Summer 2023

# Laboratory Management Models in Core Facilities

Karmen Michael Owen

# Laboratory Management Models in Core Facilities

By

Karmen Michael Owen

Bachelor of Science
Newberry College, 2015

---

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science in

Biomedical Science

School of Medicine

University of South Carolina

2023

Accepted by:

Robert L. Price, Director of Thesis

Jay D. Potts, Reader

Jason L. Kubinak, Reader

Ann Vail, Dean of the Graduate School

ABSTRACT

Core biotechnology facilities are often defined as laboratories that house shared resources for research. These laboratories are of great importance to research communities because a large portion of scientific research data is generated at these facilities. Different investigators can use core facilities to help further their research. In a university setting, there are several management strategies from small cores that house a specific type of instrument, to large cores that house many different technologies. Funding strategies also differ significantly, from those that are funded by a small group of well-funded investigators, to cores managed by a specific department or school, to completely centralized core management for the entire university. Each management style provides some advantages and disadvantages.

In this thesis, I have examined the core management strategies at 12 universities. Some house all their core instrumentation under one facility whereas others split the instruments into different cores that offer specific technologies and expertise. Funding, revenue, and expenses of these different research cores were also compared. Other aspects, including laboratory personnel, marketing strategies, and different laboratory management software systems, are also discussed for several of the cores.

# TABLE OF CONTENTS

# LIST OF TABLES

LIST OF FIGURES

# LIST OF ABBREVIATIONS

ABRF ........ Association of Biomolecular Resource Facilities

AMRIS ........ Advanced Magnetic Resonance and Spectoscopy

ASPIRE III ........ Advanced Support for Innovative Research Excellence

AURIF ........ Auburn University Research Instrumentation Facility

BINA ........ BioImaging North America

BIUK ........ BioImaging United Kingdom

BRC ........ Biotechnology Resource Center

CAIS ........ Center for Applied Isotope Studies

CAT ........ Center for Advanced Technology

CCRC ........ Complex Carbohydrate Research Center

CF ........ Core Facility

CNSP ........ The Canadian Network of Scientific Platforms

COBRE ........ Centers of Biomedical Research Excellence

CSB ........ Center for Structural Biology

CTLS ........ Core Technologies for Life Sciences Association

CTRU ........ Clinical and Translational Research Unit

DLAR ........ Division of Laboratory Animal Resources

DPCPSI ........ Division of Program Coordination, Planning, and Strategic Initiative

EICF ........ Emory Integrated Core Facilities

FCS ........ Flow Cytometry Software

GEM ........ Georgia Electron Microscopy

GerBI-GMB .................. German BioImaging Society for Microscopy and Image Analysis

I2AT ...................................................... Institute of Imaging and Analytical Technologies

ICBR .............................................. Interdisciplinary Center for Biotechnology Research

IRF ............................................................................ Instrumentation Resource Facility

MRI ................................................................................ Magnetic Resonance Imaging

MRI ........................................................................... Major Research Instrumentation

NCRR ................................................................. National Center for Research Resources

NIAD .................................................. National Institute of Allergy and Infectious Disease

NIH ................................................................................. National Institutes of Health

NMR ............................................................................. Nuclear Magnetic Resonance

NSF .............................................................................. National Science Foundation

NYSTAR... Empire State Developments Division of Science, Technology, and Innovation

ORCA ............................................................... Office of Research Core Administration

ORD ......................................................................... Office of Research and Development

PPMS ...................................................................... Pasteur Platform Management System

BINA .................................................................................. BioImaging North America

RBC .................................................................................................. Rodent Behavior Core

RII ............................................................................ Research, Innovation, and Impact

SEM .............................................................................. Scanning Electron Microscope

ShEEP .................................................................. Shared Equipment Evaluation Program

SOM ............................................................................................... School of Medicine

TEM ........................................................................... Transmission Electron Microscope

USC ............................................................................... University of South Carolina

VA .................................................................................................... Veterans Affairs

VICTR ..................................................... Vanderbilt Clinical and Translational Research

# CHAPTER 1

# INTRODUCTION

Many large universities have laboratories that are shared by multiple users and investigators. These facilities are called core research laboratories. These laboratories are of great importance to biomedical science research communities because a large portion of scientific research data is generated at these facilities. These core laboratories house state-of-the-art equipment that can be used for several different research studies. Laboratory instrumentation can be very expensive and may need a lot of maintenance. Not all laboratories can buy this expensive equipment themselves. Instead, they may choose to go to a core lab that houses the equipment they need to use. The instrumentation that is housed in a core lab is maintained by laboratory specialists that specialize in those specific instruments. These laboratory personnel can help investigators and individuals with designing their experiments and help train them on specific instruments.

Core facilities have become more popular in recent years due to the dependence of science upon technology. Genomics core facilities first began really being established more in the 1990's and early 2000's after the human genome was first sequenced (Meder et al., 2016). More core facilities started to be developed during this time. Expensive sequencing technologies made it necessary for scientific research to begin collaborating at core facilities to cut down on expenses. In the 1990's, the most offered service in core facilities was DNA sequencing (Lippens et al., 2019).

The Association of Biomolecular Resource Facilities (ABRF) is an organization of mostly molecular core facilities. It provides educational material to core leaders and publishes quarterly publications. They performed a survey in 1998 that showed the most common service was protein sequencing at that time (McMillen et al., 2000). This is still a big service today. Many facilities were originally established to offer a particular service, usually based on a single technology, like DNA sequencing (Lippens et al., 2019).

Now, existing core facilities have grown to include more services and new cores are being established. Core labs are developing new technologies and services. The German BioImaging Society for Microscopy and Image Analysis (GerBI-GMB) is a network of core facilities for imaging and microscopy in Germany (Ferrando-May et al., 2016). Figure 1.1 shows the increase in core facility registrations for the German BioImaging Society in the years from 2011-2015 (Ferrando-May et al., 2016). From the graph, you can tell that the number of core facility registrations has increased over the years.

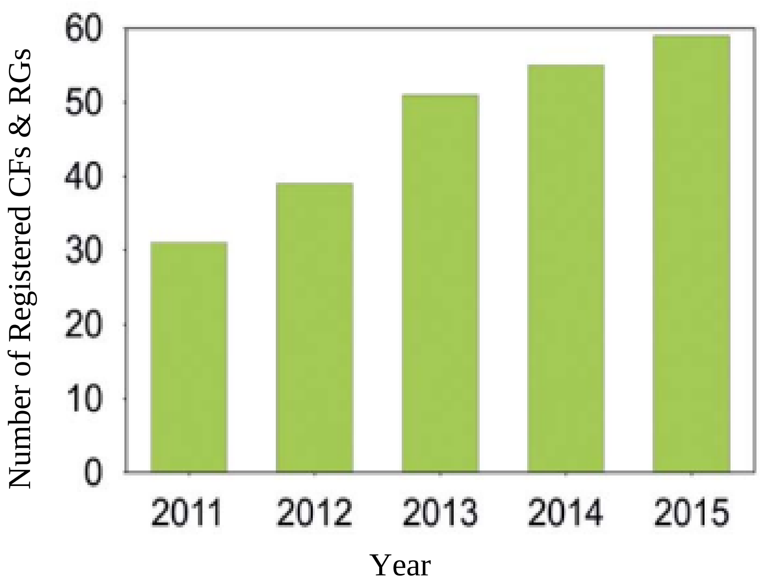



Figure 1.1 The GerBI Network number of bioimaging facility registrations per year in Germany has increased each year.
CF-Core Facility, RG-Research Group (Ferrando-May et al., 2016)

These facilities need to stay updated with state-of-the-art equipment and need to continue adding services to stay at the cutting edge of research and science. There can be multiple different core facilities within an institution or university. Today, there are more core facilities that have evolved to specialize in instrumentation. Some of the more common facilities now include light and confocal microscopy, electron microscopy, flow cytometry, and mass spectrometry. Sometimes these different labs are housed under the same core, but at other times they are separate.

The way that different core facility factors are compared is by administering surveys or studies and comparing these with previous surveys. In this paper, many surveys are discussed and compared with each other.

In this study, research was done by observing universities core websites of different universities to compare the different management models in place. The funding and income situations of each of these universities was analyzed and compared to each other. Strategies for obtaining instrumentation and funding of management personnel were also examined and compared. Lastly, the lab management software used at these different cores was analyzed. Also, over 25 scientific articles were read that related to the management of core facilities. This data was then analyzed and compared. The 12 universities that were analyzed are:

University of Georgia

University of Auburn

University of Kentucky

University of Missouri

Mississippi State University

University of Florida

Vanderbilt University Medical Center

University of Virginia School of Medicine

Cornell University

Virginia Tech

Emory University

University of South Carolina

These schools were chosen mainly because they are universities that are located in the Southeastern United States. The University of South Carolina School of Medicine is located in Columbia, South Carolina. The chosen schools are located in the area around the University of South Carolina because these states share similar financial backgrounds. Figure 1.2 shows a map of the United States. The purple dots indicate where the examined universities are.

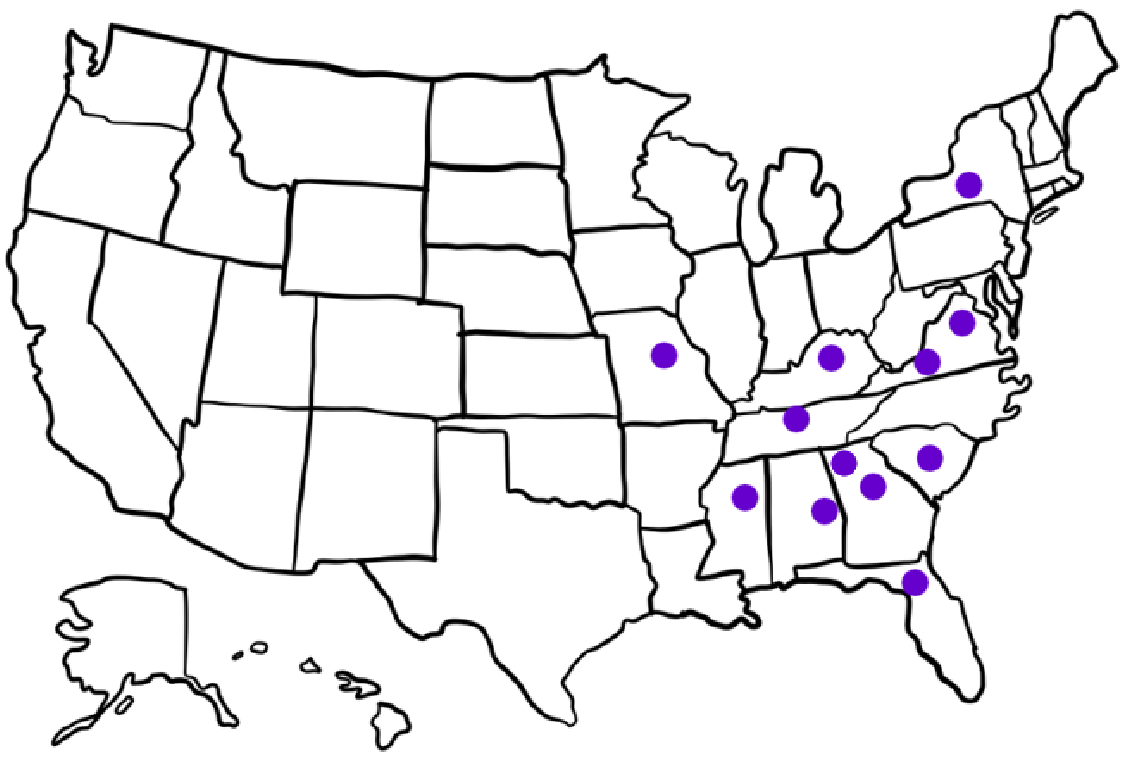


Figure 1.2 Locations of the 12 university core facilities surveyed for this thesis.

# CHAPTER 2

# DEFINITION OF A CORE FACILITY

A large obstacle in core facility management is that there is not a single unified definition of what a core facility is and how it is truly defined. The National Institutes of Health (NIH) defines core facilities as “centralized shared resources that provide access to instruments, technologies, services, as well as expert consultation for scientific and clinical investigators” (Turpen et al., 2016). In this aspect, core facilities can be thought of as small businesses that offer services (Turpen et al., 2016). The common factor that all core facilities have is that they provide a service. The service may be done by the core facility personnel, or the researcher may independently use a certain instrument located at the core facility. Most often, fees are associated with the service and the researcher must pay to use the equipment or receive a service. However, some core facilities are fully funded by the university and do not have fees. This is rare however, and was not found in any of the mentioned universities. Just having instruments in a lab does not make that lab a core facility. A service must be provided to be considered a core facility. For example, a bioinformatics core facility may not have any major instrumentation, but would still qualify as a core facility because they offer a service in exchange for a fee.

Agilent CrossLab did a benchmark study in 2019 that yielded 244 responses from all across the United States (Strubczewski, 2019). Over 50 different core types were included. This survey found that most of the facilities surveyed said their facility was

more equipment centric. This was 44.2%, while 37.4% of the answers were that the core was more service centric. There was another 18.4% that considered their lab as equal between instrumentation and services. The answers to this survey are shown in figure 2.1. Instrumentation centric laboratories require more space for the large equipment while service-focused facilities may be more expensive to operate. This is mainly because of the personnel costs (Hockberger et al., 2018).

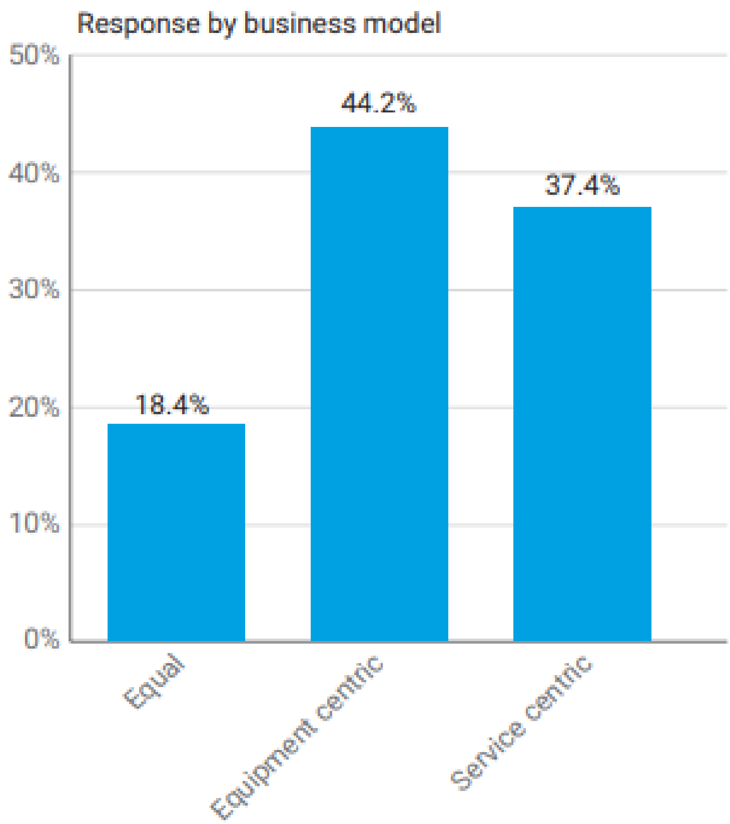



Figure 2.1 Laboratories were asked whether they offered more instrumentation services, or if their core was more service based. Most cores said that they were mostly equipment centric. This was closely followed by labs that were mostly service centric. Another proportion said they had an equal amount of services and equipment (Strubczewski, 2019).

Core facilities are most often housed at universities or research institutes, but some facilities that are still referred to as cores are within hospitals or other businesses. They are also found in other industrial settings. There is not a set location of where a core facility must be. Some cores are open to the public and offer services to outside researchers and other cores do not offer their services to outside researchers. All of the analyzed universities offer their services to external users.

A survey was done by the Core Technologies for Life Science (CTLS) Association in 2018. They are an international non-profit association that is based in Europe. This survey was emailed to all members of CTLS, all members of the Association of Biomolecular Resource Facilities (ABRF), and to the entire German BioImaging (GerBI) mailing list. This survey was completed by 275 different people who worked in core facilities all over the world (Adami et al., 2021). Figure 2.2 shows the results of this survey. Most cores, (48%) surveyed were located in universities as stated by 139 recipients of the survey. This was closely followed by research institutes at 46% (131 responses) (Adami et al., 2021). A small percentage (6%) of recipients responded that they worked in a hospital setting, an industrial company, or a different setting. This study also found that the percentage of university respondents was much higher in the United States than in Europe. This is thought to be because there may be more research institutes as opposed to universities in Europe, whereas there are more Universities in the United States (Adami et al., 2021). The biggest example of an independent core facility in the United States is St. Jude Children’s Research Hospital (Haley, 2009).

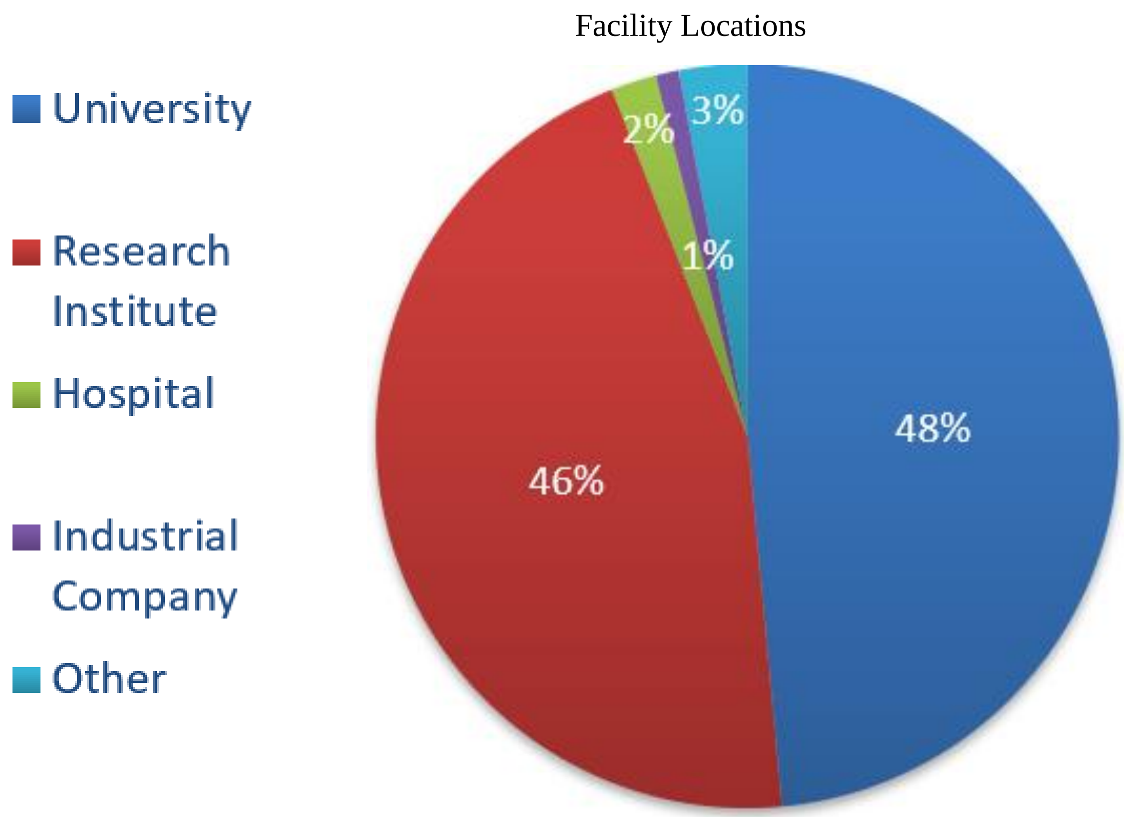



Figure 2.2 From this survey it was determined that most core facilities were associated with a university. Almost the same amount of facilities were found in research institutes. Only 6% of core facilities were found elsewhere, like in hospitals or industrial settings. (Adami et al., 2021)

A separate study was done in 2021 by BioImaging UK. This survey was completed by 114 people in 46 different light microscopy facilities in the United Kingdom. The management part of the survey was only completed by 45 of the core facility directors. Most of the answers were in university settings. This accounted for 80% of the answers. Thirteen percent of responses were from research institutes and the last 7% were from any other responses. The responses of this study are shown in figure 2.3 (Fletcher and Anderson, 2021).

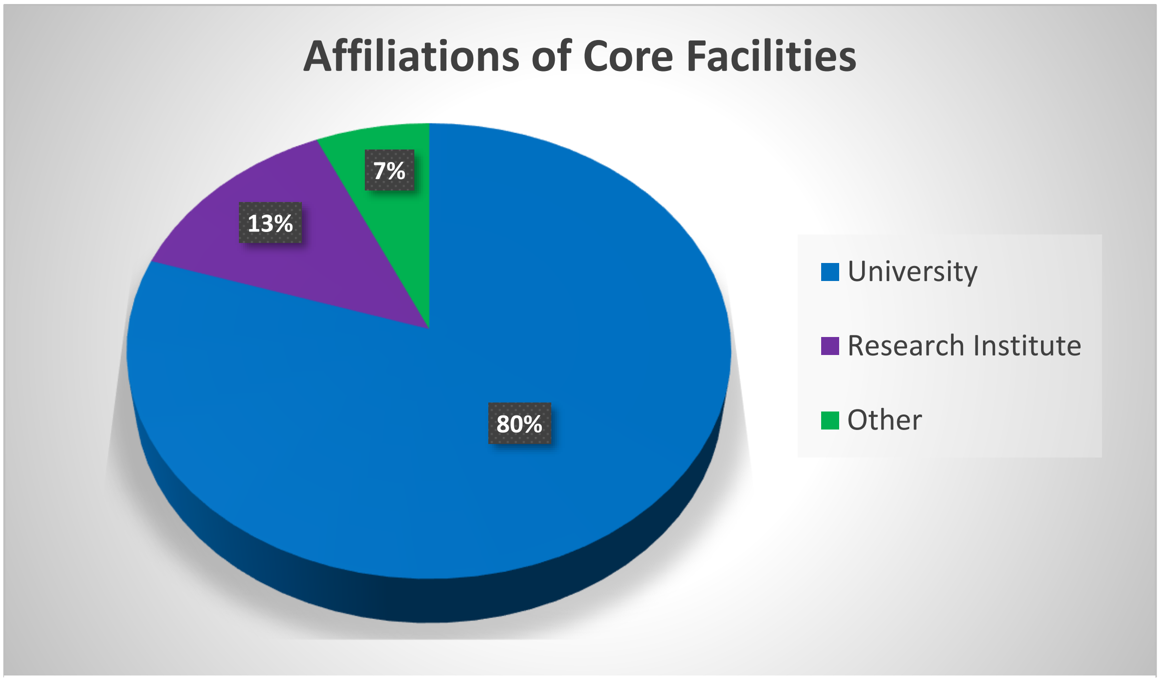



Figure 2.3 Affiliations of Core Facilities. This part of the survey was only filled out by core facility directors. There were 45 core facility directors involved in this survey. Most of the responses were from directors that worked in university settings. Another 13% of responses came from research institutes. Lastly, 7% of responses were from locations other than universities and research institutes. (Fletcher and Anderson, 2021).

An older study was done by the Association of Biomolecular Research Facilities (ABRF) survey committee in 2007. This survey was sent to all ABRF members. There were 203 responses to this survey from 13 different countries. These were from all types of different technologies. Figure 2.4 shows the surveyed institution type. The majority were in an academic setting (Loo, 2009). This accounted for 77% of the results. Private institutions were the second highest at 7.9%. Other responses included international and national labs and also industry labs.

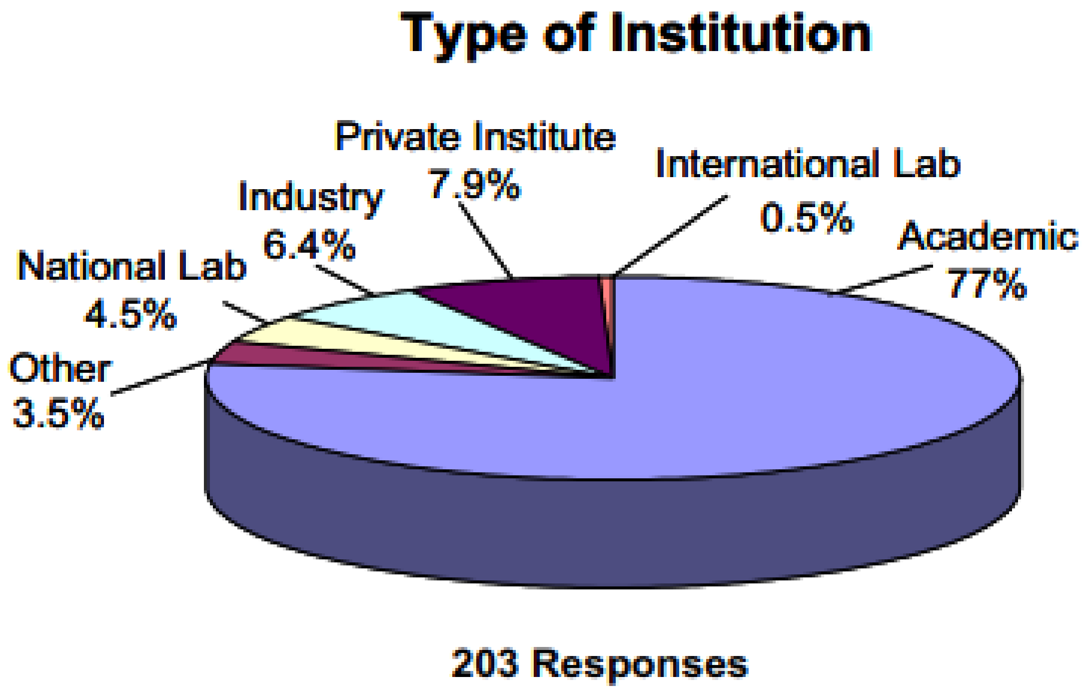



Figure 2.4 Respondents of a 2007 ABRF study were asked what type of institution their core facility was. Of the responses, 77% in this survey were from academic labs. This was the majority. Other notable responses were from industry, private institutions, and national labs. (Loo 2009)

# CHAPTER 3

# CORE FACILITY MANAGEMENT MODELS AT UNIVERSITIES

There are different types of management models for core facilities at universities. Some cores are completely centralized under the office of the Vice President for Research. This consolidates all cores under one umbrella. This method can help prevent the duplication of instruments at different cores within an institution. It can also help financially because the entire budget for all core facilities is considered. This becomes an advantage when dealing with the budget because all the funding is thought of from all of the different cores. This model also provides salary support for the management personnel of the facility and helps in covering the maintenance fees of instrumentation. This management model helps bring cores closer together and helps in collaboration. This can help the cores secure more funding through federal programs, like the National Institutes of Health (NIH) or the National Science Foundation (NSF). It can also help the university seek philanthropic resources by having a strong centralized management. Having multiple different cores united can show that there are multiple research paths that can be pursued at a university. The university will be much stronger with cores being united.

From the previously mentioned 2019 Agilent CrossLab study, it was found that 66% of cores have centralized administration (Strubczewski, 2019). The centralized management model is becoming more popular and is used more often. This shows that the centralized model can be successful.

Other core facilities are managed by a departmental management model. In this model, each core is operated separately by the different departments or colleges. This means that each department in charge of a core facility will provide the salary support of the personnel in the core and equipment maintenance fees without other core financials being considered. In this management model, there may be similar instruments at different cores around a university. For example, one lab may purchase a flow cytometer for their lab only and instead of sharing the flow cytometer, another lab who may need to use a flow cytometer will have to buy their own. This can lead to a duplication of expensive instrument when the money to buy it could go to something else. This can lead to problems in finding funds to acquire new technology. This can prevent development of research infrastructure through the addition of new technology. Sometimes the duplication of equipment is necessary. For example, the imaging of live cells cannot be transferred easily between different campuses. This makes it beneficial to have equipment at multiple campuses. However, under the departmental core management model, sometimes duplication of instrumentation happens because departments don't know about other core facilities and what instruments they may house. This also results in the core directors competing for a relatively small amount of funding.

Most often, universities use a mixed management model with attributes of both institutional and departmental management. Another way these models can be mixed is that the cores are coordinated by the Office of the Vice President but are managed by the specific departments or colleges. No management model is perfect for all core facilities and labs. That is why many cores opt for a mixed management model (Farber and Weiss, 2011).

A survey that originated from Clemson University in South Carolina was performed in 2010 (Riley, 2011). There were 36 responses to this survey by individuals who were associated with laboratories that identified as being multi-user facilities in the United States. Most of the respondents were electron microscopy (EM) facilities. In this study, the question "Is the facility associated with a department, or is it an independent, free-standing unit?" was asked. The majority of answers were that the core facility was not affiliated with a department or college in the university. This was the answer for 17 facilities, and accounted for 47.2% of the answers. Another 16 answers identified as belonging to a specific college or department. This amounted to 44.4%. The last three answers to the survey were from university research centers.

Emory University had a completely decentralized core facility structure in 2015 with over 55 independent service centers on the Emory University campus (Zwick, 2021). It was noted that this structure led to limited awareness of the core facilities, as well as duplication of services in some cores. The Emory Integrated Core Facilities (EICF) organization was established in 2016 to better support the core facility system. Since then, Emory University has become more centralized under the EICF (Zwick, 2021). However, they do still have some labs that are under departmental administration. This is an example of a mixed model management system.

There are several other aspects of different operating models that are used in core facilities. Core facilities can be full-service, self-service, or a hybrid-service facility (Kos-Braun et al., 2020). A full-service facility is where the staff at the core performs the entire service for the researchers. A self-service facility is where the researcher performs the experiment themselves at the core facility after training and a hybrid model can be if a

staff member helps collaborate with a researcher (Kos-Braun et al., 2020). Figure 3.1 shows the results of a survey that was administered in 2020. It was answered by 253 people in core facilities that were located in Europe from a broad range of laboratories (Kos-Braun et al., 2020). Most facilities answered that they had a hybrid-service model (Kos-Braun et al., 2020).

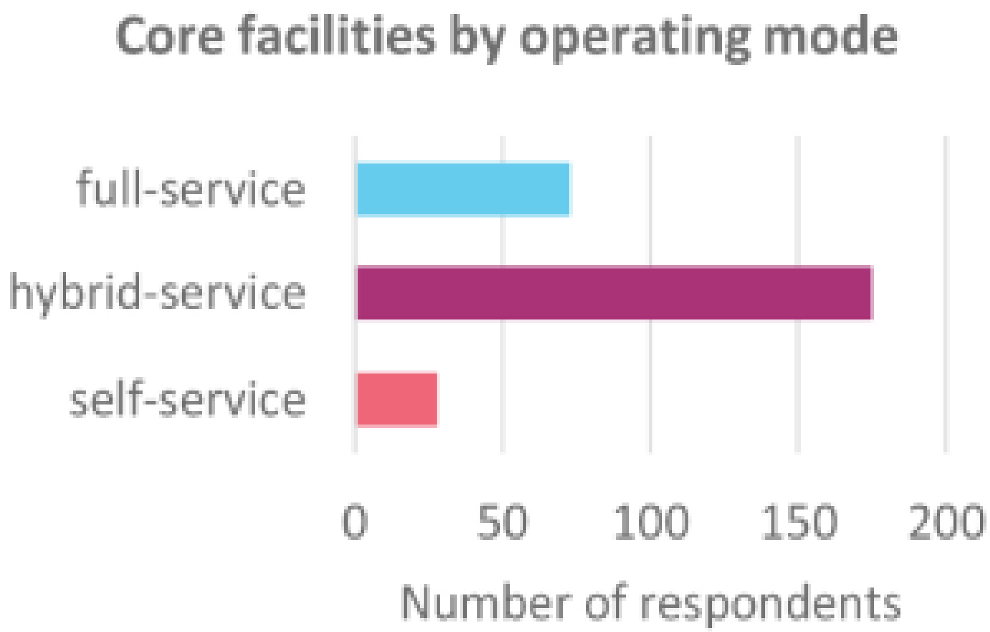



Figure 3.1 Core Facilities by Operating Mode. Most core laboratories are hybrid-service facilities and offer full-service and self-service. (Kos-Braun et al., 2020)

Another aspect of managing a core facility is advertising and marketing. The Agilent Benchmark study in 2019 asked cores what kinds of marketing they typically used. The responses are shown in figure 3.2. From this figure, most core labs have a website that they use to market themselves and show what kind of services they offer. According to Agilent, this has been the biggest response since 2014. Marketing is important to let people know about the laboratory methods that are available. It is also important because advertising the core can help get more users for the laboratory and

help the core gain more user fees to help financially. Tours of core facilities are also very common. Other activities that increase the core's visibility are seminars, workshops, and poster presentations sessions.

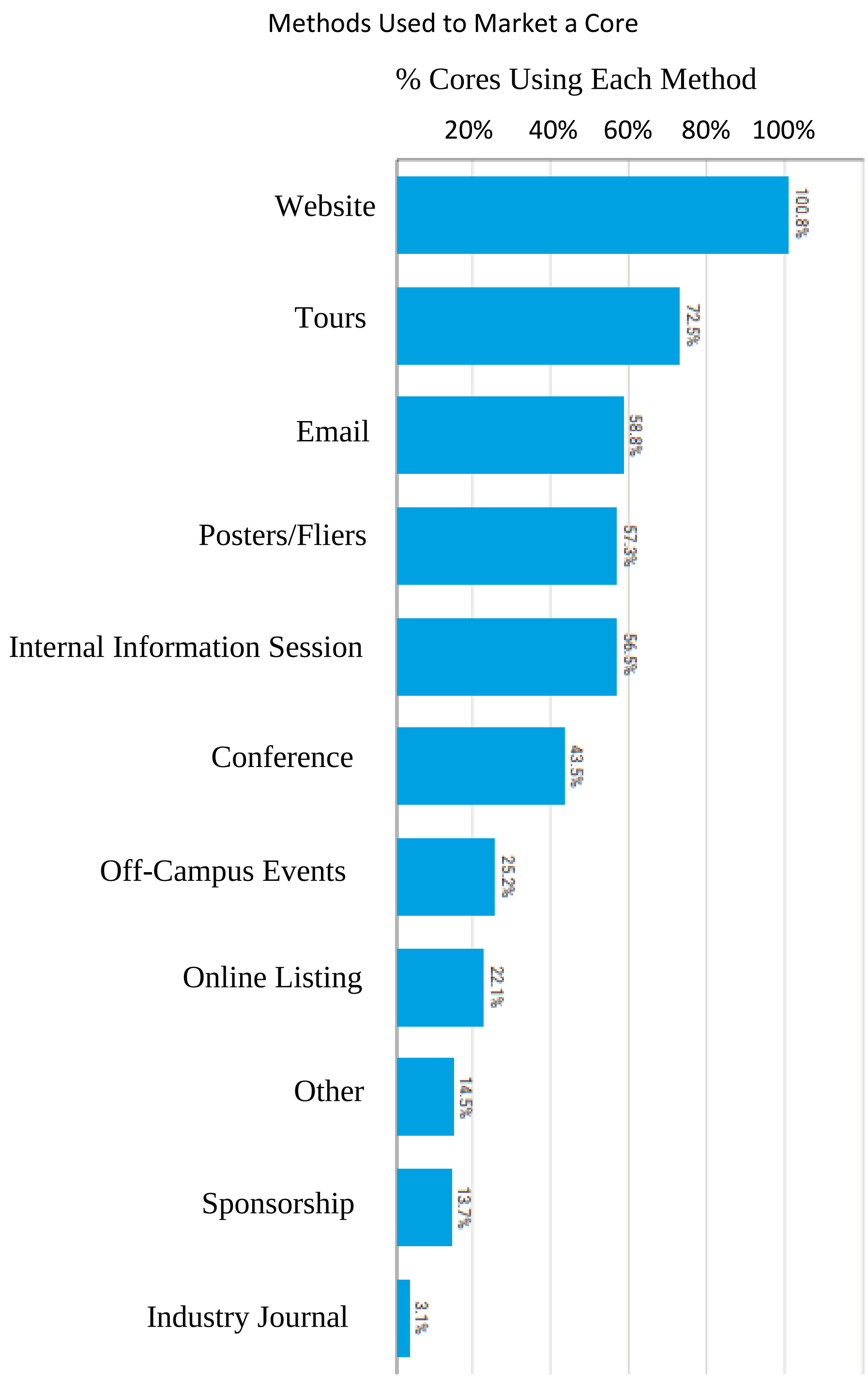



Figure 3.2 Most core facilities have a website that they advertise their core services on. Tours of core facilities are also very common. Other common ways to market a core is by email or posters. (Strubczewski, 2019)

### 3.1 Specific Facility Information

At the School of Medicine (SOM) at the University of South Carolina (USC), the Instrumentation Resource Facility (IRF) is a center that is dedicated to state-of-the-art instrumentation that is beneficial to biomedical science research. It is open to all researchers. The IRF has 190 users at the current time. Most of the IRF users are graduate or undergraduate students. There are 100 students that use the services of the IRF. There are also 49 principal investigators who use the facility and 41 postdoctoral fellows or staff members. The Instrumentation Resource Facility at the University of South Carolina School of Medicine houses many different technologies under one main lab. While the flow cytometry is still under the IRF, it has its own associate director responsible for cell sorting. A single core facility director oversees all the instrumentation in the facility. Separately, there is also a viral vector core at the School of Medicine. There is another main campus of University of South Carolina that also has core facilities. There does appear to be overlap in some instrumentation. There is an electron microscopy core on USC's main campus and there is also an electron microscopy core on the School of Medicine campus in the IRF. This is an overlap of electron microscopy equipment. Another example of overlap is that there is a flow cytometry core lab on USC's main campus and a flow cytometry facility at the IRF. USC has a Mass Spectrometry Center that is administered by the chemistry department as well as an NMR facility. The neuroscience department at USC has a Center for Brain Imaging. The Center for Drug Discovery has a Microscopy Core and a Genomics Core. The University of South Carolina School of Medicine Instrumentation Resource Facility (IRF) has also developed a master's level concentration program that has five graduate level courses. This is

another way a core lab can market themselves. They employ a mixed model of management at the University of South Carolina.

The University of Florida has a primary core organization that falls under the Interdisciplinary Center for Biotechnology Research (ICBR). They provide a seminar series in biotechnology for marketing purposes. Most ICBR faculty reports to the ICBR and do not have competing demands from a department. The McKnight Brain Institute is another major core facility. The University of Florida has their different cores working very closely with one another. They have an electron microscopy core that contains several scanning and transmission electron microscopes. They have a cytometry core that contains flow cytometers, confocal microscopes and a spinning disk confocal microscope. This is also where the histology work is performed. They have a proteomics and mass spectrometry core as well. The University of Florida also has a bioinformatics core facility. The Advanced Magnetic Resonance Imaging and Spectrometry (AMRIS) facility at the University of Florida has around 325-375 users. The AMRIS facility houses the magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) facilities. About 45% of that is principal investigators, 30% are students, 13% are technicians or staff members, and 12% are postdoctoral fellows. The director and the associate director of the AMRIS facility are faculty members that teach 5 classes (Amy Howe, Research and Outreach Coordinator, Personal Communication, 2023)

The University of Georgia has a very centralized core facility management. Their cores are administered under the Office of the Vice President for Research. They have all the most common cores that were mentioned before. They have a Biomedical Microscopy Core that has equipment such as confocal, super-resolution, and light sheet

microscopy. They also have equipment for live and fixed cell imaging. They have a Cytometry Shared Resource Laboratory that houses their flow cytometers, and they have the Georgia Electron Microscopy (GEM) facility that has access to transmission and scanning electron microscopes. They also have a scanning transmission electron microscope. The University of Georgia also has a Complex Carbohydrate Research Center (CCRC) that provides analytical services. They have mass spectrometers and NMR machines in this facility. They house their MRI and other imaging systems in the Bioimaging Research Center. The University of Georgia also has a Proteomic and Mass Spectrometry Core, an Animal Health Research Center, and a Bioinformatics core.

The University of Virginia School of Medicine has an Office of Research Core Administration (ORCA) that helps with the overall centralization of all their cores. They have a Senior Associate Dean for Research Infrastructure. The Flow Cytometry Core Facility offers a flow cytometry training program that is a five-day comprehensive training course. This helps them advertise the core. The University of Virginia School of Medicine is very similar to the University of Georgia and has all the most common core facilities. They have an Advanced Microscopy Facility that contains transmission and scanning electron microscopes. This facility also has confocal microscopes and a light-sheet microscope. They also have a separate Molecular Electron Microscopy Core. This core specializes in high-resolution electron cryomicroscopy and electron cryotomography and produced 5 publications in 2020 and 2021. This university also has a Molecular Imaging Core, a Research Histology Core, and a Bioinformatics core.

Much like the Universities of Georgia and Virginia, the University of Kentucky has all the main core facilities too. Most cores at the University of Kentucky are

organized under the office of the Vice President for Research, but some, like their Electron Microscopy Core are independently managed. This makes it a mixed model management system. The Flow Cytometry and Immune Monitoring Core is a single core where the flow cytometers are located. They also have confocal microscopes housed there. The light microscopy core contains a confocal microscope, super-resolution microscopy and it has an MRI machine.

The University of Missouri has approximately 31,000 students and 3,000 faculty members and researchers. The University of Missouri has a Division of Research, Innovation, and Impact (RII). This division is administered by the Office of the Vice Chancellor for Research and contains all the advanced technology core facilities. The RII gives seminars, workshops, and presentations about how to help manage core facilities. The RII helps cores to find funding, they help with proposal development, and offer mentorship to their cores. The University of Missouri seems to be completely centralized. This university is also like the University of Georgia and Virginia. They have all the most common core labs. They have an Advanced Light Microscopy Lab with a confocal microscope and a light-sheet microscope. They also have a separate lab for the electron microscopy core that contains a scanning electron microscope and a transmission electron microscope. The Cell and Immunobiology Core contains the flow cytometry services. This university has a small animal phenotyping lab, an x-ray microanalysis, a Bioinformatics and Analytics Facility and a metabolomics center where they perform GC/MS. The first core research facility at the University of Missouri was the Nuclear Magnetic Resonance Center. This core is managed by the Department of Chemistry. The

Christopher S. Bond Life Sciences Center reports to the Provost through the Office of Research.

Cornell University Institute of Biotechnology is administered through the Office of the Vice President for Research and Innovation by the Empire State Developments Division of Science, Technology, and Innovation (NYSTAR). They also have The Center for Advanced Technology (CAT), which is a center for collaboration between the university and private industry. They are also completely centralized. Cornell University seems to have a smaller number of labs that could be duplicated. The instrumentation cores are grouped under the Biotechnology Resource Center (BRC). This seems to be where most of the instrumentation is housed. There is a flow cytometry facility and there is also an imaging facility. This facility has super-resolution microscopes and a confocal microscope. Cornell University has a bioinformatics facility as well. All of these facilities are grouped under the Biotechnology Resource Center (BRC).

At Vanderbilt University, the Associate Vice Chancellor for Research is in charge of coordinating all of the major cores. Some cores, however, do not fall under the Vice Chancellor for Research, therefore Vanderbilt has a mixed management model. The Vanderbilt Institute of Clinical and Translational Research Center (VICTR) is supported by the Office of Research and the NIH. Vanderbilt University Medical Center is lacking some of the more common cores. However, these other instrumentation cores might be called a different core name. Vanderbilt has over 85 centers and institutes in total. The Center for Structural Biology (CSB) contains their electron microscopy equipment including three cryo-electron microscopes. X-Ray and NMR equipment is also located in this lab. They have a Mass Spectrometry Research Center with ten mass spectrometers

and access to a cryostat is also within this facility. There is also a Proteomics Laboratory. There is a Tissue Core and a Bioinformatics core, but not much information was found on them. While there seems to be fewer cores at Vanderbilt, the cores have more instrumentation in them to lessen the chances of duplication of equipment.

The University of Auburn core facilities are sponsored by the Office of the Vice President. They also have an applied biotechnology major at this university through the College of Agriculture. Some of these cores are managed by the departmental model. The University of Auburn has fewer facilities as well. They do have the Auburn University Transgenic Facility. They also have the Auburn University Research Instrumentation Facility, although it is unclear from their website what kind of instruments might be located there. They have a separate mass spectrometry center, an NMR Center and a flow cytometry laboratory. There are also separate x-ray and MRI units. They also have a genomics sequencing laboratory.

Virginia Tech has limited core facilities but still has all the common cores mentioned previously. The research core webpage does not entail much information about the cores. Virginia Tech has an electron microscopy service laboratory. This facility is run by the College of Veterinary Medicine as well as the flow cytometry laboratory. The Fralin Imaging Center has access to confocal microscopy. The genomics sequencing center specializes in next generation sequencing. The chemistry department runs the mass spectrometry and chromatography lab as well as the NMR spectroscopy lab.

Mississippi State University Institute of Imaging and Analytical Technologies ($I_2AT$) is administered out of the Mississippi State University Office of Research and

Economic Development. They seem to have a mostly decentralized model. Mississippi State University does not have many core facility centers. All the instrumentation is grouped under a single unit. This can help efficiency by having one well-developed laboratory instead of multiple small laboratories. The Imaging and Analytical Technologies ($I_2AT$) is a core facility that has confocal, atomic force, scanning electron and transmission electron microscope. They also have x-ray and MRI instruments. It is not indicated on their website any cores that contain flow cytometry or mass spectrometry.

As mentioned before, Emory University has established the Emory Integrated Core Facilities (EICF). This is a division of Emory that contains all of the major cores. They have a Flow Cytometry lab, an Electron Microscopy Core, and a Cellular Imaging Core. They also have a Genomics Core and a Gnotobiotic Animal Core. All these cores are administered under the EICF. They also have a number of facilities that are administered independently as well. Emory University also sponsors a Core Day which is an event that is held for all staff members of their core facilities. Directors of all the core facilities are there to show what their core is and does. Some directors give keynote speeches and presentations about their core. This is a way for the cores to get together and network with other core facilities and vendors who support research. This is another way to promote advertising for the core facilities.

Table 3.1 was created to show the different management models at the universities that were analyzed.

| | |
|---|---|
| University of Georgia | Completely Centralized |
| University of Auburn | Mostly Centralized/Mixed |
| University of Kentucky | Mixed Model |
| University of Missouri | Completely Centralized |
| Mississippi State University | Completely Decentralized |
| University of Florida | Mixed Model |
| Vanderbilt University Medical Center | Mostly Centralized/Mixed |
| University of Virginia School of Medicine | Completely Centralized |
| Cornell University | Completely Centralized |
| Virginia Tech | Mostly Departmental |
| University of South Carolina | Mixed Model |
| Emory University | Mostly Centralized/Mixed |

Table 3.1 Management Models of Analyzed Laboratories. Most labs are either centralized or have a mixed model management style with both centralized administrations and departmental administrations.

# CHAPTER 4

# MANAGEMENT PERSONNEL

A very important part of core facility management is the people who work in the facility. Staff in core facilities should be experts in their field of technology and able to train users in the operation of highly specialized instrumentation. They help researchers perform and understand different laboratory methods that the core provides. They can help researchers design their own experiment. They also help in taking care and maintaining the instrumentation that is housed in the lab. Personnel help create and write protocols for the instrumentation in the laboratory.

The number of core laboratory personnel can vary between different facilities. Core facilities should generally have at least two employees to ensure continuous operation and cover vacations and sick leave. From the previously mentioned Clemson University study in 2010, 36 responses were observed from all different cores (Riley, 2011). In this study, it was determined that the majority of responding labs (63.9%) had only 1 or 2 personnel working full-time in the facility (Riley, 2011). Some other individuals worked in the labs but were not full-time. In some cases, core labs have graduate students working in the lab to gain experience. Figure 4.1 shows the results of how many full-time employees are working in the surveyed facilities. More recently, the Agilent benchmark study in 2019 found that the average core had 3.2 personnel working in them (Strubczewski, 2019).

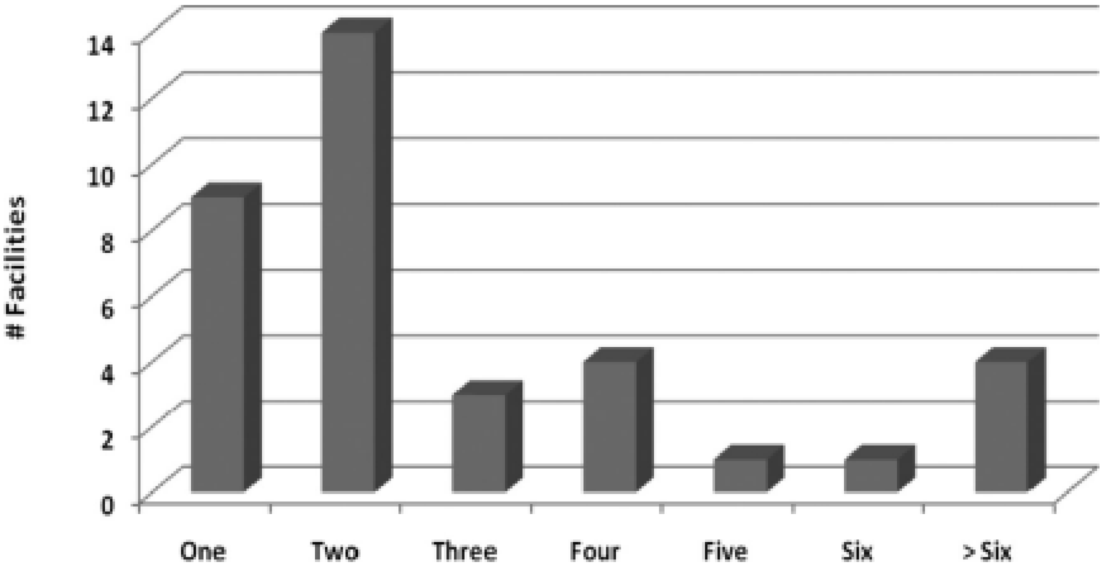



Figure 4.1 Average number of laboratory personnel working in core facilities. Most core facilities have one or two staff members who work in the core. (Riley, 2011)

Core laboratory staff should be educated in various fields and capable of operating multiple instruments (McMillen et al., 2000). A lot of the training of staff is on-the-job training. Another skill needed for staff members is communication skills so they can interact with the scientists about their experiments. It is important to have leadership skills and to also know how to work with a team (Brown, 2018). Most positions in these types of laboratories require either a bachelor's or a master's degree (Brown, 2018). Most entry level positions do not necessarily require a degree. Personnel with PhD's are very common as well. Some students in undergraduate or graduate programs may also work there part-time (Brown, 2018). Administrative personnel are also beneficial to a core facility. An administrator can oversee the management of a budget.

The BioImaging UK (BIUK) study also asked questions about personnel in light microscopy laboratories. From this survey, 41% of all staff had previously worked as a

post-doctoral fellow before they came to work in the core research lab. Also, 24% of staff members had worked previously in a research setting and 17% of staff members had previously worked in another core lab (Fletcher and Anderson, 2021).

In a 2000 survey from the Scripps Research Institute, the types of degrees held of the laboratory personnel was asked (McMillen et al., 2000). This survey was sent to all ABRF members. The answers are shown in figure 4.2. According to the figure, most of the laboratory staff had a bachelor's degree (33%), 25% of the surveyed personnel had PhD's, and 21% of staff had a master's degree. The last 21% included degrees that were not listed. Also from this study, it was found that during 1998, the average facility had a director, 2 full-time, and 1 part-time workers (McMillen et al., 2000).

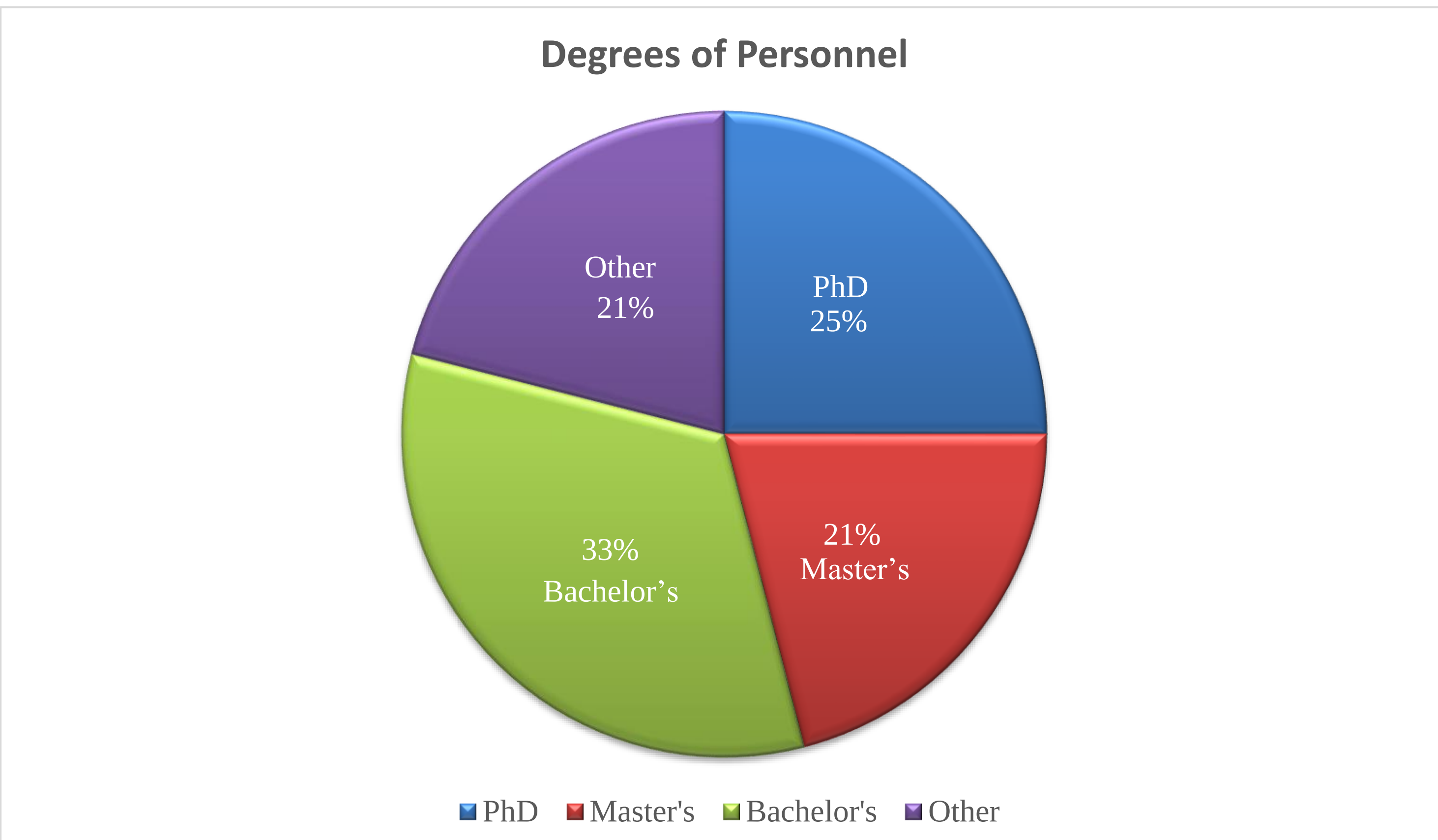



Figure 4.2 Degrees of Personnel working in core facilities. The highest percentage was for a bachelor's degree, followed by a PhD. Both master's degree and all other degrees both had a percentage of 21%. (McMillen et al., 2000)

The German BioImaging Society for Microscopy and Image Analysis (GerBI) conducted a survey in 2015 that was sent out to all its members. There were 27 facilities that gave data related to laboratory personnel in Germany. Most of these facilities were imaging facilities. This survey showed that 69% of all facility personnel held a PhD. (Ferrando-May et al., 2016). All the facilities had at least one person holding a doctoral degree in their staff (Ferrando-May et al., 2016).

The CTLS survey from 2018 also showed data about laboratory personnel. In figure 4.3, the survey asked respondents what role they had at their core facility. Most of the respondents were the facility head or the manager role. Figure 4.3 also visualizes the degree status of individuals that work in the labs (Adami et al., 2021). Seventy-four percent of research scientists had a PhD and less than 40% of technical staff held a PhD (Adami et al., 2021).

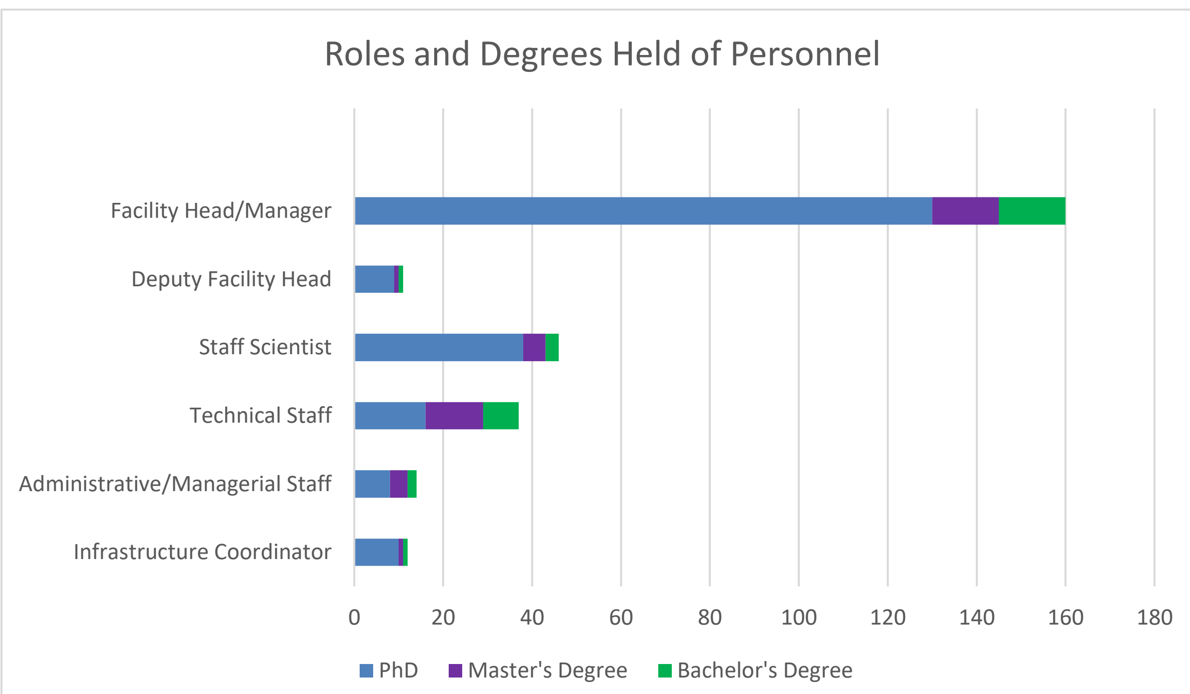



Figure 4.3 Roles and Degrees Held of Personnel. Most of the people that answered this survey were facility heads or managers. The majority of directors had a PhD. (Adami et al., 2021)

Most institutions in the United States have a PhD level director who oversees the daily operations of the lab (Riley, 2011). In the Clemson study in 2010, of the 36 facilities who answered the survey, 32 of the cores were led by individuals with a Ph.D. Two of the facilities had individuals with a master's degree as the leader of the laboratory (Riley, 2011). It is not a requirement that the director must hold a PhD, however.

In the survey from the CTLS, questions were asked that were related to core facility heads. These questions were only asked of people who were the head of a core. Figure 4.4 shows the educational degree level of core directors from different countries in the world. From the figure, it is obvious that most core directors have PhD's. This survey showed that 80% of facility directors overall had a PhD. This survey also found that 100% of the core directors in Germany had PhD's (Adami et al., 2021).

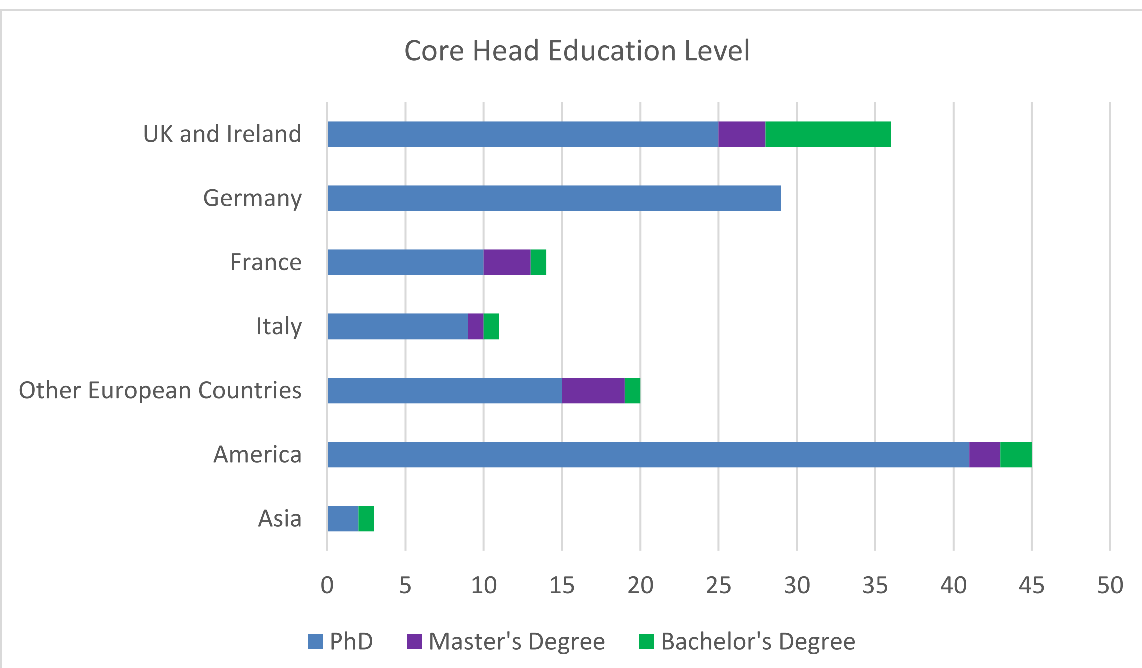



Figure 4.4 Core Head Education Level. Most core directors have a PhD. Most directors that answered this survey were in America. (Adami et al., 2021)

The core directors were then asked what position they held before becoming the head of a core facility. The results are presented in figure 4.5. Most core heads had a job as a postdoctoral fellow within a lab (34%) or previously worked in a core lab (24%) prior to becoming the core head (Adami, et al., 2021).

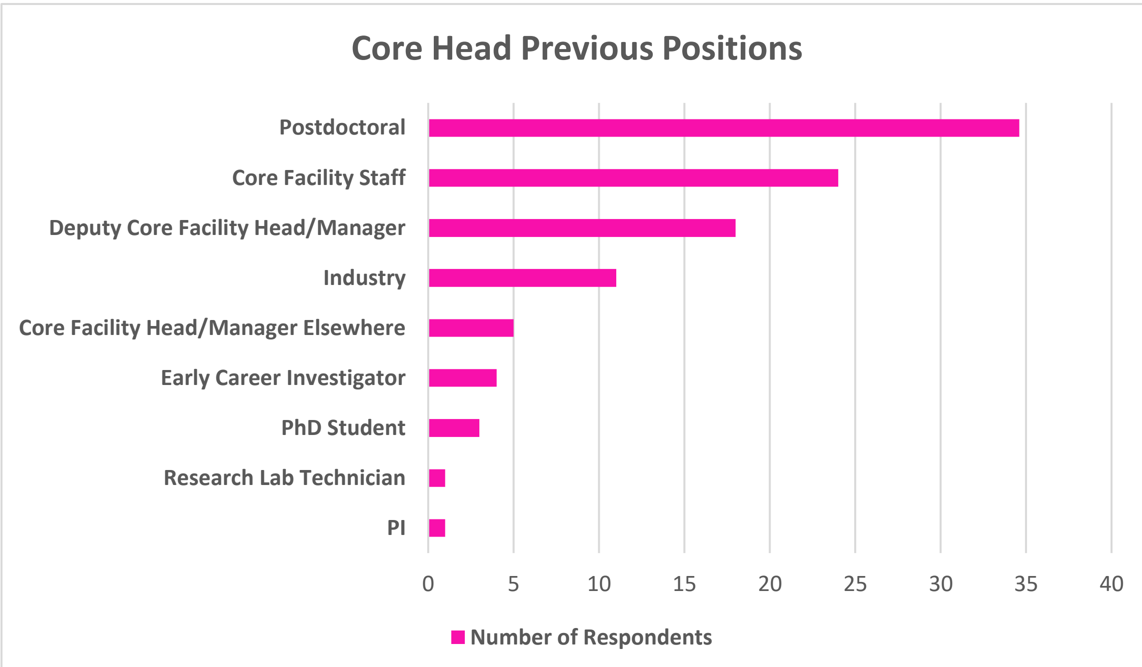



Figure 4.5 Core Head Previous Positions From this survey, most core directors previously worked in a postdoctoral environment or at a core facility. Another large number of respondents were the manager of another core facility. (Adami et al., 2021)

Many labs also have an advisory board or an advisory committee. This is a group of people that can help the core labs make important decisions. This committee can help the facility determine what technologies are needed or which are outdated. They can help in deciding new equipment purchases and staffing decisions. This can be important for the overall success of the core facility. Senior faculty can be a part of the advisory committee, as well as other administration from the schools, centers, and the Office of Research. Usually, there is also an external consultant that has a separate unbiased view

of the facility (Turpen et al., 2016). The advisory committee can also perform a regular evaluation of the performance of the core facility.

The University of Florida has minimal staff and mostly directors. All of their staff are called core research facility technicians or specialists and there are three levels. Their cores and staff work closely together. The Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) facility has a total of 15 full-time employees. Two of those positions are faculty members and those are the director and the associate director. They have two administrative personnel and five core system specialists. One of the specialists is also considered the MRI core director. There are another 3 MRI technologists and 3 engineering and mechanical staff.

At the University of Missouri there is minimal staff in their facilities. There is usually 1 to 3 staff members other than the director. At the Dalton Cardiovascular Research Center, different staff members are assigned to different microscopes. The University of Virginia also has minimal staff. The cores have a director and 1 or 2 staff members. Virginia Tech only has lab managers in charge of their cores and no director is mentioned. Cornell University has a director and a faculty advisory board for all of its cores. At the University of Vanderbilt, some individuals are the directors of multiple facilities. Auburn University mostly has PhD level directors. However, the Flow Cytometry Laboratory has a manager who does not have a PhD and there is only one other staff member in that lab.

Some laboratories at the University of Kentucky have a larger number of staff. The Division of Laboratory Animal Resources (DLAR) has many facilities within it and therefore has a large staff to help manage them. The Flow Cytometry and Immune

Monitoring Core has a scientific director, a manager, and an assistant manager. The Rodent Behavior Core (RBC) has a PhD director and a core manager.

At the University of Georgia not all of the directors have PhD's. They do seem to have a larger amount of staff members. The Georgia Electron Microscopy (GEM) core has an academic director and a managing director.

Some facilities have different types of directors for different things. A scientific director handles all matters relating to the science and instrumentation of the facility. This person may interact with the scientific advisory board and help manage core activities. A managing director helps to supervise staff and mainly does administrative tasks. They can help in networking and advertising for the core and also do financial management. An academic director is another type of director that is sometimes employed. This person usually oversees classes and academic related things.

Figure 4.6 is a word cloud created that represents responses to the question "List 2-3 key characteristics of effective/highly effective core facilities directors/supervisors." posed by Carter et al., (2019). The larger words were suggested most often.


Figure 4.6 Word cloud that represents the question “List 2-3 key characteristics of effective/highly effective core facilities directors/supervisors.” The larger words were suggested the most often (Carter et al., 2019)

# CHAPTER 5

# FINANCES

## 5.1 Budget and Expenses

Money and funding seem to be the largest obstacle for core facilities. There are several different things that a core facility must spend money on. This is due to the high expenses that are associated with large instrumentation. Many instruments require service contracts, and the instruments need to be serviced, repaired from time to time, and maintained. The instrumentation housed in a core facility will occasionally need to be replaced as that piece of equipment ages. As new technologies change and evolve, instrumentation becomes outdated relatively fast. The core may need to upgrade their equipment frequently. This helps the core to stay state-of-the-art. Another large expense for core laboratories is salary support for the staff.

In a 2000 survey, from the Scripps Research Institute, a question about the overall greatest operating expenses was asked (McMillen et al., 2000). Figure 5.1 shows the answers to that question. There were 81 data sets that were collected. In this study, supplies and reagents seem to cost the most for core laboratories. This makes sense because they are shared pieces of equipment and therefore, the supplies used will be more. Salaries of the employees and service contracts all tend to be another big expense for core laboratories.

Overall Operating Expenses

| Expense | Thousands of U.S. Dollars | | | | |
|---|---|---|---|---|---|
| | N | Median | Mean | SD | Range |
| Supplies/reagents | 40 | 50.0 | 99.1 | 93.5 | 9.2–350.0 |
| Service/repairs | 39 | 16.4 | 22.9 | 19.1 | 2.0–88.0 |
| Depreciation | 6 | 30 | 34.8 | 23.9 | 10.0–70.0 |
| Salaries | 39 | 104.0 | 138.5 | 103.0 | 1.0–28.0 |
| Professional development | 25 | 2.2 | 4.1 | 3.5 | 1.0–15.0 |

Figure 5.1 Overall operating expenses for core facilities. Forty responses say that supplies and reagents are the greatest cost for core facilities. Services and repairs on equipment and the salaries of staff members are both large expenses as well. (McMillen et al., 2000)

Agilent iLab's 2016 study also examined common expenses of core facilities (iLab, 2016). In this survey, labor costs seem to be the biggest expense for these facilities and maintenance contracts are the second highest cost. Consumables ranked third in this survey. The results of this survey are similar to the previous survey from the Scripps Research Institute from 2000 because staffing expenses is one of the largest expenses during both of the surveys, as well as service contracts on the equipment and consumables. Administration tools were also included in this survey and accounted for only 1%. The results of the Agilent survey are shown in figure 5.2.

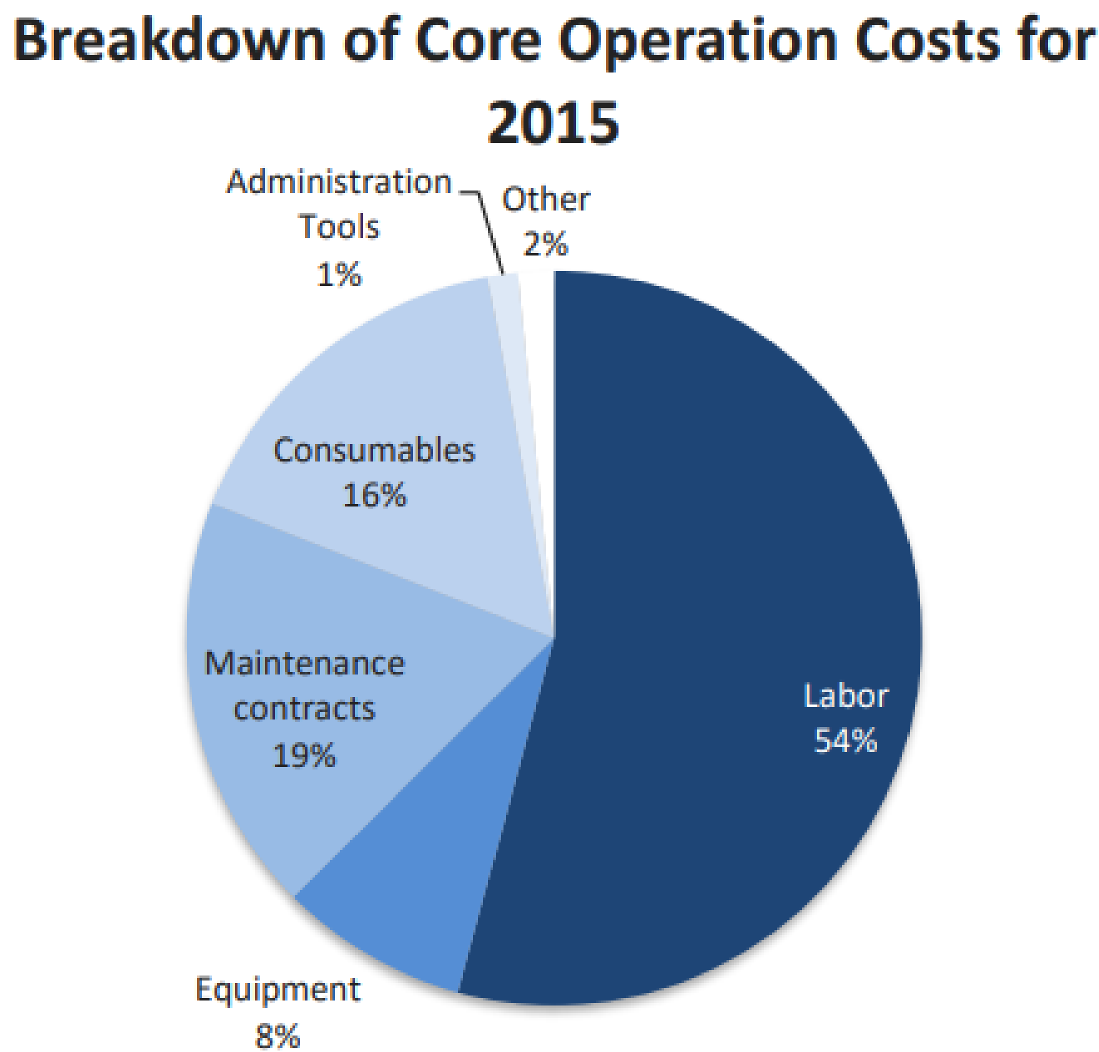



Figure 5.2 From the Agilent iLab Benchmark study, the main cost to a core facility is labor charges to pay staff of the core. Consumables and instrument maintenance contracts are also a large portion of costs for core facilities. (iLab Solutions, 2016)

Agilent iLab more recently did a 2019 study that also examined core facility expenses. The results are shown in figure 5.3. According to this study, over the span from

2016-2018, staffing costs were the largest expense and consumable costs and service contracts were the second most expensive to a core laboratory (Strubczewski, 2019).

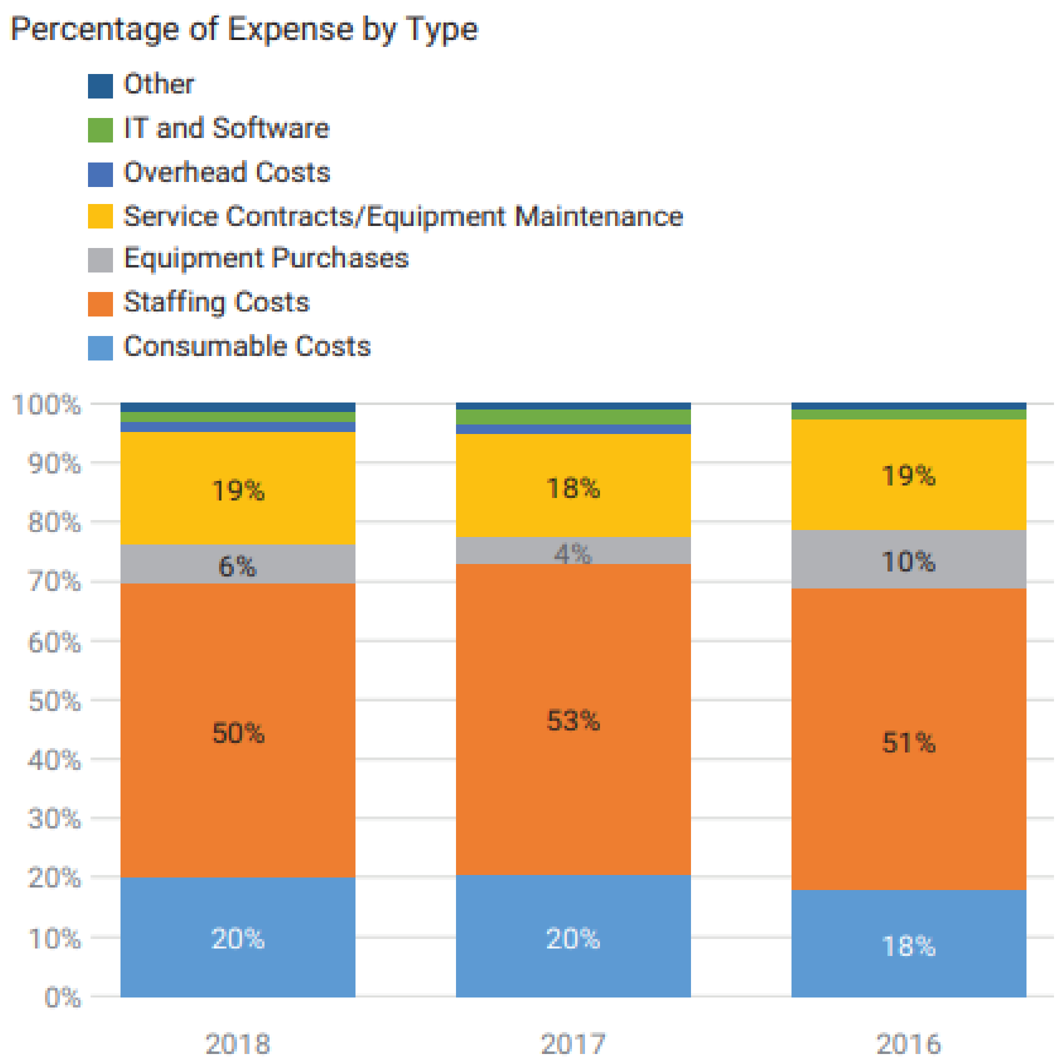



Figure 5.3 The largest cost to core facilities in 2016-2018 has been staffing costs to pay the staff of the facility. This is consistent with the Benchmark study that took place in 2015. During these years, consumable costs and service contracts were also a large portion of costs for core facilities. (Strubczewski, 2019)

## 5.2 Income and Funding

There are several different ways a core facility can be funded. A core can receive funding from federal grants, non-federal grants, institutional support, philanthropy, and user fees (McMillen et al., 2000). Many core facilities are non-profit facilities and all of the examined universities in this thesis are non-profit.

User fees are one of the greatest sources of income for a core facility. The amount of income that is produced from user fees depends on how much the core charges for certain services and how heavily used the core is. Some labs can be completely self-sufficient on user fees, although this is rare. In the Clemson University study from 2010 it was found that only 2 out of 36 cores that were surveyed ran strictly on user fees. User fees in general cover the maintenance and operation of equipment.

Some cores do not offer any of their services for external customers. It is typical for a lab to charge much larger fees for external users (McMillen et al., 2000). Sometimes these charges can be raised 60%-91% more. Lately, more emphasis has been put on the need for external users since they do generally tend to have higher fees. This is especially true in EM facilities (Riley, 2011). At a federally funded core, it is required for the core to charge external customers more. This avoids unfair competition with private industries that provide similar services. All federal grants must be charged the same fee from the institution. Figure 5.4 shows survey results from the Clemson University study. This figure shows that out of the surveyed institutions, most facilities charged at least twice as much as internal users.

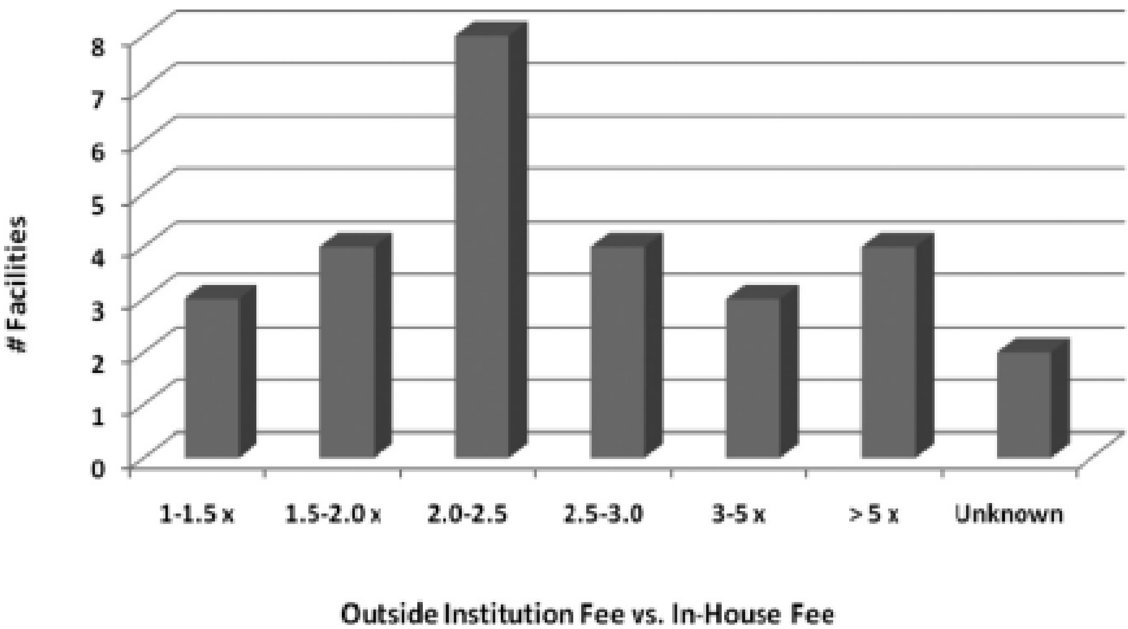



Figure 5.4 Outside Institution Fees vs. In-House Fees. Most core facilities charge at least twice as much for external customers. (Riley, 2011)

In the 2019 Agilent Benchmark survey, it was found that most facilities serve the most customers internally. Around 57% of the work performed in 2018 from all cores surveyed was from internal customers. However, only 9% of all customers were external customers (Strubczewski, 2019). Likewise, the Clemson University study showed that, on average, user fees accounted for about 60.5% of the total operation income (Riley, 2010).

Grants are another one of the biggest ways a core lab receives funding. Grants can be federally or non-federally funded. To get a grant funded, researchers must demonstrate a need to be given funding and show that the technologies will support numerous research programs (Brown, 2018). The National Institutes of Health (NIH) have created shared equipment grants that help fund core facilities (Brown, 2018). These are called S10 grants and must be used on a shared basis (Zwick, 2021). These grants allow for the

purchase of expensive state-of-the-art equipment. The core must demonstrate that multiple users will benefit from their use. This makes them cost-effective and serves to be a starting point for collaborative research projects. The NIH provides around $900 million dollars annually to support research cores (Chang and Grieder, 2016).

The Veterans Affairs (VA) Office of Research and Development (ORD) offers a Shared Equipment Evaluation Program (ShEEP). This program is for any facility that is related to the VA to acquire expensive equipment that is needed for VA-supported projects. It supports VA-salaried investigators. This program can be used to get a new piece of equipment or a replacement instrument. All equipment must cost at least $20,000 but no more than $500,000.

The National Science Foundation (NSF) has a Major Research Instrumentation (MRI) Program that serves to advance the scientific community. This program sponsors new instrumentation or upgrades to existing equipment. This program helps support the next generation of scientists in developing innovative projects. This program can fund equipment up to $4 million dollars and up to four proposals from an institution can be submitted annually. The NSF requires matching funds while the NIH and VA do not.

Another way a university core lab can obtain money is through the institution itself. Many universities provide a subsidy to help cover costs (Riley, 2010). However, some universities don’t subsidize at all (Gould, 2015). The Agilent Benchmark survey from 2019 showed that 68.9% of the institutions that were surveyed said that internal subsidies were actively provided to their cores (Strubczewski, 2019). Sometimes universities have internal programs that researchers can request money from. At the University of South Carolina, there was a program called the ASPIRE (Advanced

Support for Innovative Research Excellence) program. This program allowed researchers to compete for funding for new equipment. The University of South Carolina School of Medicine Instrumentation Resource Facility received this award in 2022 and the new Echo Revolve light microscope was installed.

A survey that was conducted by Michigan Technical University partnered with the Association for Public and Land Grant Universities Council on Research in Michigan was performed in 2018 (Carter et al., 2019). There were 58 responses from core research leaders from all technologies in the United States. This survey asked how the core facility they worked in was mostly funded and those answers are shown in figure 5.5. From this survey, 96% of the 50 core facilities surveyed were funded by user fees. Forty institutions said they received funding for directors and staff. Sixteen institutions (31%) said that most of their funding came from internal grants. Other answers to this question included philanthropy and state funding (Carter et al., 2019).

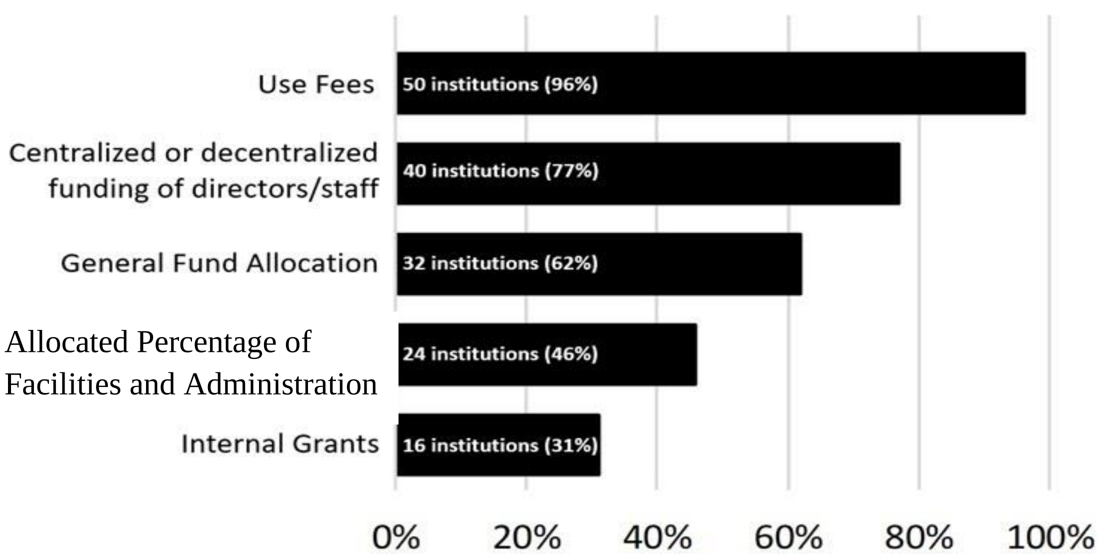



Figure 5.5 Funding Sources of Core Facilities. Most facilities in this survey stated that most of their income came from use fees. (Carter et al., 2019)

The ABRF survey that was done in 2007 also posed financial questions to the facilities. There were 203 responses to this survey from 13 different countries and all technologies. In this survey, cores were asked about how much funding they get from each source on average. Figure 5.6 shows the average fractions of funding of each source. Institutional support and user fees were by far the biggest percentage of funding. Grants only accounted for 12% of the average funding.

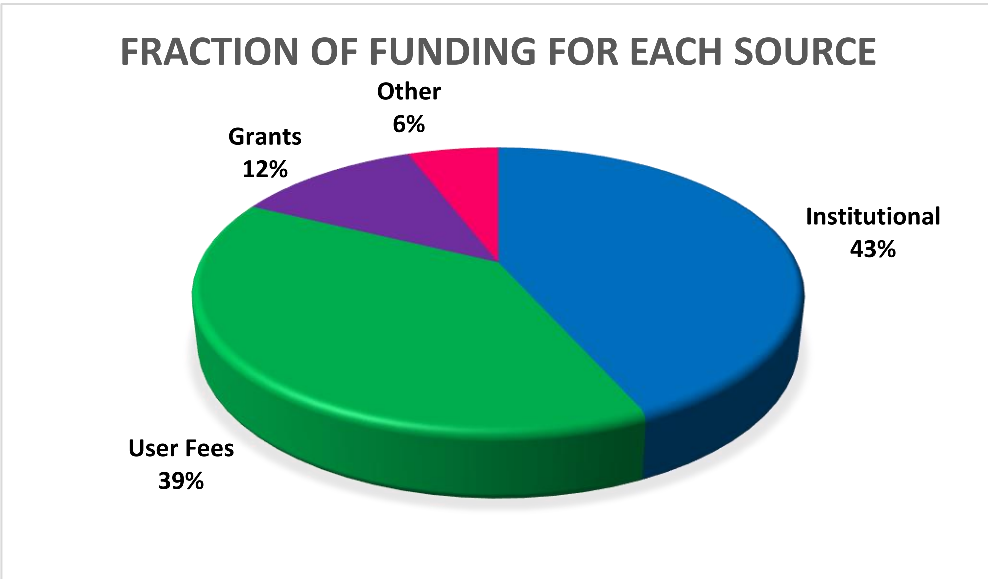



Figure 5.6 Fraction of Funding for Each Source. This shows the average fractions of funding for the average core facility. Most of the funding comes from user fees and institutional support. (Loo et al., 2009)

Agilent iLab's benchmark studies also provided information about how cores receive funding. Figure 5.7 shows the sources of income for the year 2015 and figure 5.8 shows the sources of incomes for the years 2016-2018. In both of these figures, customer revenue or user fees is the largest income source for core laboratories. This means user fees were the leading source of income for core facilities since 2015 through 2018.

Institutional support was also a big source of funding in 2015. Grants were also indicated as a large funding source for cores. These findings are consistent with the ABRF study in 2007.

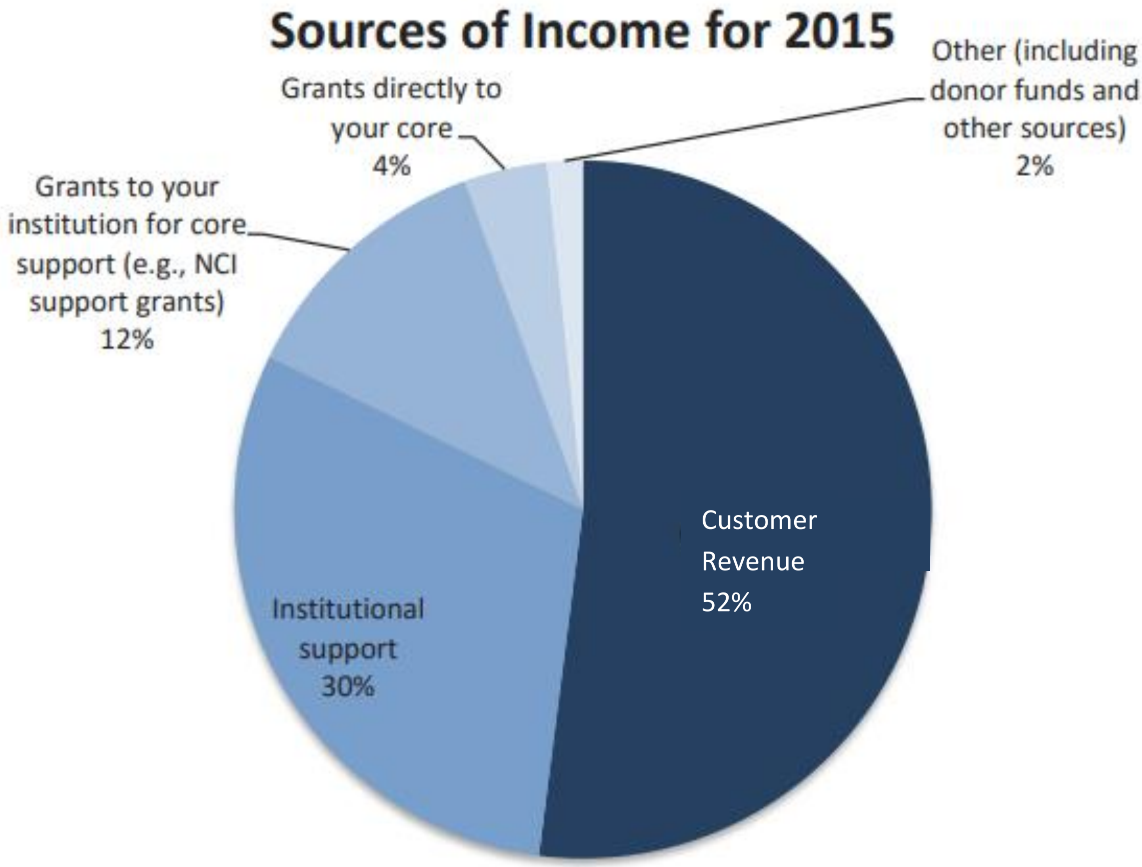



Figure 5.7 Sources of Income for 2015. Core labs were asked what their biggest source of income was. The largest response was that their biggest source of income came from customer revenues. Support from the institution was also a large portion of responses. (iLab Solutions, 2016)

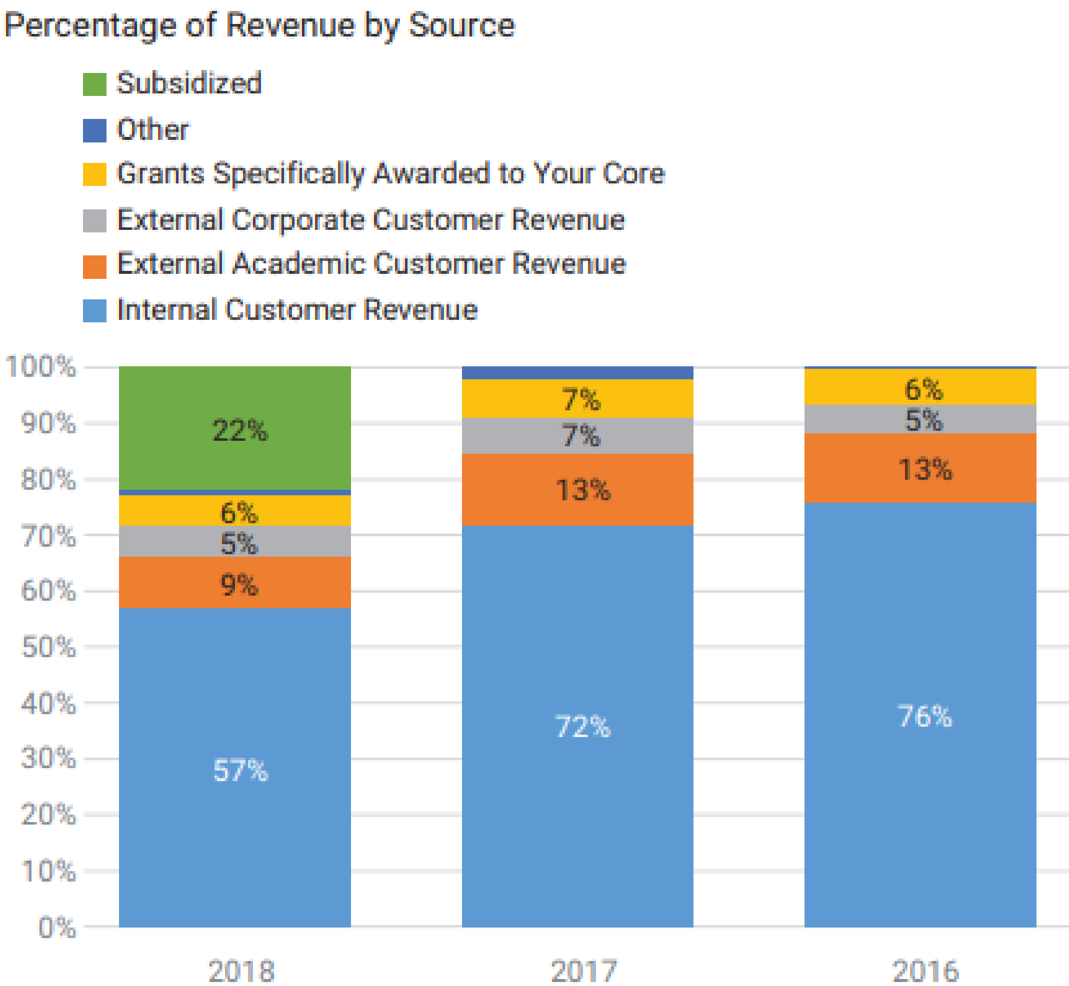



Figure 5.8 Sources of revenue for core facilities are shown for the years 2016-2018. The largest response has been internal customer revenue since 2015. Customer revenue accounts for greater than 50% of core income for the years 2015-2018. (Strubczewski, 2019)

At the Instrumentation Resource Facility at The University of South Carolina School of Medicine, most of the funding comes from federal grants and averages about $663k every year. Secondly, $300k is from School of Medicine support. The IRF makes about $192k in service fees every year. This lab is supported 51% by the NIH, 31% VA, 15% NSF, and 3% from the US Army.

The University of Kentucky Pathology Core has a 50% subsidy that is covered by a grant that will last through the end of 2023 and then they hope to be self-sustaining by 2024 completely on user fees (Wendy Katz, Scientist III – Pathology Lab, Personal Communication, 2023). They also charge more for external customers.

The University of Missouri spends an annual expenditure of about $355 million dollars and makes a $5 billion annual impact on Missouri's economy. All of their core research centers are federally funded. The Bioinformatics and Analytics core at the University of Missouri has 2 different funding models. They have a departmental "retainer" model where a department can purchase a certain amount of technician time or they have the fee-for-service model with a fixed time and cost. The Laboratory for Infectious Disease Research receives funding from the National Institute of Allergy and Infectious Diseases (NIAD). The X-ray Microanalysis Core has a grant supported by the National Science Foundation Division of Earth Sciences Instrumentation and Facilities. The Christopher S. Bond Life Sciences Center receives financial support from the state, federal, and also private sources. The Mutant Mouse Resource and Research Center is funded by a grant from the Division of Program Coordination, Planning, and Strategic Initiative (DPCPSI) at the NIH.

Cornell University Institute of Biotechnology serves as part of their research division and receives an investment from the Provost office. Their Flow Cytometry facility receives support from the Office of the Provost and Vice Provost for Research as well as The Colleges of Veterinary Medicine, Engineering, Human Ecology, Agriculture and Life Sciences, and Art and Sciences. They also have a Genomics Innovation Hub that uses a collaborative model instead of a fee-for-service model of payment. The National

Swine Resource and Research Center and the Animal Science Research Center are both funded by the NIH as well.

The Auburn University Research Instrumentation Facility (AURIF) receives funding from the Office of Vice President of Research.

University of Florida is also funded through the Research Office. They receive around $2 million dollars a year from state funding. The state funding is primarily used to pay the salaries of the technical staff. The Bioinformatics laboratory and EM core uses a fee-for-service payment model.

The Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) Facility at the McKnight Brain Institute at the University of Florida has multiple sources of income. They have NIH funding that covers about 75% of instrumentation costs. They currently receive funding through the NSF and the State of Florida as well. The University of Florida pays for the rest of the expenses. The AMRIS Facility uses a fee-for-service model of income and they do serve external customers. It is a non-profit organization. The McKnight Brain Institute was developed mostly through a grant from the Department of Defense (Personal Communication – Amy Howe, 2023).

The University of Virginia School of Medicine has an Office of Research Core Administration (ORCA) that provides administrative support to their research cores. The Advanced Microscopy Facility has a NIH SIG grant for their SEM. They are supported through the University of Virginia Cancer Center National Cancer Institute with a P30 Center grant. The Mass Spectrometry laboratory within the Biomolecular Analysis Facility was first funded by a grant from the W.M. Keck foundation. The rest of the Biomolecular Analysis Facility is funded by the NIH, user fees, the School of Medicine,

and grants for instrumentation from the Virginia Equipment Trust Fund. The Flow Cytometry Core Facility has a NIH S10 Instrument Program grant for their Sony MA900 Cell Sorter. The Cancer Center Support Grant provides a 20% co-pay for all investigators. The Genome and Analysis and Technology Core uses a fee-for-service model. The Biorepository and Tissue Research Facility primarily serves internal users and the external services are limited. The Research Histology Core is supported through the University of Virginia Cancer Center National Cancer Institute P30 grant. They are also financed by user fees and supplemented through an annual contribution from the School of Medicine.

The Virginia Tech Flow Cytometry Laboratory advertises that they are open to all external users. The Fralin Imaging Center uses a fee-for-service payment model.

The Vanderbilt University Mass Spectrometry Research Center was first created with funding from the National Center for Research Resources (NCRR) of the NIH. They also are funded by the National Institute of General Medicine Sciences. They are supported by 7 NIH-funded investigators and also receive institutional support. Another core facility at the Vanderbilt University is the Institute of Clinical and Translational Research (VICTR). They are also supported by the Office of Research and the NIH.

# CHAPTER 6

# INSTRUMENTATION

There are multiple different instrumentation and technologies that can be housed at different core facilities. Instrumentation can range from small to large instruments. Technologies change and evolve with time and may need to be replaced eventually. Most instrumentation has a life span of around 10-15 years. However, many times instruments are being used past their lifetime to save money. A survey was completed in the spring of 2010 by Clemson University in South Carolina (Riley, 2011). This survey had 36 responses from multiple facilities from all disciplines. Figure 6.1 shows how many facilities have equipment that is at or around its lifespan and continues to be used. The type of equipment was not indicated in the survey. After an instrument has reached several years old it is harder to obtain parts to fix it when needed. This study also found that most facilities update their equipment based on need. It was also found that many facilities have equipment that they do not know how old it is. This may be because the instrumentation was there before the staff was.

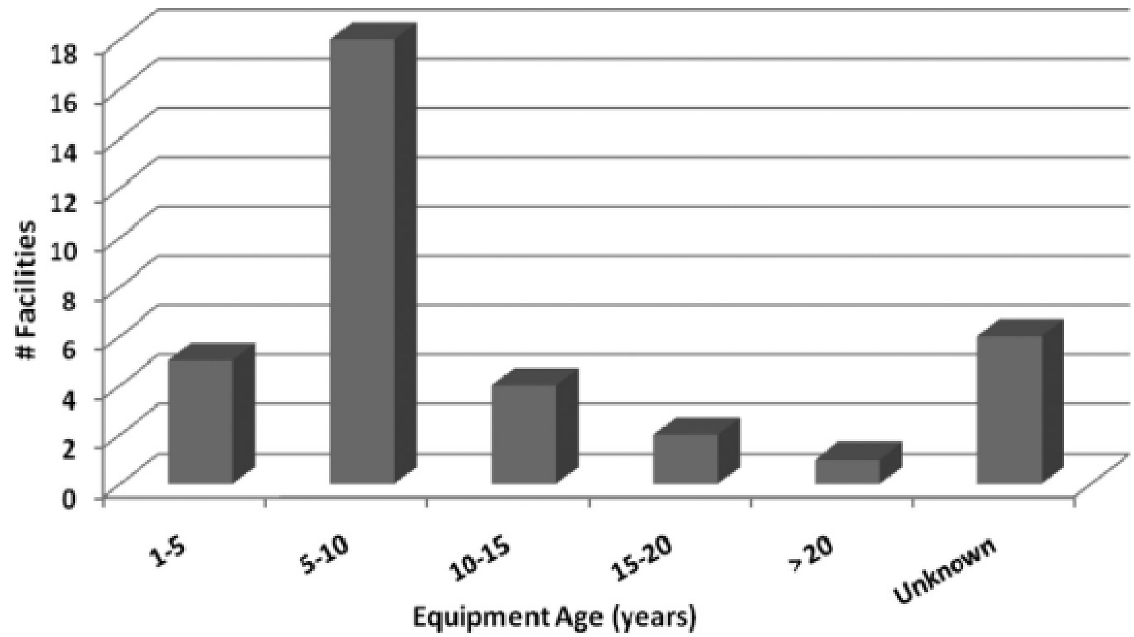



Figure 6.1 Average Age of Equipment Associated with Multi-User Facilities. The average age of equipment in core facilities is roughly around 5-10 years old. A lot of equipment is unknown how old it may be. (Riley, 2011)

Some core facilities have many different groups under a main lab. Other core labs have the different labs completely separated into different departments. This way the different departments each have their own funding. This can sometimes cause an overlap in equipment at the different labs. When the different departments become centralized under a single core facility, all the labs share funds. This allows for less wasted money by having all the finances going through one administrative unit. This prevents duplication in instrumentation and ultimately costs less to the institution.

There are different types of core facilities, and some are more common than others. Microscopy cores and flow cytometry cores seem to be the most common facilities (Kos-Braun et al., 2020). It seems that electron microscopy is the most common core (Riley, 2011). Other common cores are mass spectrometry, nuclear magnetic

resonance (NMR)/X-ray/magnetic resonance imaging (MRI) cores and rodent research centers. Bioinformatics cores are also beginning to become more common.

The study that was performed in the spring of 2010 by Clemson University, also showed the different types of facilities that were surveyed. The results are shown in figure 6.2. In this survey, electron microscopy was the most common core facility. Mass spectrometry was the second most common core (Riley, 2011).

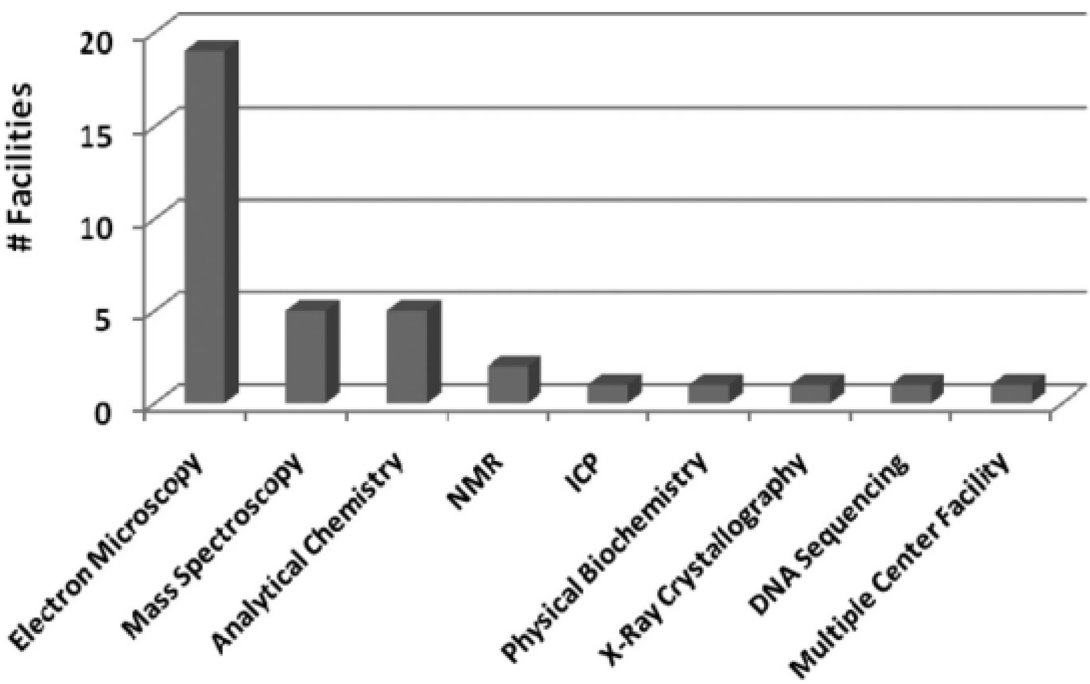



Figure 6.2 Types of Facilities Responding to Survey. Most cores that answered this survey were electron microscopy cores. (Riley, 2011)

Another study was done in 2018 by the Core Technologies for Life Science Association (CTLS) and the ABRF. This survey was sent to all of the members of these groups and also to all German BioImaging members (Adami et al., 2021). There were 275 respondents to this survey. Figure 6.3 shows the results of the fields of activity of all

the respondents. The highest number worked in microscopy with 22.6% (Adami, et al., 2021). Flow cytometry was second with 15%. Proteomics and metabolomics were 12% and genomics and transcriptomics was 9.5%. Another 6% answered for bioinformatics.

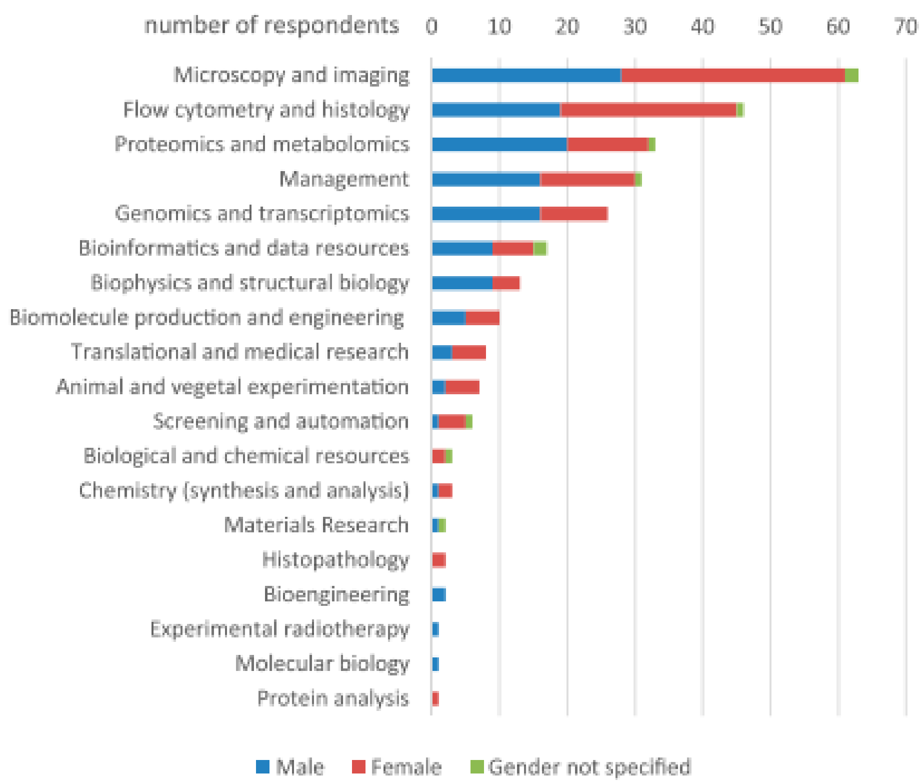



Figure 6.3 Fields of Activity. In this survey, microscopy and imaging facilities were the most common facilities. Other common facilities were flow cytometry, histology, and proteomics (Adami et al., 2021).

The 2019 Agilent iLab study also asked about different types of core labs (Strubczewski, 2019). These responses were from 244 different core labs in the United States. There were answers that came from 15 different major technologies. The results of this survey are shown in figure 6.4. The highest amount of answers came from the Imaging and Microscopy category with 26.7%. Flow Cytometry and Cell Sorting was the second most popular technique along with Proteomics and Mass Spectrometry. They

were both at 12.3%. Genomics was also popular and had 11%. The category ‘other’ was also a large portion of the answers and was 14.4%. This category contains any other discipline that was not mentioned. This study was consistent with the previous 2018 CTLS survey.

Agilent also did a benchmark study in 2016 that included 282 core managers. This survey also found that the microscopy/imaging field was the largest response, followed by the flow cytometry and cell sorting field. The Genomics and Mass Spectrometry category was also a very common core. This survey is also consistent with the other two surveys.

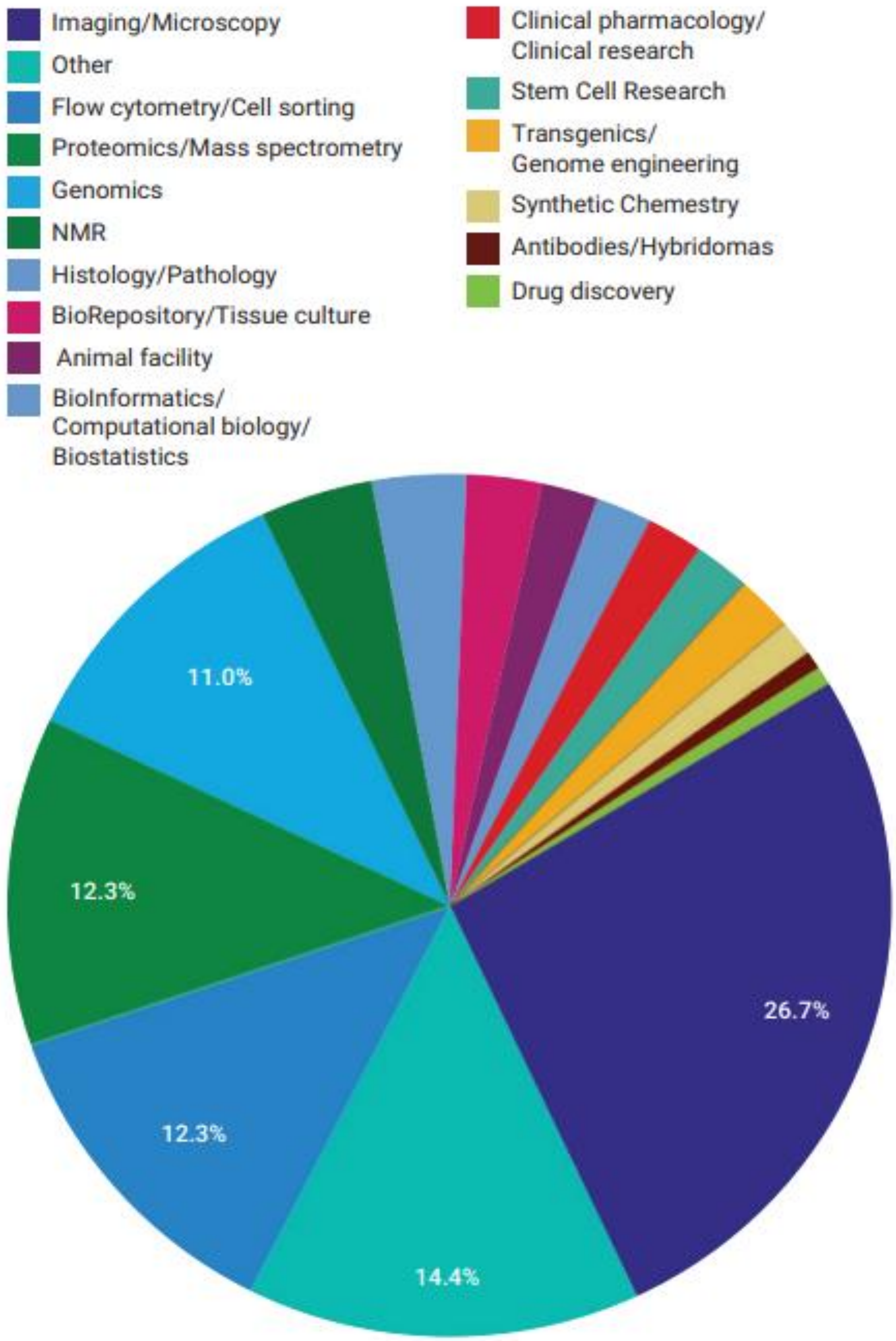



Figure 6.4 Core Laboratory Types. Most of the core facilities that were surveyed were imaging/microscopy facilities. Flow cytometry and mass spectronomy are both large categories as well. (Strubczewski, 2019)

The University of South Carolina has about 133 core instruments total in all of their core facilities. The School of Medicine has the most instrumentation with 44 pieces of equipment. The College of Arts and Sciences and the College of Pharmacy both have 35 pieces of equipment. Lastly, the College of Engineering and computing has a total of 19 pieces of instrumentation. Out of all this instrumentation, 121 instruments are fully functional. Three pieces of equipment partially work and 8 are currently non-functional. This information was gathered from a survey conducted by Mischa Shtutman, who is the director of the Functional Genomics Core at USC.

Table 6.1 shows the different universities that were analyzed and cores that they have. It also includes other information like software they use, financial situations, marketing tactics, and personnel they employ.

Table 6.1 Cores in Different Universities

| Universities and Management | Cores and Research Centers | Software, finances, marketing, personnel |
|---|---|---|
| University of Georgia<br><br>Completely Centralized | Animal Health Research Center<br>Bioimaging Research Center<br>Biomedical Microscopy Core<br>Complex Carbohydrate Research Center<br>Cytometry Shared Resource Laboratory<br>Georgia Electron Microscopy (GEM)<br>Georgia Genomics & Bioinformatics Core<br>Proteomic & Mass Spectrometry Core | Clinical and Translational Research Unit (CTRU) - Uses LIMS |

| | | |
|---|---|---|
| University of Auburn<br><br>Mixed/Mostly Centralized | Transgenic Facility<br>Research Instrumentation Facility<br>Mass Spectrometry Center (Chemistry Department)<br>NMR Center<br>Flow Cytometry Laboratory<br>Genomics and Sequencing Laboratory<br>Magnetic Resonance Imaging Center<br>X-Ray Diffraction Facility | -College of Agriculture - Applied Biotechnology Major<br>- Funds provided by the Office of VP of Research |
| University of Kentucky<br><br>Mixed Model | Division of Laboratory Animal Resources<br>Flow Cytometry and Immune Monitoring Core<br>Light Microscopy Core<br>Magnetic Resonance Imaging and Spectroscopy Center<br>Proteomics Core Facility<br>Rodent Behavior Core<br>Electron Microscopy Core<br>Mass Spectrometry Facility<br>Genomics Core Laboratory | -Flow data is backed up every night<br>-Funding by state, industry, and federal agencies |
| University of Missouri<br><br>Completely Centralized<br><br>Some Departmental | Advanced Light Microscopy<br>Animal Modeling<br>Bioinformatics & Analytics<br>Cell & Immunobiology Core<br>Electron Microscopy Core<br>Gehrke Proteomics Center<br>Genomics Technology<br>Metabolomics Center<br>Nuclear Magnetic Resonance Core<br>Small Animal Phenotyping<br>NextGen Center for Imaging<br>Rat Resource & Research Center | -Office of the Vice Chancellor for Research and Economic Development<br>-31,000 students<br>-3000 faculty and researcher<br>-Annual research expenditure ($355 million)<br>$5 billion annual impact on Missouri's economy<br>Fee-for-service model<br>-Christopher S. Bond Life Sciences Center – funding from state, federal, and private sources<br>-30 principal investigator users |
| Mississippi State University<br><br>Completely Decentralized | Institute for Imaging and Analytical Technologies<br>-Confocal Microscopy<br>-Atomic Force Microscope<br>-Scanning Electron Microscopy<br>-Transmission Electron Microscopy<br>-X-ray Diffractometers<br>-MRI | MRI - .7 million grant from the Office of Naval Research |

| | | |
|---|---|---|
| University of Florida<br><br>Mixed Model | Bioinformatics<br>Cytometry<br>Electron Microscopy<br>Gene Expression and Genotyping<br>Proteomics and Mass Spectroscopy<br>Vector Core Lab | -Seminar series (ICBR)<br>-58 Staff members<br>-22% Faculty<br>-45% Full time staff<br>-33% Postdoctoral associates, temporary, part-time positions<br>-Fee-for-service<br>-Bioinformatics - iLab |
| Vanderbilt University Medical Center<br><br>Mixed/Mostly Centralized | Center for Structural Biology<br>Mass Spectrometry Research Center<br>Proteomics Laboratory<br>Tissue Core<br>Bioinformatics | -The Associate Vice Chancellor for Research<br>-More than 85 centers and institutions<br>-Mass Spectrometry Research Center – 20 personnel<br>-funding from National Center for Research Resources (NCRR) and NIH<br>-uses iLab |
| University of Virginia School of Medicine<br><br>Completely Centralized | Advanced Microscopy Facility<br>Bioinformatics Core<br>Biomolecular Magnetic Resonance Facility<br>Flow Cytometry Core Facility<br>Genome Analysis and Technology Core<br>Molecular Imaging Core<br>Research Histology Core | -Senior Associate Dean for Research Infrastructure<br>-The Office of Research Core Administration (ORCA)<br>-centralized budget and billing using iLab<br>-Research Histology Core – supported by the University of Virginia Cancer Center National Center Institute P30 grant<br>-Molecular Electron Microscopy Core – 5 publications in 2020 and 2021<br>-NIH SIG grant (SEM)<br>-NIH S10 Instrument program (Cell Sorter)<br>-Flow cytometry classes<br>-iLab |
| Cornell University<br><br>Completely Centralized | Bioinformatics Facility<br>Flow Cytometry Facility<br>Genomics Facility<br>Imaging Facility<br>Proteomics and Metabolomics Facility | -Receives investment from the Provost<br>-Each facility has an advisory board<br>-Center for Advanced Technology (CAT): collaboration between private industry |

| | | |
|---|---|---|
| Virginia Tech<br><br>Mostly Departmental | Electron Microscopy Service Laboratory<br>Flow Cytometry Laboratory<br>Fralin Imaging Center<br>Genomics Sequencing Center<br>Laboratory Animal Facilities<br>Mass Spectrometry and Chromatography Lab<br>NMR Spectroscopy | -Mostly lab managers<br>-Fee-for-service<br>-Genomics Sequencing Center – supports 700 principal investigators worldwide |
| Emory University<br><br>Mostly Centralized/ Mixed Model | Biostatistics and Collaboration Core<br>Center for Systems Imaging Core<br>Division of Animal Resources<br>Flow Cytometry Core<br>Glycomics and Molecular Interactions Core<br>Gnotobiotic Animal Core<br>Integrated Genomics Core<br>Integrated Metabolomics and Lipidomics Core<br>Integrated Proteomics Core<br>Cellular Imaging Core<br>Electron Microscopy Core | -Have some cores that are administered independently<br>-Emory Integrated Core Facilities (EICF) organization was established in 2016<br>-Uses PPMS |
| University of South Carolina<br><br>Mixed Model | Instrumentation Resource Facility<br>Electron Microscopy Center<br>Microscopy and Flow Cytometry Core<br>Functional Genomics Core<br>Bioinformatics Core<br>Viral Vector Core<br>Mouse Experimentation and Gnotobiotic Core Facility<br>Nuclear Magnetic Resonance Facility<br>Mass Spectrometry Center | -Applied Biotechnology Program<br>-Uses iLab |

# CHAPTER 7

# SOFTWARE AND DATA MANAGEMENT

Keeping track of a core lab by using lab management software is an important part of having a core facility. Laboratories need a way to communicate with the researchers and users that use their facility. It is also essential for a core lab to keep track of how much time users spend on different equipment. This information can be crucial for the lab to report to continue to receive funding for that instrument. They also need to keep track of the different orders that come through the lab and specific requests from researchers. Some core labs have an automated computer system that keeps track of everything. Facilities need a way to keep track of how much money they are making from user fees or grants or other ways the lab makes income. This software can also keep track of billing of customers and training records. Management software is one of the best tools to improve time management in core facilities. Having a centralized system that tracks all of these aspects for a laboratory can greatly reduce the amount of time that core directors spend on the business aspects of running the facility (Farber and Weiss, 2011).

From the Kos-Braun (2020) survey done in Europe in 253 surveys, management software was rated as one of the best tools to improve laboratory management operations. Some examples of this kind of software include PPMS (Pasteur Platform Management System) from Stratocore and iLab from Agilent (Kos-Braun et al., 2020). These software plans help core facility staff manage daily operations.

In the 2016 Agilent benchmark survey it was found that using this kind of software helped save laboratory personnel an average of 7 hours a month over billing manually with spreadsheets (iLab, 2016). Figures 1-7 shows how different labs keep track of different things. The highest answers for all of them were electronic systems, except for customer requests and managing the lab's budget. Many labs keep track of customer requests by email and most labs used an excel spreadsheet to track the budget and expenses of the core laboratory.

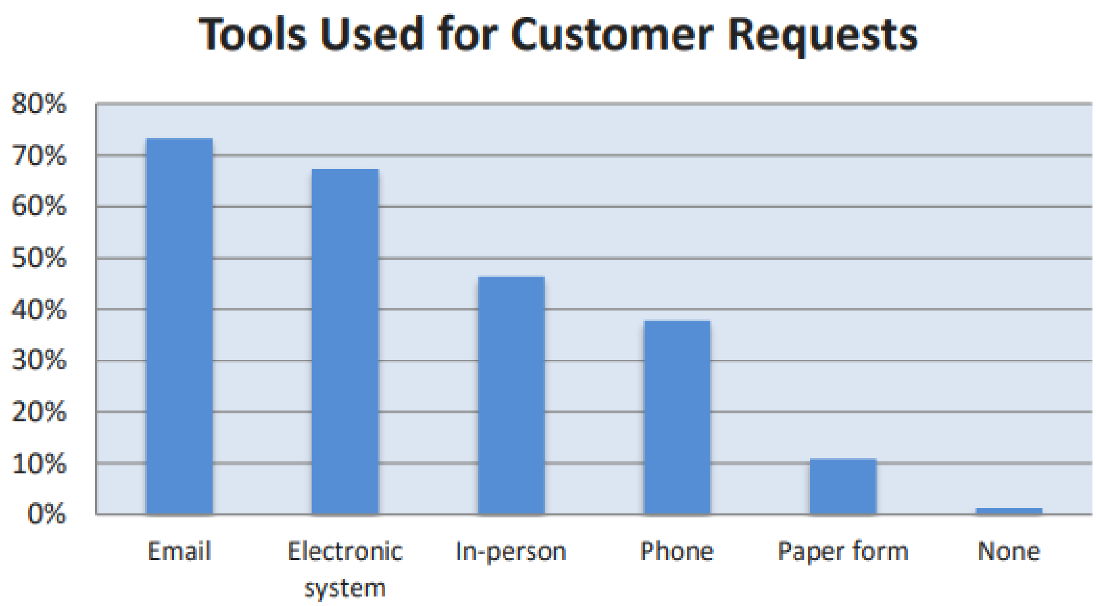



Figure 7.1 (iLab, 2016) Tools Used for Customer Requests. The most used method of tracking customer requests was using an email system. Electronic system tracking was another highly used method.

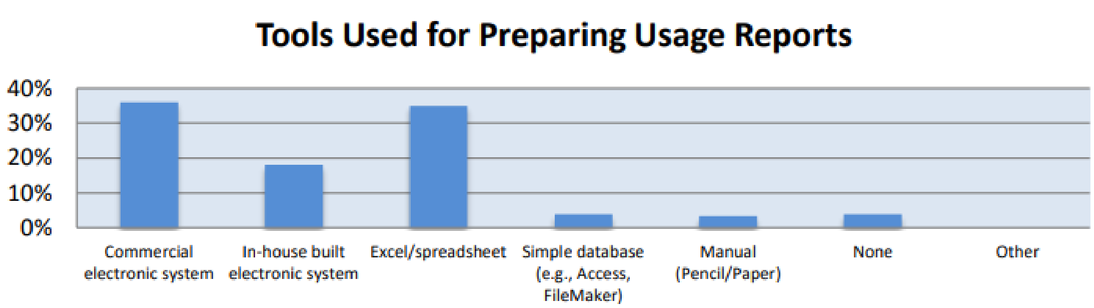



Figure 7.2 (iLab, 2016) Tools Used for Preparing Usage Reports. The most commonly used tool for preparing usage reports for customers were using an electronic system and using an excel spreadsheet. Both of these categories were almost equal.

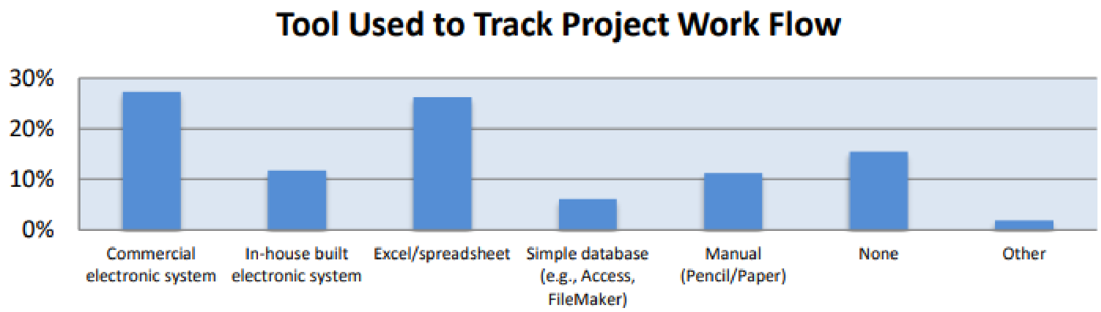



Figure 7.3 (iLab, 2016) Tool Used to Track Project Workflow. Most core laboratories indicated that they use a commercial electronic system to keep track of the project workflow within the lab. Another common method was using an excel spreadsheet. These two methods were almost equal.

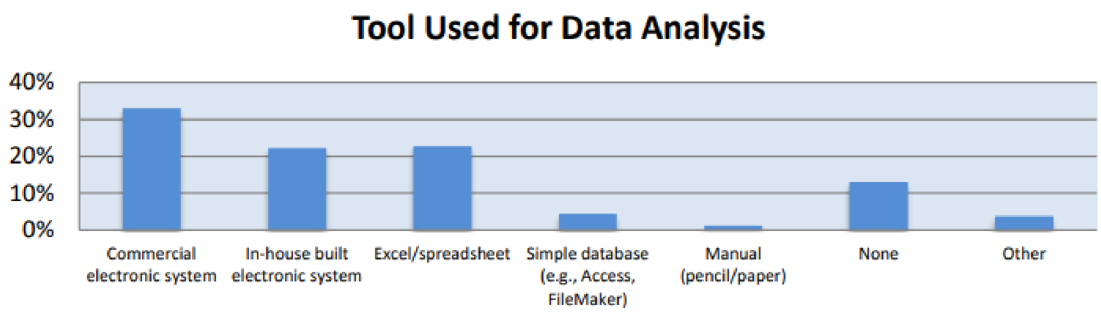



Figure 7.4 (iLab, 2016) Tool Used to for Data Analysis. Most labs use a commercial electronic system to perform data analysis. In-house built electronic systems and excel spreadsheets were also very common.

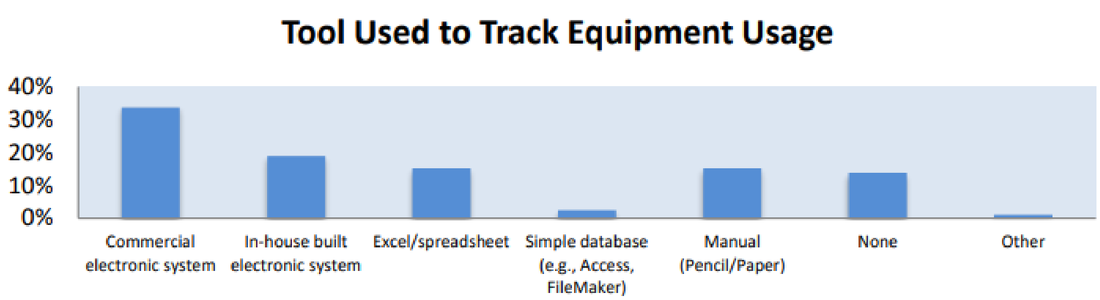



Figure 7.5 (iLab, 2016) Tool Used to Track Equipment Usage. Equipment usage was tracked by most labs using a commercial electronic system.

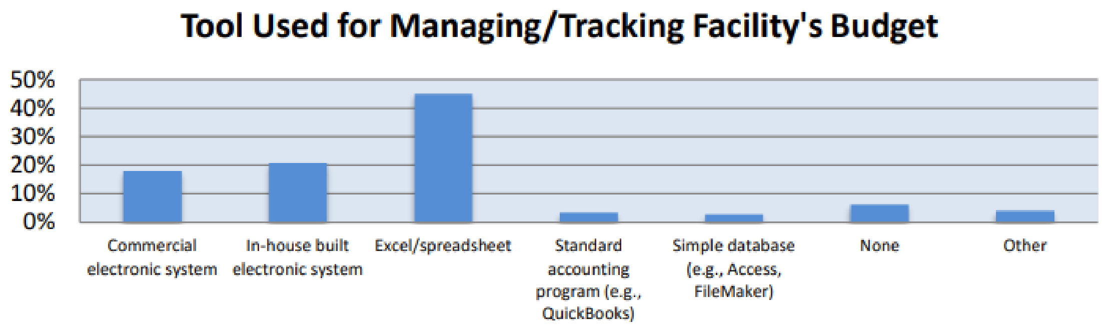



Figure 7.6 (iLab, 2016) Tool Used for Managing/Tracking Facility's Budget. The majority of core laboratories use an excel spreadsheet to keep track of the facility's budget.

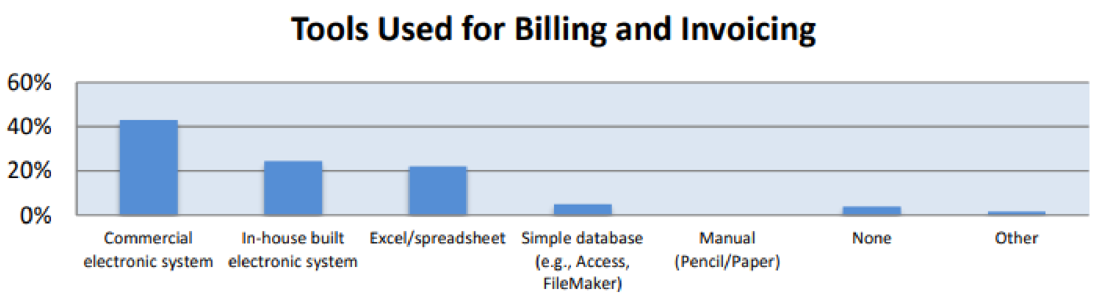



Figure 7.7 (iLab, 2016) Tools Used for Billing and Invoicing. Most labs use a commercial electronic system to help with billing and invoicing. The second most commonly used tool is an electronic system that was built in-house. Having an electronic system helps in centralizing all the finances.

A lot of raw data is generated at a core facility. Depending on the facility, the core may store that data, or it may be the sole responsibility of the user to store their own data. Data management software can also be used to track different sample IDs. A data management plan can be acquired by facilities to store large amounts of raw data. The Laboratory Information Management Systems (LIMS) is an example of this type of software (Kos-Braun et al., 2020). This helps the core keep the generated data backed up at their facility. Image data is sometimes removed from the facility after the experiment is finalized (Ferrando-May et al., 2016).

From the same European survey mentioned before, the question "who is responsible for the long-term storage of raw data?" was asked in a survey from Kos-Braun (Kos-Braun et al, 2020). Figure 7.8 shows that most people believe it was ultimately the responsibility of the user to collect and store the raw data, but that the core facility should also have a stored version of that data. It is good for core facilities to keep track of all the raw data that is coming from inside the core lab. This can help determine the core's success rate.

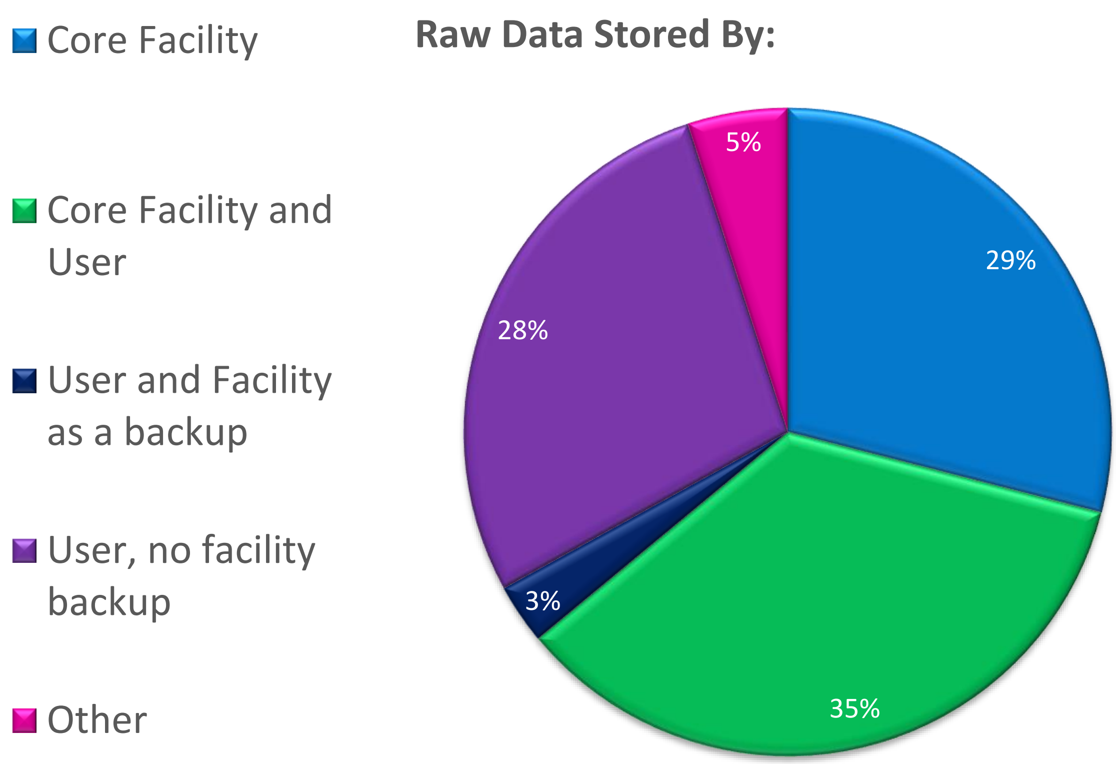



Figure 7.8 (Kos-Braun et al., 2020) "Who is responsible for the long-term storage of raw data?" was asked in this survey. Most people believe that it is the responsibility of the user and the core facility to store the raw data from a project.

Some labs will have both systems in place, a management platform, and a data storage plan, and some labs will have neither system in place. The most cited reason for

not having one of these systems was because of financial concerns (Kos-Braun et al., 2020). Storing large amounts of data can cost a lot of money.

In the same European study from Kos-Braun, the labs were asked "Which management software did they use?" The results of this question are shown in figure 7.9. From this survey, LIMS, PPMS, and iLab seem to be the most popular management software (Kos-Braun et al., 2020). According to the study, PPMS was the most used tool in self-service models and iLab was the most used in full-service model facilities (Kos-Braun et al., 2020)

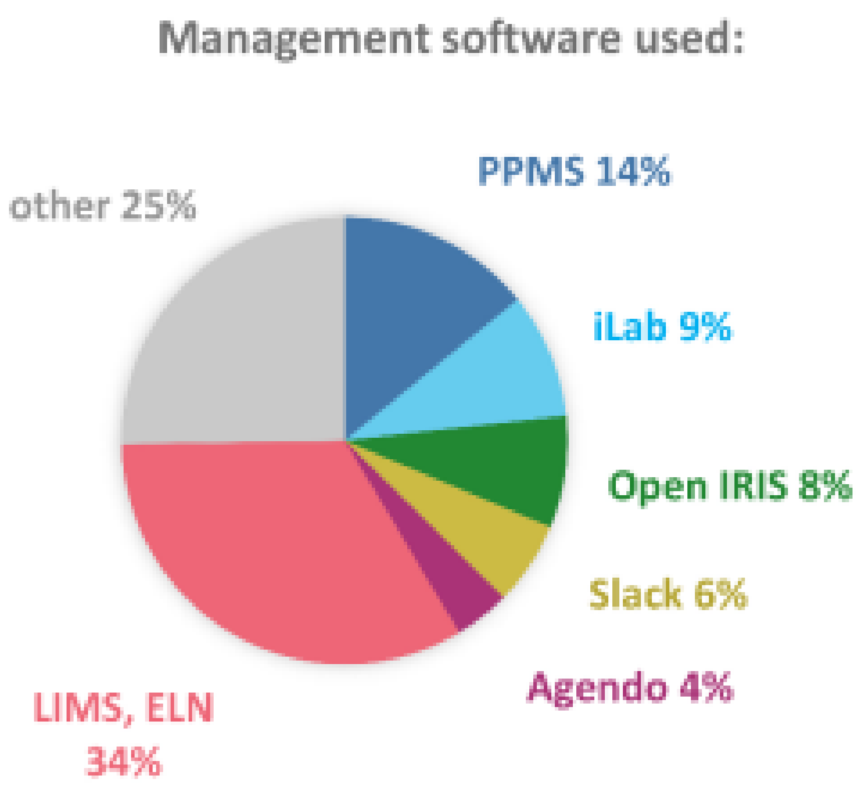



Figure 7.9 There are different kinds of laboratory management software that are used in core facilities. This figure shows that LIMS is one of the most popular tools used in laboratory management software. PPMS and iLab are both popular as well. (Kos-Braun et al., 2020)

At the University of Georgia, the Clinical and Translational Research Unit (CTRU) uses LIMS for sample tracking. At the Kentucky Flow Cytometry and Immune Monitoring Core, the IT services department backs up their flow data storage every night. The Florida University Bioinformatics lab and Flow Cytometry lab uses iLab for all their management. The AMRIS facility there has nightly network backups to back up the data on their equipment. The data stays on the instrument for three months before it is overwritten. At the University of South Carolina, the Instrumentation Resource Facility uses iLabs as their management platform as well. The University of Virginia School of Medicine has all of their cores using iLab. This helps centralize the billing and the budget systems. All core facilities at Emory University in Georgia also used a centralized management platform with a single user database (Zwick, 2021). They use PPMS from Stratocore.

The Instrumentation Resource Facility at the University of South Carolina uses iLab to create kinds of graphs that show data usage, scheduling, equipment usage and other information. Figure 7.10 shows an example of how iLab can track how much usage each piece of equipment in the facility gets. This graph was generated from March 2020 to March 2023. The largest percentage was for BioRad Stockroom orders. The instrument that had the most use during this time is the BD FACS Aria II cell sorter.

Equipment Usage from March 2020-March 2023

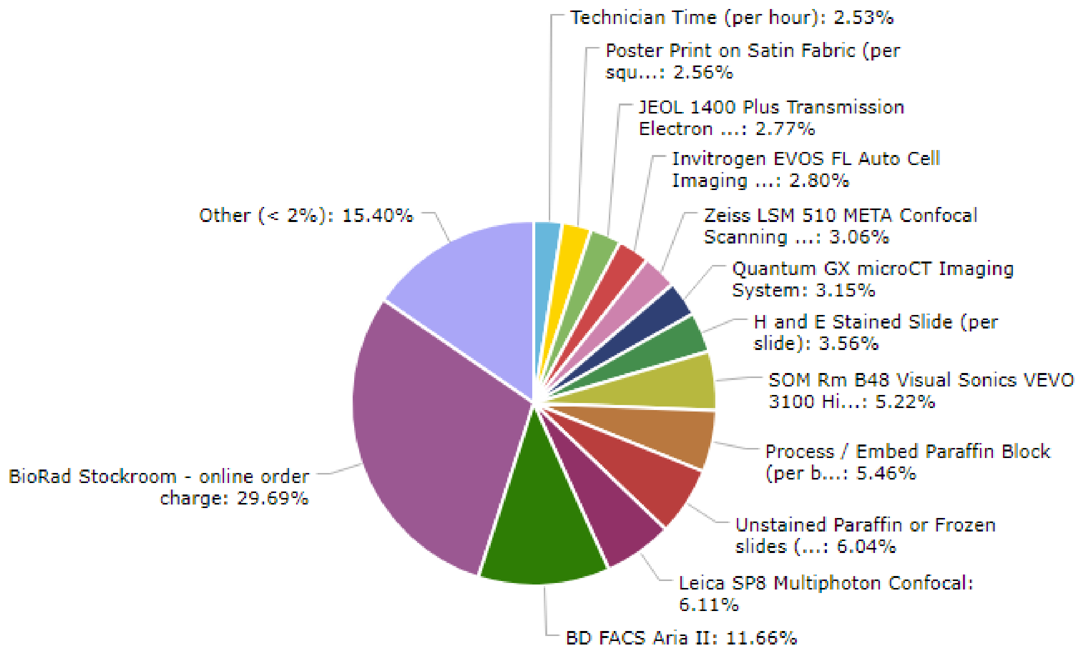
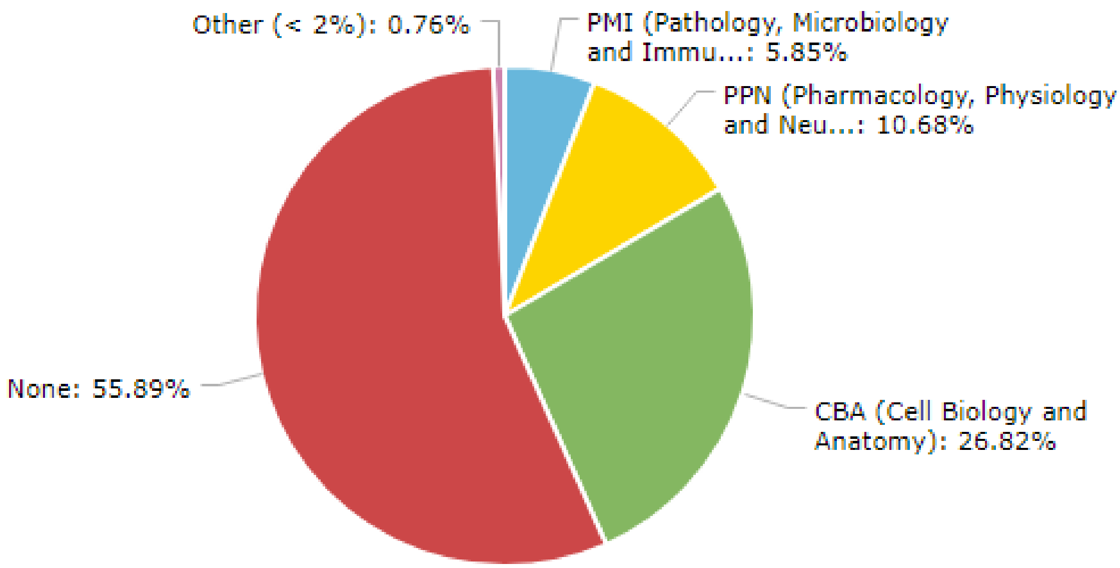



Figure 7.10 University of South Carolina Instrumentation Resource Facility Equipment Usage from March 23, 2020-March 23, 2023. A majority of the equipment usage is from stockroom equipment orders. The most used instrument over these three years was the BD FACS Aria II Cell Sorter.

Figure 7.11 shows an example of how iLab software can track departmental usage for specific equipment. This figure was created just for the usage of histology service requests. This graph was made for March 2020 to March 2023. It shows how much each department at the School of Medicine used histology services during that time. The 'none' category were not associated with a department and the other category represents other departments that are not listed.




Usage By Department from March 23, 2020-March 23, 2023. From this chart, more than half of the histology users in this three-year span were not associated with a certain department. The Cell Biology and Anatomy department used the histology services twice as much as the other departments.

Figure 7.12 is a figure that was created in iLab to show the histology expenditures of each department. This figure was created for the timeframe from March 2022 to March 2023. This figure shows that the Cell Biology and Anatomy Department spent the most money of all departments during that time. The Pathology, Microbiology, and Immunology department and the Pharmacology, Physiology, and Neuroscience departments spent about equal expenses during this year.

Histology Expenses by Department from March 2022-March 2023

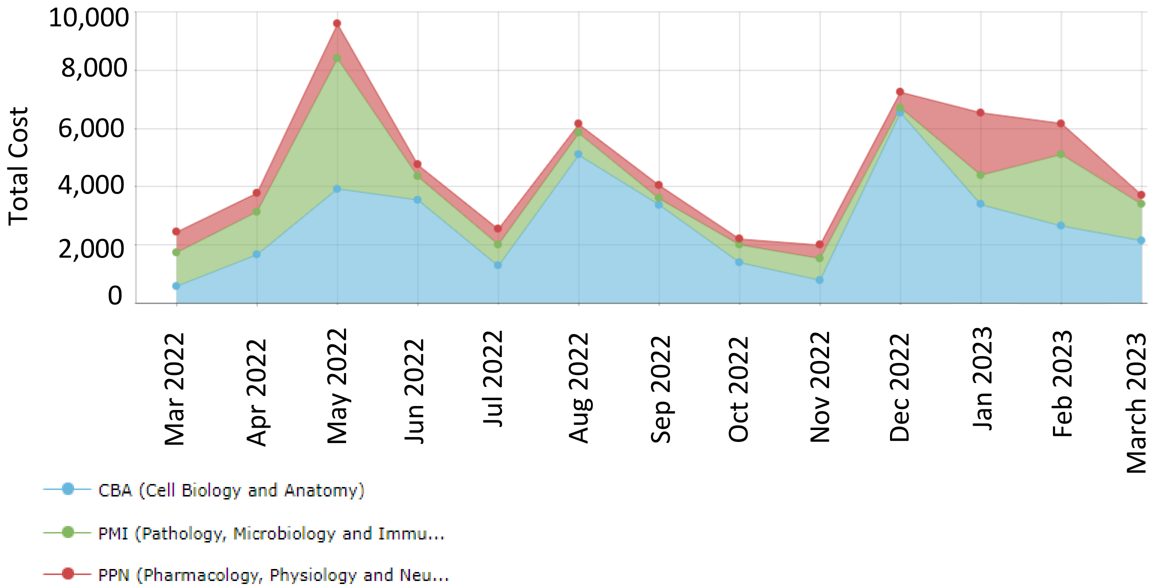



Figure 7.12 University of South Carolina Instrumentation Resource Facility Histology Expenses by Department from March 23, 2020-March 23, 2023

Figure 7.13 was also created in iLab. This figure shows the comparison of two different labs usage of histology in the Instrumentation Resource Facility at the University of South Carolina School of Medicine.

Histology Usage from 2 Different Labs

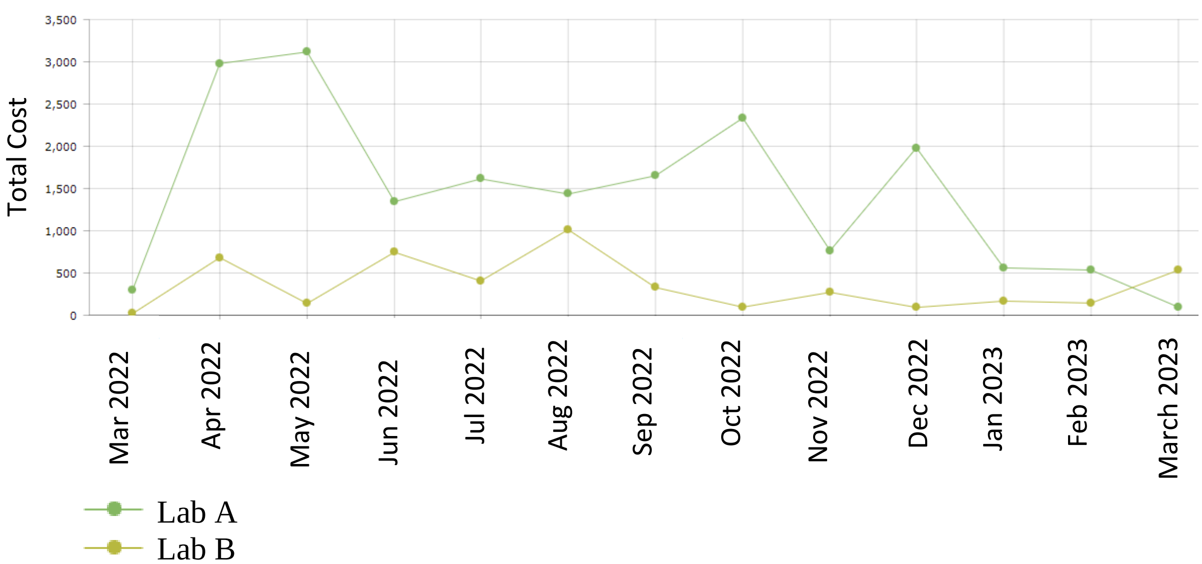



Figure 7.13 University of South Carolina Instrumentation Resource Facility Histology Usage from March 2022-March 2023

# CHAPTER 8

# CONCLUSION

Core facility labs are becoming increasingly important to the research community as they produce much of the scientific data. There is a large demand for biomedical research core facilities. These facilities are places that scientists can use the technologies and instruments without having to buy a large or expensive piece of equipment. Core facilities are staffed with people that know about the equipment in their lab. They can offer training services on several different technologies. Core facilities should try to collaborate whenever possible to share resources and to minimize duplication of technology and expertise. It should also be encouraged to add resources to existing cores rather than establishing new ones.

It seems that most universities are either in the process of becoming more centralized or are already centralized as it has shown many benefits. There is no single method of management that is right for every institution or facility. A decentralized management can also work very well.

Surveys are a great way to access trends in core facility management. In the future, the best way to compare facilities is to perform surveys and then compare these surveys with previous surveys. This provides certain limitations since each survey is different and goes to different people through email. Response percentages to surveys are

fairly low however and it is not easy to get many answers to questions. Possibly a better way to perform surveys is to make them as short as possible. People are more likely to answer short surveys that will not take long to answer. The larger the number of responses, the more meaningful the data will be. It is also hard to find information about core facilities and their resources. The information presented online is either not easily available or is incomplete (Farber and Weiss, 2011).

Figure 8.1 is a word cloud created that represents responses to the question “How do you characterize success of a core facility?” posed by Carter et al., (2019). The larger words were suggested most often.


Figure 8.1 (Carter et al, 2019). A word cloud was created that shows the responses to the question “How do you characterize success of a core facility?” The larger words were the most common words suggested.

Research needs, extramural funding and publications are obviously the driving force behind the development of the many core facilities that exist. This trend and centralization of cores will continue to grow in importance in the future.

# REFERENCES

Adami V, Homer N, Utz N, Lippens S, Rappoport JZ, Fernandez-Rodriguez J. An international survey of Training Needs and Career Paths of Core Facility Staff. J Biomol Tech. 2021 Apr;32(1):1-9. doi: 10.7171/jbt.21-3201-002. PMID: 33880077; PMCID: PMC8040527.

Brown CM. Careers in Core Facility Management. Cold Spring Harb Perspect Biol. 2018 Aug 1;10(8):a032805. doi: 10.1101/cshperspect.a032805. PMID: 30068529; PMCID: PMC6071492.

Carter JR, Delahanty DL, Strasser JE, Knoedler AJ, Wilson G, Davis RK, Engel D. Operational and Fiscal Management of Core Facilities: A Survey of Chief Research Officers. Society of Research Administrators International. 2019 December 9. Volume L, Number 3. https://www.srainternational.org/blogs/srai-jra1/2019/12/09/operational-fiscal-management-of-core-facilities

Chang M, Grieder FB. Sharing Core Facilities and Research Resources--An Investment in Accelerating Scientific Discoveries. J Biomol Tech. 2016 Apr;27(1):2-3. doi: 10.7171/jbt.16-2701-004. Epub 2016 Jan 11. PMID: 26763487; PMCID: PMC4701235.

Farber GK, Weiss L. Core facilities: maximizing the return on investment. Sci Transl Med. 2011 Aug 10;3(95):95cm21. doi: 10.1126/scitranslmed.3002421. PMID: 21832235; PMCID: PMC3161425.

Ferrando-May E, Hartmann H, Reymann J, Ansari N, Utz N, Fried HU, Kukat C, Peychl J, Liebig C, Terjung S, Laketa V, Sporbert A, Weidtkamp-Peters S, Schauss A, Zuschratter W, Avilov S; German BioImaging network. Advanced light microscopy core facilities: Balancing service, science and career. Microsc Res Tech. 2016 Jun;79(6):463-79. doi: 10.1002/jemt.22648. Epub 2016 Apr 4. PMID: 27040755; PMCID: PMC5071710.

Fletcher G, Anderson KI. What is the structure of our infrastructure? A review of UK light microscopy facilities. J Microsc. 2022 Feb;285(2):55-67. doi: 10.1111/jmi.13076. Epub 2022 Jan 10. PMID: 34841540; PMCID: PMC9302651.

Gould J. Core facilities: Shared support. Nature. 2015 Mar 26;519(7544):495-6. doi: 10.1038/nj7544-495a. PMID: 25815394.

Haley R. A framework for managing core facilities within the research enterprise. J Biomol Tech. 2009 Sep;20(4):226-30. PMID: 19721824; PMCID: PMC2729482.

Hockberger P, Meyn S, Nicklin C, Tabarini D, Turpen P, Auger J. Best practices for core facilities: handling external customers. J Biomol Tech. 2013 Jul;24(2):87-97. doi: 10.7171/jbt.13-2402-001. PMID: 23814500; PMCID: PMC3605920.

Hockberger P, Weiss J, Rosen A, Ott A. Building a Sustainable Portfolio of Core Facilities: a Case Study. J Biomol Tech. 2018 Sep;29(3):79-92. doi: 10.7171/jbt.18-2903-003. Epub 2018 Aug 6. PMID: 30140172; PMCID: PMC6078059.

iLab Solutions. The 2015 core facility benchmarking study. Available at: https://www.agilent.com/cs/library/whitepaper/public/2015_Benchmarking_Study.pdf

iLab Solutions. The 2016 core facility benchmarking study. Available at: https://www.agilent.com/cs/library/whitepaper/public/2016_Benchmarking_Study.pdf

Kos-Braun IC, Gerlach B, Pitzer C. Assessing and Improving Research Quality in Core Facilities. J Biomol Tech. 2022 Jan 31;33(1):3fc1f5fe.97057772. doi: 10.7171/3fc1f5fe.97057772. PMID: 35837001; PMCID: PMC9258915.

Kos-Braun IC, Gerlach B, Pitzer C. A survey of research quality in core facilities. Elife. 2020 Nov 26;9:e62212. doi: 10.7554/eLife.62212. PMID: 33241998; PMCID: PMC7714392.

Lippens S, D'Enfert C, Farkas L, Kehres A, Korn B, Morales M, Pepperkok R, Premvardhan L, Schlapbach R, Tiran A, Meder D, Van Minnebruggen G. One step ahead: Innovation in core facilities. EMBO Rep. 2019 Apr;20(4):e48017. doi: 10.15252/embr.201948017. Epub 2019 Mar 14. PMID: 30872318; PMCID: PMC6446189.

McMillen DA, Bibbs L, Denslow N, Ivanetich KM, Naeve C, Niece RL, Tindall S. Biotechnology core laboratories: An overview. J Biomol Tech. 2000 Mar;11(1):1-11. PMID: 19499032; PMCID: PMC2291618.

Meder D, Morales M, Pepperkok R, Schlapbach R, Tiran A, Van Minnebruggen G. Institutional core facilities: prerequisite for breakthroughs in the life sciences: Core facilities play an increasingly important role in biomedical research by providing scientists access to sophisticated technology and expertise. EMBO Rep. 2016 Aug;17(8):1088-93. doi: 10.15252/embr.201642857. Epub 2016 Jul 13. PMID: 27412771; PMCID: PMC4967956.

Ogorzalek Loo R, Nicolet CM, Niece RL, Young M, Simpson JT. Association of biomolecular resource facilities survey: service laboratory funding. J Biomol Tech. 2009 Jul;20(3):180-5. PMID: 19568457; PMCID: PMC2700468.

Riley MB. University multi-user facility survey-2010. J Biomol Tech. 2011 Dec;22(4):131-5. PMID: 22131888; PMCID: PMC3221449.

Strubczewski N. Core Facility Market Analysis. iLab Solutions. 2018. Available at: https://www.agilent.com/cs/library/whitepaper/public/whitepaper-crosslab-core-facility-market-analysis-5994-0452Een-agilent.pdf

Strubczewski N. Core Facility Market Analysis. iLab Solutions. 2019. Available at: https://www.agilent.com/cs/library/whitepaper/public/whitepaper-led-ilab-core-facility-shared-resources-5994-1620en-agilent.pdf

Turpen PB, Hockberger PE, Meyn SM, Nicklin C, Tabarini D, Auger JA. Metrics for Success: Strategies for Enabling Core Facility Performance and Assessing Outcomes. J Biomol Tech. 2016 Apr;27(1):25-39. doi: 10.7171/jbt.16-2701-001. Epub 2016 Feb 2. PMID: 26848284; PMCID: PMC4736753.

Waters JC. A Novel Paradigm for Expert Core Facility Staff Training. Trends Cell Biol. 2020 Sep;30(9):669-672. doi: 10.1016/j.tcb.2020.06.001. Epub 2020 Jul 1. PMID: 32622700.

Zwick ME. Organizing core facilities as force multipliers: strategies for research universities. J Biomol Tech. 2021 Apr;32(1):36-41. doi: 10.7171/jbt.21-3202-002. PMID: 34025222; PMCID: PMC8121078.