this space as well as the heating and cooling needs for the required supply and exhaust airflows as calculated by Jeremy Johnson, a CU Boulder Mechanical Engineer.

Calculation of air volume in BCCF for a year:

$$6 \text{ ACH} \times 15{,}540 \text{ ft}^3 = \frac{93{,}240 \text{ ft}^3}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{365 \text{ days}}{1 \text{ year}} = \frac{816{,}782{,}400 \text{ ft}^3}{\text{year}}$$

Calculation of cost to ventilate lab space per cubic foot:

$$\$7.02 \text{ per CFM/year} = \frac{\$7.02 \text{ min}}{\text{ft}^3 \text{ year}} \times \frac{1 \text{ hour}}{60 \text{ min}} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1 \text{ year}}{365 \text{ days}} = \frac{\$\, 1.336 \times 10^{-5}}{\text{ft}^3}$$

Calculation of the cost to ventilate BCCF:

$$\frac{816{,}782{,}400 \text{ ft}^3}{\text{year}} \times \frac{\$1.336 \times 10^{-5}}{\text{ft}^3} = \frac{\$10{,}909}{\text{year}}$$

Calculation 2. The cost per year to ventilate our hypothetical scenario where 16 labs conduct cell culture independently. Assuming a 10-foot-high ceiling such as the BCCF has, the volume of the space needed for 16 labs to conduct cell culture in independent spaces is 22,200 cubic feet. This calculation uses 6 ACH and $7.15 per cubic foot per minute-year as calculated by Jeremy Johnson, a CU Boulder Mechanical Engineer. As above, this calculation is also based on the horsepower required to provide supply and exhaust air to and from this space as well as the heating and cooling needs for the required supply and exhaust airflows.

Calculation of air volume in hypothetical scenario for a year:

$$6 \text{ ACH} \times 22{,}200 \text{ ft}^3 = \frac{133{,}200 \text{ ft}^3}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{365 \text{ days}}{1 \text{ year}} = \frac{1{,}166{,}832{,}000 \text{ ft}^3}{\text{year}}$$

Calculation of cost to ventilate lab space per cubic foot:

$$\$7.15 \text{ per CFM/year} = \frac{\$7.15 \text{ min}}{\text{ft}^3 \text{ year}} \times \frac{1 \text{ hour}}{60 \text{ min}} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1 \text{ year}}{365 \text{ days}} = \frac{\$\, 1.36 \times 10^{-5}}{\text{ft}^3}$$

Calculation of the cost to ventilate hypothetical scenario of 16 individual cell culture spaces:

$$\frac{1{,}166{,}832{,}000 \text{ ft}^3}{\text{year}} \times \frac{\$1.36 \times 10^{-5}}{\text{ft}^3} = \frac{\$15{,}873}{\text{year}}$$

Appendix 6. Time spent on various cell culture tasks

This table was developed in consultation with the BCCF Facility Manager, and shows the amount of time per week that the Facility Manager spends on each cell culture-related task. Taking her expertise into account, this also shows best-guess estimates for the amount of time per week it would take a single lab to complete the same tasks. Many factors went into the estimate of how much time it would take a single lab member to do one of these tasks including considerations about whether it would take more or less time than the BCCF Facility Manager to do it, the number of pieces of equipment the individual is responsible for, the number of users in the facility, and volume of media, ethanol, or biohazard trash used or produced. All hours per year were rounded to the nearest whole hour.

	Hours per week the Facility Manager spends on essential tasks for BCCF	**Estimated hours per week one lab member would need to spend on same task for a lab doing cell culture independently**	**Estimated total hours per week that 16 labs would need to spend on tasks for cell culture if working independently and not using BCCF**
Equipment and facility maintenance including exchange of gas cylinders	9	1	16
Addressing biohazard trash including autoclaving	5.5	2	32
Media preparation	5	0	0
Accounting	4.85	1	16
Stocking, purchasing, picking up supplies	4.5	2	32
Aliquoting substances into smaller stocks including FBS	3.5	0.5	8
Training of users	2	1	16
Fetal bovine serum testing	1.5 (78 hours per year)	0.1 (5 hours per year)	1.6 (83 hours per year)
Autoclaving and dishwashing of media bottles and glassware	1.5	0.5	8
Recycling	0.5	0.25	4
Ethanol prep	0.5	0.25	4
Safety, regulatory, building issue notifications for group and updating chemical inventory	0.5	0.5	8
Biosafety cabinet certification and related prep-work	0.5 (26 hours per year)	0.15 (8 hours per year)	2.4 (125 hours per year)
Mycoplasma testing	0.5 (26 hours per year)	0.13 (7 hours per year)	2.08 (108 hours per year)
Autoclave certification and spore testing	0.15 (8 hours per year)	0.02 (1 hour per year)	0.32 (17 hours per year)
Total hours per week required to do the above listed cell culture tasks	**40**	**9.4**	**150.4**

Appendix 7. Annual Salary Cost Avoidance

Annual salary cost avoidance as a result of the BCCF Facility Manager (Senior Professional Research Assistant) accomplishing the tasks necessary to do cell culture research instead of lab members.

	Facility Manager of BCCF (Senior Professional Research Assistant within College of Arts & Sciences, median salary)	**Post-comprehensive exam graduate student classified as a Research Associate in the Division of Biochemistry, FY17 (Hypothetical Scenario)**	**Second-year postdoctoral researcher on a NIH Kirschstein-NRSA award, FY16 data (Hypothetical Scenario)**
Salary or stipend per year	$60,000	$31,709	$47,268
Fringe benefit rate	37.70%	13.7% + Tuition ($10,836)	37.70%
Fringe benefits including tuition benefit	$22,620	$15,180	$17,820
Cost of salary + fringe benefits for one year	$82,620	$46,889	$65,088
From Appendix 6, **hours per week** required to do cell culture tasks. A graduate student is working in half the labs and a postdoctoral researcher is working in half the labs of the hypothetical scenario	40	75.2	75.2
Cost per year for individual to do cell culture tasks	$82,620	$88,151	$122,365
Subtotal	$82,620	$210,516	
Annual salary cost avoidance to CU Boulder scientists when the BCCF Facility Manager does cell culture duties versus if graduate students and postdoctoral researchers do them as in the hypothetical scenario	$127,896		

Appendix 8. BCCF End User Survey Results

Figure 11. Survey respondents' role in their lab

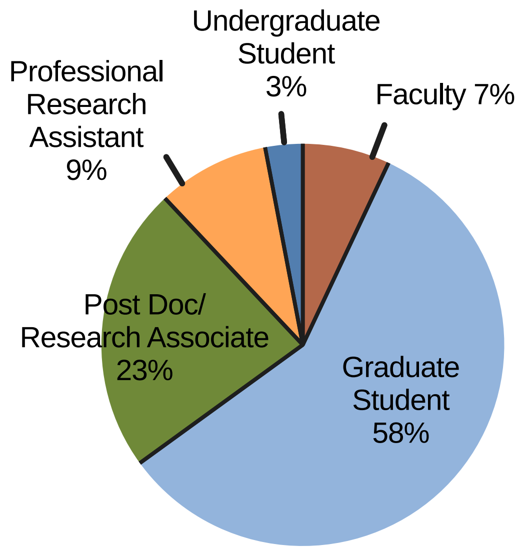


Figure 12. Length of time worked in the BCCF

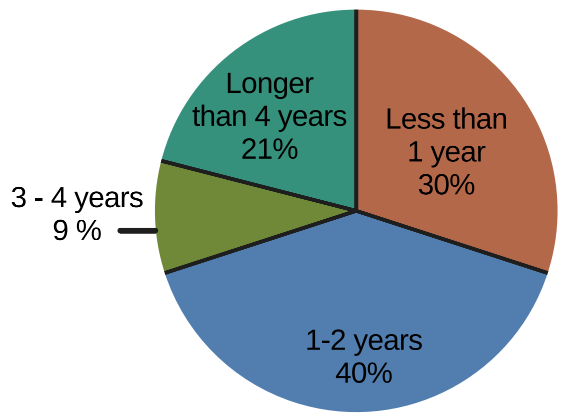


Figure 13. Frequency of use of the BCCF by end users

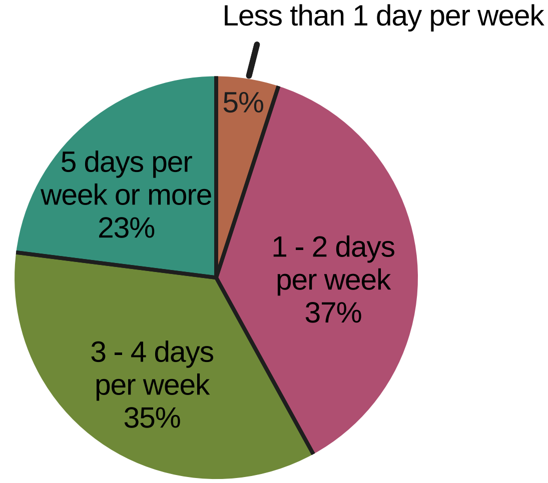


Figure 14.

End users were given a choice: "Would your preference be to use the shared BCCF or would you prefer that your lab have its own cell culture space? If your lab did cell culture on its own, you would be responsible for some of the tasks currently done by the BCCF Facility Manager such as ordering, media prep or purchasing, biohazard disposal, training new users, scheduling equipment repairs and certifications, etc."

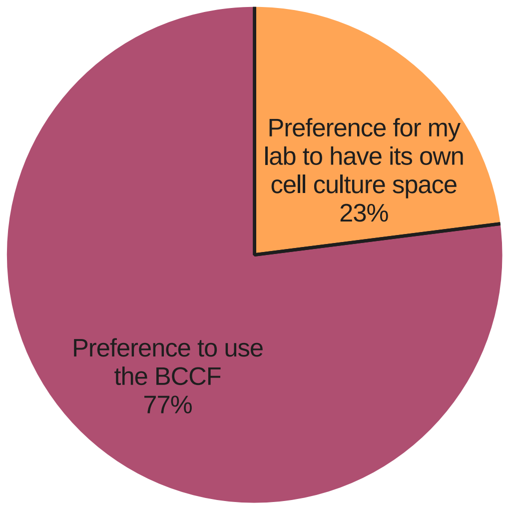


Figure 15. In your opinion, what are the benefits of the BCCF? Select all that apply.

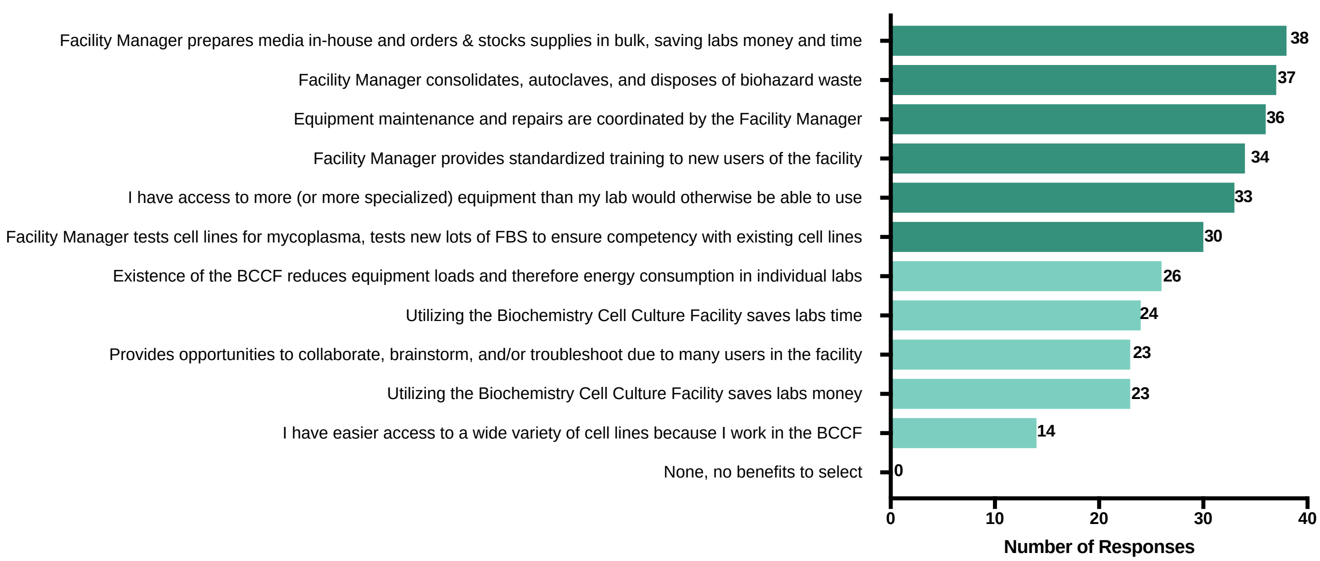


Figure 16. In your opinion, what do you dislike or what are the disadvantages of the BCCF? Select all that apply.

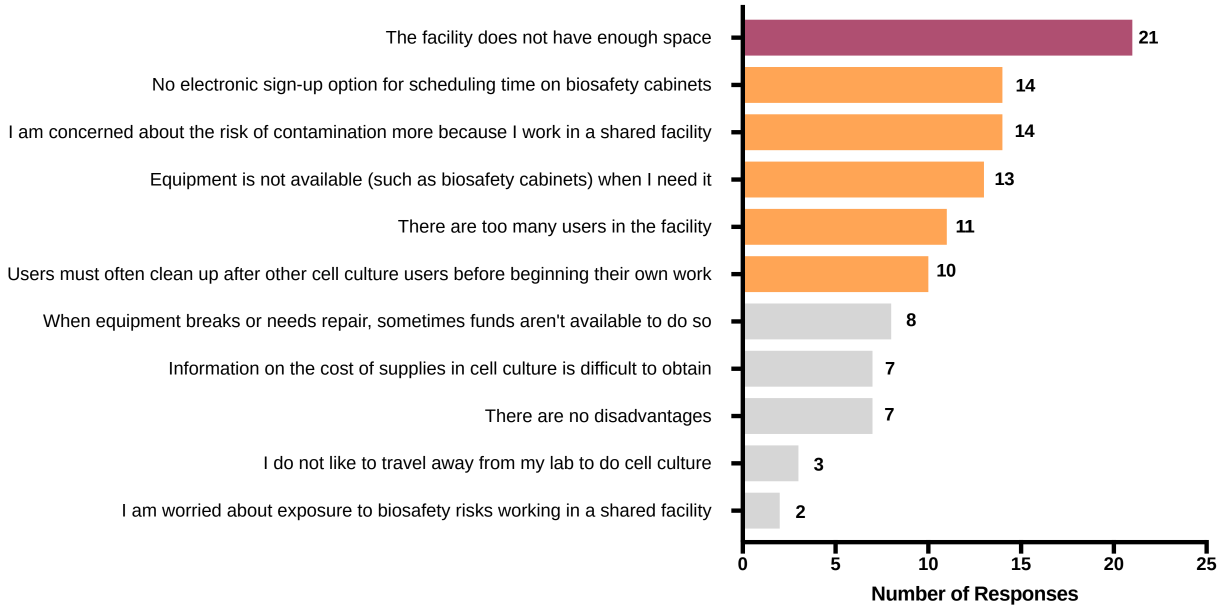


Figure 17. Number of users with cell culture experience outside of the BCCF at CU Boulder or at another institution. If they did have other experience we asked them to select the option that best describes their other experience.

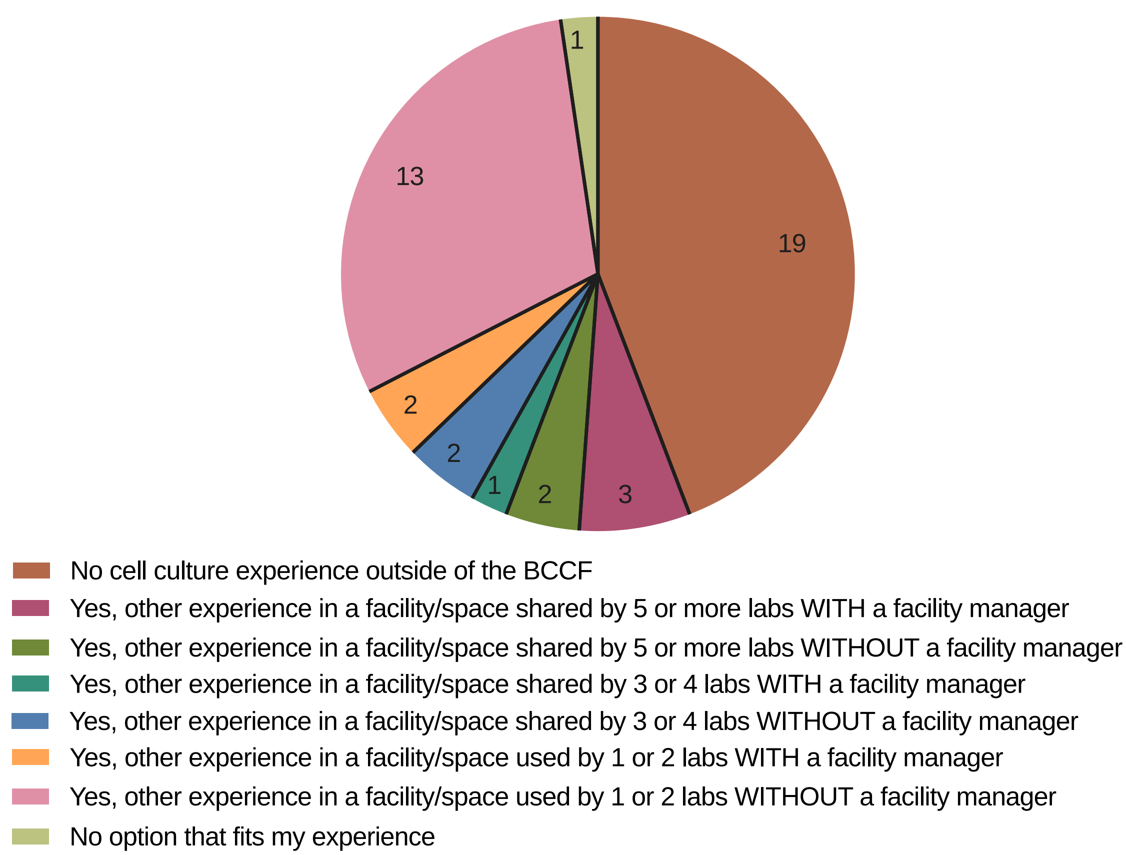


Figure 18. Use the below scale to identify your overall satisfaction with the BCCF.