

QNFCF

Quantum Nano Fabrication
and Characterization Facility

Quantum Nano Fabrication and Characterization Facility
Core Scientific Research Platform
Annual update: Fiscal Year 2024 – (May 2023 – April 2024)



Taso Alkiviades and Nathan Nelson-Fitzpatrick leading a tour of the Inert Atmosphere Fabrication Lab at the Transformative Quantum Technologies: Quantum Opportunities and Showcase event (December 2023)

Nathan Nelson-Fitzpatrick

Director, Quantum-Nano Fabrication and Characterization Facility

1. INTRODUCTION

The operational milestones and data for the Quantum-Nano Fabrication and Characterization Facility for the 2023/24 fiscal year have been summarized in this annual report. For more background information regarding our lab, operations and governance structure, please refer to our website:

<https://uwaterloo.ca/quantum-nano-fabrication-and-characterization-facility/>

2. OPERATIONAL HIGHLIGHTS

The Quantum-Nano Fabrication and Characterization Facility is an ever-evolving resource which changes to meet the needs of our community of lab members. Some operational highlights for the 2023/24 year include:

- **Spring/Summer 2023:** Internal familiarization and development work on the new JEOL F200 S/TEM was conducted (the tool was commissioned in March 2023). Notable milestones include the first staff operated imaging sessions in July 2023 and the first focused ion beam (FIB) lamellae sample (fabricated on the QNFCF's Zeiss Auriga FIB-SEM) imaged on the transmission electron microscope (TEM) in August 2023.
- **September 2023:** Dr. Sandra Gibson delivered a "Lunch and Learn" lecture summarizing the capabilities of the new JEOL F200 S/TEM. This lecture was attended by more than 50 community members and served to officially announce that the new S/TEM was available for both "user training" and "staff service" modes of access. This new S/TEM capability was made possible through support from the Canada First Research Excellence Fund – Transformative Quantum Technologies (CFREF-TQT) program and the Canada Foundation for Innovation (CFI) project 39548.



Figure 1: Photo of Dr. Sandra Gibson delivering the TEM "Lunch and Learn" lecture.

- **Fall 2023/Winter 2024:** Nicki Shaw and Dr. Greg Holloway delivered presentations at the WIN “Pitches and Demos” events, demonstrating the new technical capabilities of the QNFCF’s Zeiss Auriga FIB-SEM system.
- **January 2024:** Dr. Lino Eugene delivered a “Lunch and Learn” lecture, providing a technical overview of plasma etching technologies with a special emphasis on the capabilities that are available in the QNFCF cleanroom. The event was attended by more than 60 community members.



Figure 2: Photo of Dr. Lino Eugene delivering the plasma etching “lunch and learn” lecture.

- **March 2024:** The Inert Atmosphere Fabrication Lab in RAC1 was commissioned and released to the community. This lab has been referred to as the “cleanroom in a glovebox” and is intended to enable a complete fabrication process, without the need for a sample to leave the inert glovebox environment. This new capability was made possible through support from CFREF-TQT. An open house event was held in June 2024, which brought more than 60 community members to the RAC1 facility for lectures and lab tours. The University Relations group reported on the event and the article is included in the link: <https://uwaterloo.ca/news/taking-quantum-community>
- **Winter/Spring 2024:** Dr. Greg Holloway led a project to replace the QNFCF’s Badger lab management software with a modernized NEMO software package. The lab management software transition was supported by Nicki Shaw, Dr. Nathan Nelson-Fitzpatrick and Guillermo Gomez. The goal of this initiative was to improve security, bring our data “in house”, and future proof our platform by removing our dependence on Java 8. The transition to NEMO also provided benefits in terms of a reduction of operating costs, based on the elimination of the license and management fees associated with the Badger system. The NEMO software was rolled out to the QNFCF community members on May 1st 2024.

In terms of staffing, the following personnel changes occurred in the 2024 fiscal year:

- **Chris Kleven**, the QNC Facility Technician, joined the QNFCF on May 1st 2023. The position was transferred from the Space Planning Office (SPO) to the QNFCF. Chris has maintained his existing set of responsibilities and now reports to the QNFCF group, who is one of the primary beneficiaries of Chris’ excellent work in maintaining the building systems within the QNC.
- **Stefan Heinemann** resigned from his position as the Senior Facility Microscopist at the end of May 2023.
- **Guillermo Gomez** joined the Faculty of Engineering as a Faculty Financial Officer in September 2023 and vacated his position as the Manager of Finance and Administration for the QNFCF.
- **Nicki Shaw** joined the QNFCF as the Senior Facility Microscopist in September 2023. Nicki is primarily responsible for member service and training on the FIB-SEM and S/TEM systems at the QNFCF.
- **Sarah Mickelson** joined the QNFCF as the Manager of Finance and Administration in March 2024.

3. LAB DEMOGRAPHICS AND TRENDS

This section summarizes the attributes of the QNFCF lab member population. The population of lab members in this discussion refers to the number of unique users who register *at least one* instance of equipment use or laboratory fees within the fiscal year. For the 2023/24 fiscal year, the QNFCF registered 219 unique lab users, reflecting a 7% decrease from the 2022/23 fiscal year. The graph below represents this trend over time:

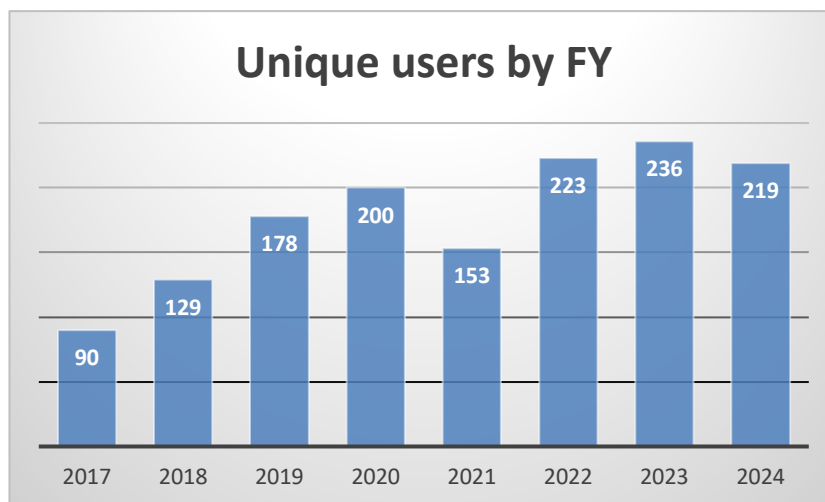


Figure 3: Number of unique QNFCF lab users per year.

If we investigate the data for the 2023/24 fiscal year, the QNFCF user population can be broken down by affiliation. The lab users are typically grouped by faculty if they are within the University of Waterloo and into the categories of “*external academic*” and “*industry*” if they are

external to the University. The following pie chart provides an overview of the QNFCF's user population by affiliation:

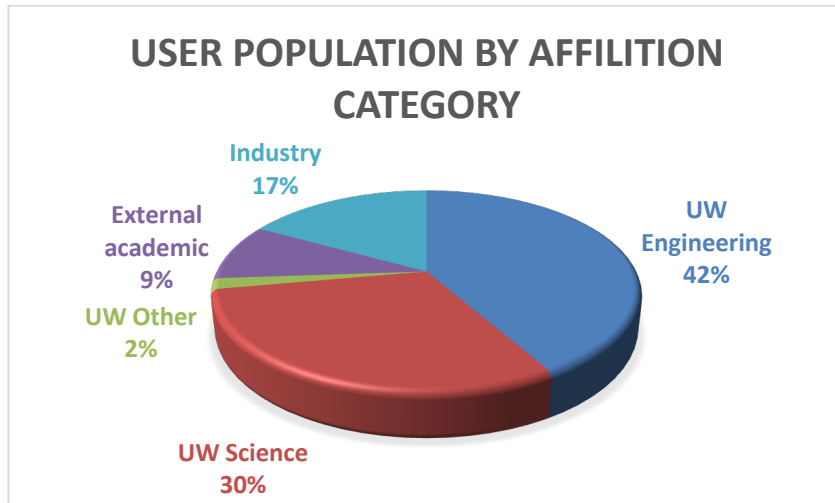


Figure 4: Pie chart of the users grouped into the affiliation categories.

All the user accounts within the QNFCF are tied to an account holder, the principal investigator (PI). The population of principal investigators showed a modest increase during the year, from 78 in the previous year to a total of 87 in the current year. A graph of this population over time is included below:

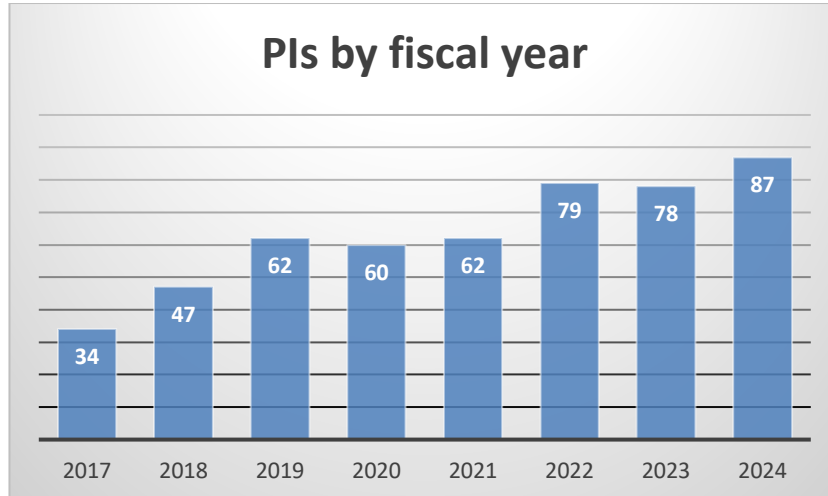


Figure 5: Number of unique PIs per year.

If we investigate the data for the 2024 fiscal year, we can apply the same internal and external affiliation categories to the PI population. The following pie chart provides an overview of the QNFCF's PI population by affiliation:

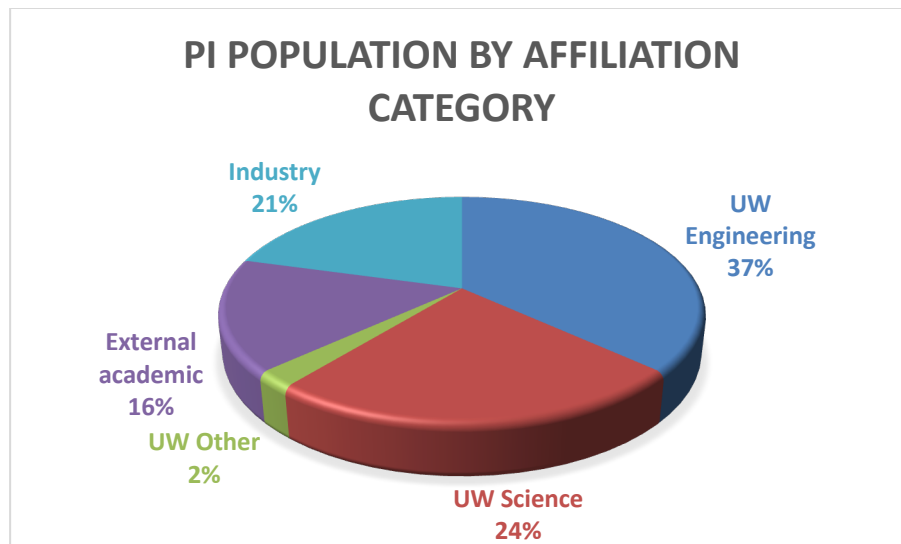


Figure 6: PI population grouped by their affiliation categories.

Brief comments regarding the QNFCF lab demographics for the 2024 fiscal year:

There is a notable disconnect between the trends for the number of lab users that has decreased by 7%, and the number of PIs that has increased by 12%. We believe that there are a couple of factors that have contributed to the trends. The CMC Microsystems’ MNT award program was halted in June 2023. This program had previously reimbursed up to 80% of the lab fees (up to \$4,000) for approved projects and was a significant source of support for some of the research groups. This program’s pause in June 2023 may have contributed to a reduction in the flow of new lab users to the QNFCF. One of the factors that supported the increase in the number of PIs relative to the users, may have been the commissioning of the JEOL S/TEM system in early 2023. This system had been commissioned late in the 2023 fiscal year and began to see significant use in the 2024 fiscal year. The JEOL S/TEM enables research from a broader range of researchers than the existing QNFCF toolset, contributing to the growth in the number of PIs. At the same time, the usage on this instrument is split relatively evenly between operator service and end user training, and there is therefore less demand for user training on this instrument relative to the existing QNFCF toolset. This factor could have also contributed to the decrease in the number of users during the 2024 fiscal year.

4. EQUIPMENT USE AND EQUIPMENT REVENUE TRENDS

The QNFCF’s mandate is to provide a world-class nanofabrication and characterization facility to our stakeholders in the University of Waterloo community. The annual volume of equipment usage is a useful quantification that demonstrates the impact of the QNFCF on the University of Waterloo community. To measure the use of the QNFCF equipment, we rely on our lab management software which can measure almost every user interaction with a piece of equipment. It is important to note that the QNFCF’s lab management software features both equipment reservation tracking and equipment use tracking. The metrics in this report are

based exclusively on the equipment use data that measures the volume of interactions with our toolset and are not based on the equipment reservations that tend to be higher due to the inefficiencies inherent in equipment scheduling.

As previously mentioned in the operational highlights section of this document, the QNFCF laboratories transitioned from the Badger lab management system to the NEMO lab management software at the end of the fiscal year. The 2024 fiscal year is, therefore, the final year that the equipment use and other metrics will be tracked through the Badger system. The lab management functions will begin to be administered through the NEMO system in the beginning of the 2025 fiscal year. The QNFCF's instance of NEMO has been specifically configured to mimic the measurement methodologies of the Badger system, to maintain our ability to compare the year-over-year datasets.

A figure representing the number of equipment use hours that have been invoiced per fiscal year is included below. The 2023/24 year represents a new record for the QNFCF, surpassing the previous years. The volume of equipment use has increased by 20% compared with the 2022/23 year.

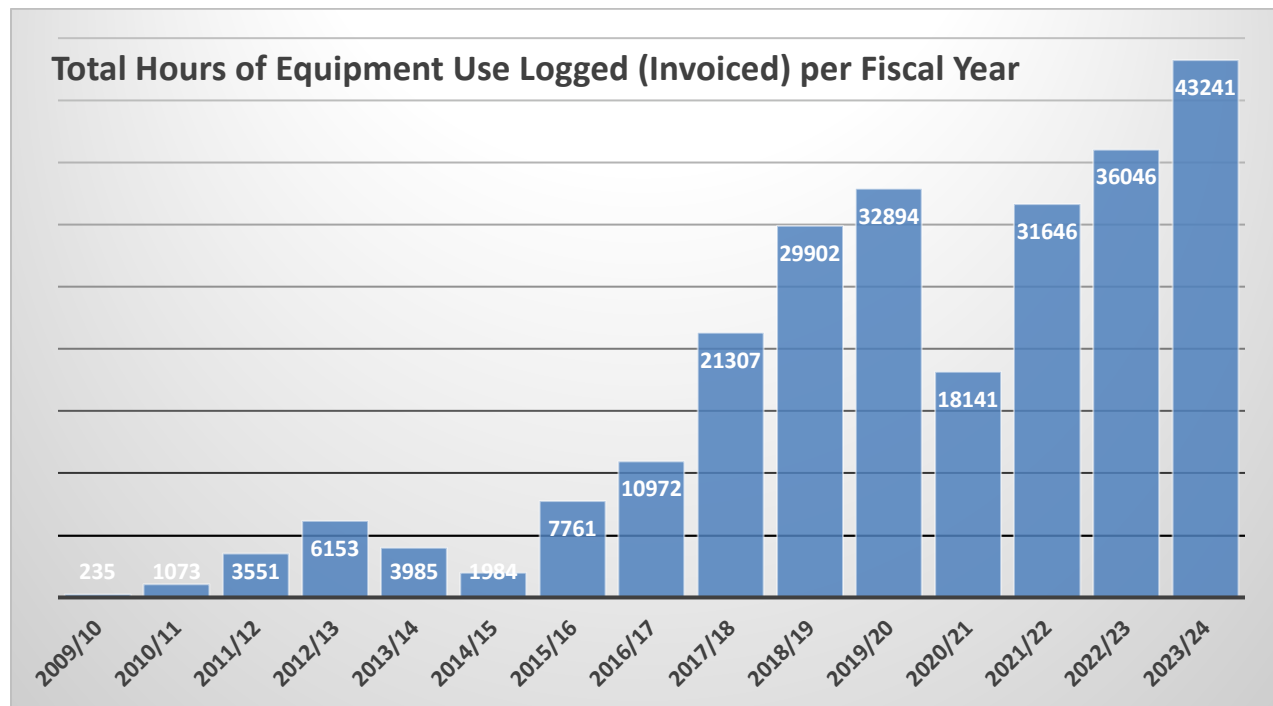


Figure 7: Hours of equipment use logged per fiscal year.

The following pie chart represents the equipment use as a function of the affiliation categories.

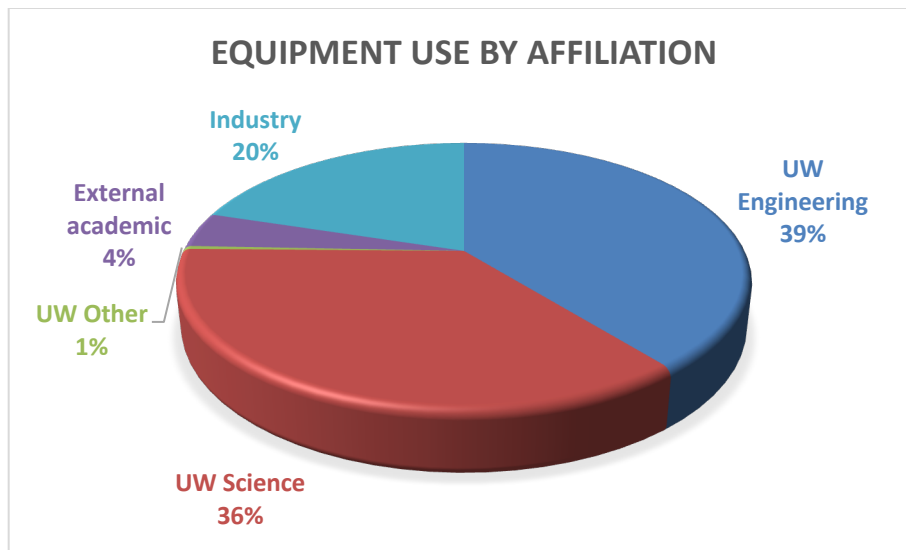


Figure 8: QNFCF equipment use hours grouped by the affiliation categories.

The pie chart of equipment use broken down by affiliation that is included in Figure 8 is similar to the pie chart of the user population broken down by affiliation in Figure 4. This similarity indicates that equipment use does not vary significantly across the demographic groups.

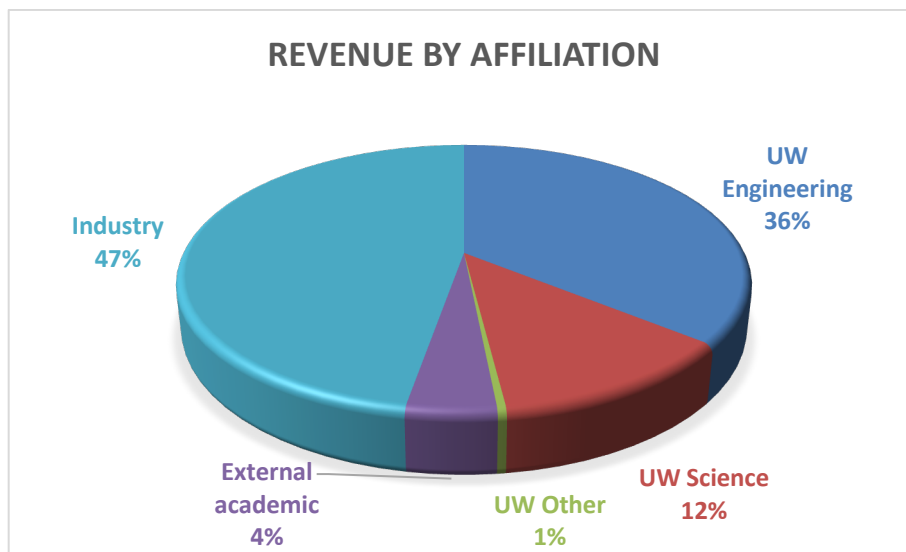


Figure 9: QNFCF invoiced equipment revenue grouped by the affiliation categories.

Figure 9 represents the components of the equipment revenue as a function of the affiliation categories. The pie chart above begins to show stark differences when compared with the pie charts that represent the equipment use in Figure 8 and the user population in Figure 4. It is evident from Figure 9 that the lab revenue from industrial users forms a significant portion of the QNFCF revenue. Industrial equipment fees are three times higher than the partially subsidized fees for the academic user community. A disproportionate contribution to the facility’s revenue is therefore expected from the Industrial groups.

A comparison of the equipment use by affiliation category in Figure 8 with the equipment revenue by affiliation category in Figure 9 demonstrates that the UW Engineering users represented 39% of all lab use, and this lab usage constitutes 36% of the total lab revenues. In contrast, the UW Science users represented 36% of all lab use, and this lab usage constitutes 12% of the total lab revenues. An inference can be drawn from this observation that the UW Engineering users are making use of the more expensive pieces of equipment, whereas the UW Science users are overrepresented on the equipment with a lower hourly cost of operation.

Individual tool trends:

The following figure shows the top 20 pieces of equipment in terms of the hours of use in the 2023/24 fiscal year:

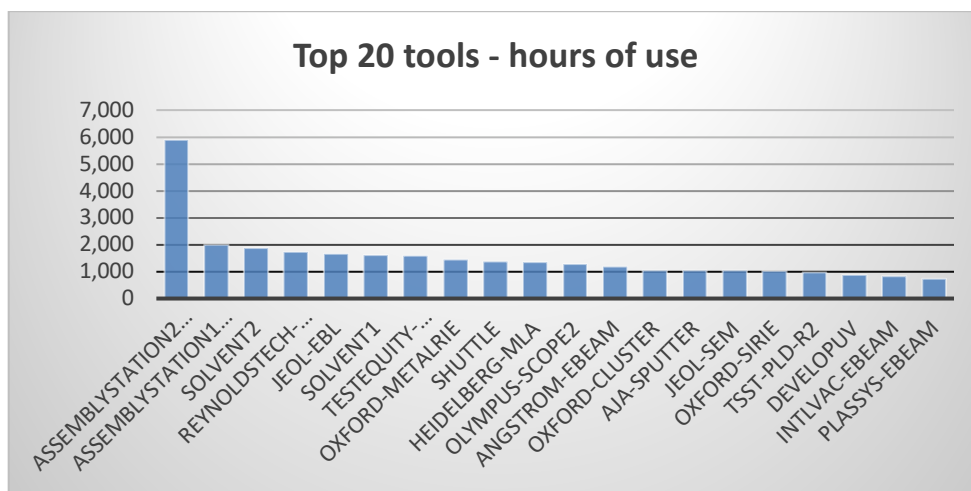


Figure 10: The top 20 tools in the QNFCF, based on the hours of use in the 2023/24 fiscal year.

Figure 10 demonstrates that the most popular tools, in terms of use, are split between the “workhorse” types of tools that might be found in many microelectronics cleanroom labs (wetbench tools, lithography, plasma etch) and unique tools with a narrow, dedicated following, including the clean assembly tools at the RAC1 facility (TESTEQUITY oven, clean assembly workstations 1/2).

The following figure represents the top 20 pieces of equipment in terms of the invoiced revenue in the 2023/24 fiscal year:

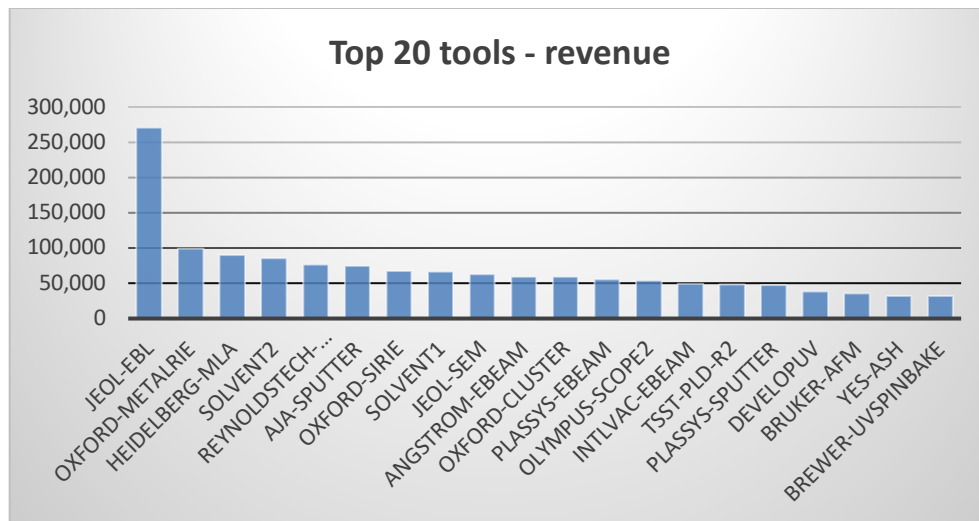


Figure 11: The top 20 tools in the QNFCF based on the invoiced revenue in the 2023/24 fiscal year.

The pieces of equipment with the highest levels of invoiced revenue in the QNFCF are primarily located in the QNC cleanroom and are heavily biased towards the equipment with higher operating costs. Notably, every piece of equipment that carries a service contract from the vendor is represented on this graph. Service agreements are in place for the JEOL Electron Beam Lithography (EBL) and the Scanning Electron Microscope (SEM) equipment, the Oxford Instruments tools and the Heidelberg Maskless Aligner (MLA). The simpler tools on this list, including the solvent and development wetbenches, resist spinners, and optical microscopes, may have lower equipment hardware maintenance costs, although their use factors heavily into the pre- and post-lithography processing of samples. The UV and Electron beam lithography processes rely heavily on costly and proprietary chemicals, the cost of which must be borne by these relatively simple tools and their presence on this list is therefore appropriate.

5. TRAINING

To benefit our stakeholder community at the University of Waterloo, the Quantum Nano Fabrication and Characterization Facility has always had a solid focus on training our lab members to operate the fabrication and characterization equipment themselves. We pride ourselves on providing helpful standard operating procedure manuals (SOPs) for every piece of equipment and conducting one-on-one, hands-on training for almost every piece of equipment in the laboratories. We hope that this focus on training highly qualified personnel will contribute to the success of the University of Waterloo's researchers, as well as the Waterloo technology ecosystem. The following graph represents the equipment training hours that have been logged during the previous fiscal years.

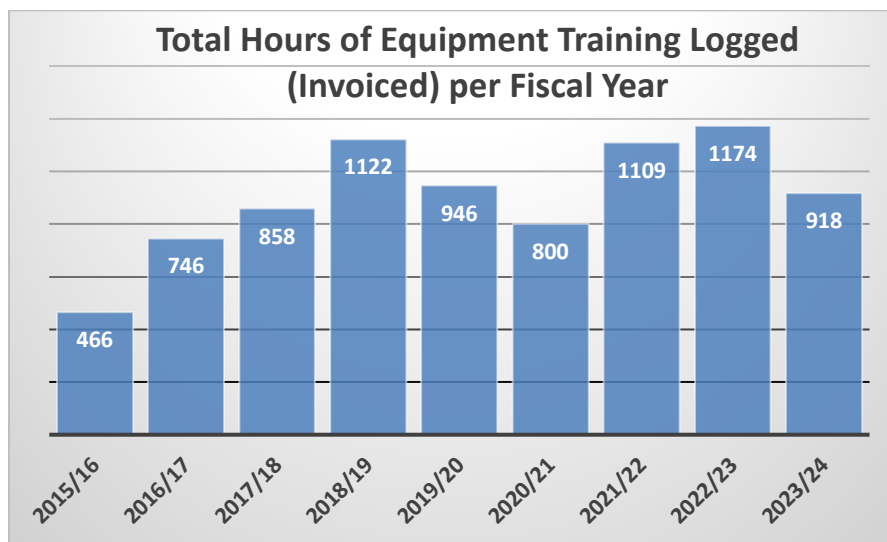
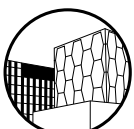


Figure 12: Total hours of equipment training per fiscal year.

The graph of the total equipment training hours shows that the QNFCF reached a pre-pandemic high of training hours in the 2018/19 year, which approximately corresponds with the lab's growth to the current level of technical staffing, thanks to support from the CFREF-TQT program. The 2019/20 and 2020/21 fiscal years were significantly impacted by the pandemic, resulting in reduced levels of training. The number of training hours began to recover in the 2021/22 year and surpassed the 2018/19 pre-pandemic high in the 2022/23 year. A marked decrease in the training hours logged occurred in the 2023/24 year, falling from 1,174 hours in the previous year to 918 hours in the current year. The reduction of the training hours is consistent with the reduction in the volume of users that have interacted with the QNFCF this year.

On a tool-by-tool basis, the following tools had the highest amount of training hours that had been logged during the 2023/24 year:



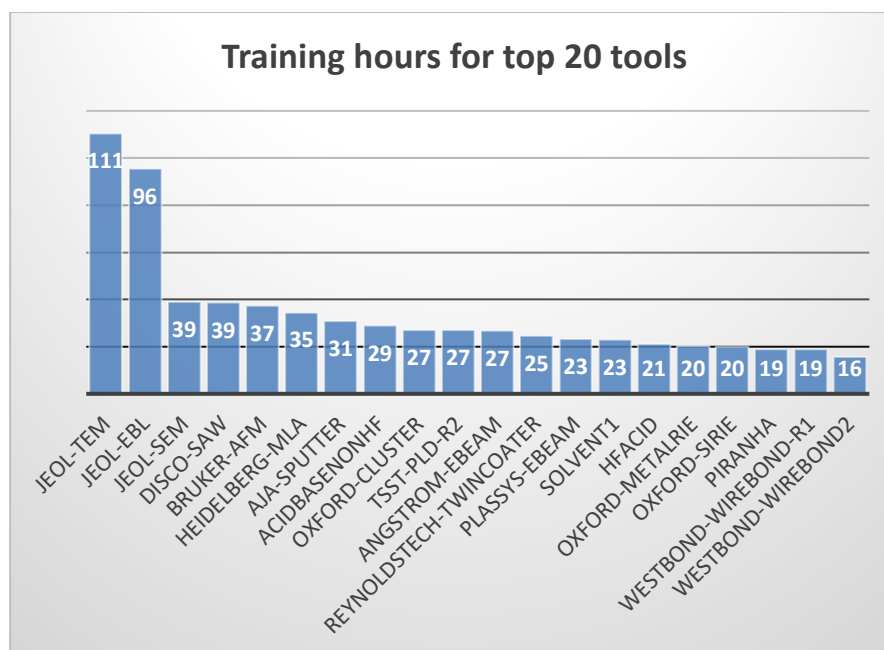


Figure 13: Top 20 tools for the training hours that had been logged in the 2023/24 year.

The equipment on this list extends across a wide spectrum of tools; from simple, widely used tools like the chemical workstations to more specialized tools such as the JEOL electron beam lithography system. It is important to note that several of the highly specialized tools will require multiple training sessions for a prospective user to be qualified to operate the equipment (the JEOL-TEM, JEOL-EBL, HEIDELBERG-MLA, JEOL-SEM and PLASSYS-Ebeam) and this increases the tool’s relative position on the list.

A notable new inclusion in Figure 13 is the appearance of the new JEOL F200 S/TEM system in the 2023/24 year, which registered the highest number of training hours, despite being available for use solely during the second half of the year. The volume of training delivered on this system bodes well for its potential to positively impact the University of Waterloo community in the future.

6. FINANCIAL SUMMARY

For more than 10 years, the Quantum-Nano Fabrication and Characterization Facility (QNFCF) has published a financial summary to report the laboratory expenses, user fee revenues and the financial support that has been received from various sources. An updated summary for the 2023/24 fiscal year is included below:

	2019	2020	2021	2022	2023	2024
Salaries	\$ 1,512,080	\$ 1,625,255	\$ 1,681,851	\$ 1,690,106	\$ 1,360,802	\$ 1,441,602
Supplies, Maintenance & Repairs	\$ 1,279,675	\$ 1,254,116	\$ 1,034,485	\$ 1,082,626	\$ 1,307,433	\$ 1,545,732
Total Expenses	\$ 2,791,755	\$ 2,879,371	\$ 2,716,336	\$ 2,772,732	\$ 2,668,235	\$ 2,987,334
User fees	\$ 1,323,489	\$ 1,763,769	\$ 877,024	\$ 1,320,204	\$ 1,522,381	\$ 2,060,129
Funds from CFREF-TQT	\$ 358,602	\$ 694,699	\$ 605,646	\$ 589,698	\$ 769,324	\$ 829,005
Funds from IQC	\$ 776,187	\$ 257,177	\$ 259,412	\$ 321,377	\$ -	\$ -
Funds from CFI-IOF	\$ 638,038	\$ 694,187	\$ 661,320	\$ 312,465	\$ -	\$ -
Ongoing operating budget - Nitrogen	\$ 140,194	\$ 140,194	\$ 142,998	\$ 145,858	\$ 122,474	\$ 93,873
Ongoing operating budget - Salaries	\$ 221,205	\$ 178,103	\$ 181,271	\$ 183,814	\$ 235,037	\$ 292,655
Total Revenue	\$ 3,457,716	\$ 3,728,130	\$ 2,727,671	\$ 2,873,416	\$ 2,649,216	\$ 3,275,663
Net Cash Flow	\$ 665,961	\$ 848,759	\$ 11,335	\$ 100,684	\$ (19,020)	\$ 288,328
% of contributions						
User fees	38%	47%	32%	46%	57%	63%
Funds from CFREF-TQT	10%	19%	22%	21%	29%	25%
Funds from IQC	22%	7%	10%	11%	0%	0%
Funds from CFI-IOF	18%	19%	24%	11%	0%	0%
Ongoing operating budget - Nitrogen	4%	4%	5%	5%	5%	3%
Ongoing operating budget - Salaries	6%	5%	7%	6%	9%	9%

Figure 14: Annual financial summary of the QNFCF laboratories.

During the 2023/24 fiscal year, the QNFCF operating *Salaries* expenses increased by 6% and the *Supplies, Maintenance & Repairs* expenses increased by 18%. The most significant factors contributing to the increase in the salaries expenses for the 2023/24 year were driven by the addition of one FTE staff member (the QNC Facility Technician), the hiring of a co-op student, and the annual salary increases. The net increase was partially offset by favourable payroll costs resulting from two positions that had been vacant for a portion of the year. The increases in the *Supplies, Maintenance & Repairs* costs were primarily attributable to the increased use of the lab (the invoiced equipment hours have increased by 20%). The remainder of the increase in the *Supplies, Maintenance & Repairs* expenses can be anecdotally attributed to inflation related increases in the cost of various cleanroom supplies and services and to the increased maintenance demands of ageing equipment. Overall, the total costs of the QNFCF operations in the 2023/24 fiscal year were aligned with the rolling average over the past three years and with the operating costs from the previous year (2022/23). The year-over-year increase in the operating costs has been commensurate with the increase in the revenues and the activities throughout the facilities.

The *User Fees* that were invoiced by the QNFCF have increased and the total revenues have grown by 24% compared with the prior year and are aligned with the increased equipment usage in the labs (the invoiced equipment hours were up by 20%). The QNFCF's *User Fee* revenue for the 2023/24 fiscal year reached the highest level in the lab's history. The 2023/24 *User Fee*



revenue represented approximately 63% of the *Total Contributions* for the facility, which is a new record for this performance metric. The *User Fees* as a percentage of the *Total Contributions* is well above the 5-year rolling average of 49%.

A comparison of the QNFCF's *User Fee* revenue to the *Total Expenses* demonstrates that the revenue has grown to offset 69% of the *Total Expenses* in the 2023/24 fiscal year. The gap between the QNFCF's *User Fee* revenue and the laboratory expenses has historically been bridged by robust support from several partners across the University of Waterloo, effectively subsidizing the costs of operations for the benefit of the community. Significant ongoing sources of support for the QNFCF have been received from the Canada First Research Excellence Fund – Transformative Quantum Technologies program, the Office of the Vice-President, Academic and Provost, the Office of the Vice-President, Research and International, and the Institute for Quantum Computing.

Finally, it should be noted that the financial support discussed in this section was limited to the support for the ongoing lab operations. As such, we have not included the financial contributions that have funded the acquisition of new tools and equipment, although the constant renewal of lab equipment is vital to ensuring that the QNFCF continues to be relevant and beneficial for the University of Waterloo community.

7. CONCLUSIONS AND KEY TAKE AWAYS

The 2023/24 year was an eventful year for the Quantum-Nano Fabrication and Characterization Facility, with the new equipment acquisitions and installations and the continued improvements in most of the metrics that are recorded by the lab. This year, the QNFCF set new records for the number of **unique PIs**, as well as **volume of invoiced hours of equipment usage**. A point form summary of the performance metrics is included below:

- Lab user population (unique users per year) decreased by 7% to 219.
- PI population (the number of different research groups) increased by 9 to 87.
- Logged equipment hours increased to over 43,000 hours, which is a **new all-time high**.
- The cost of operations has increased by 12% relative to the prior year and is aligned with the higher revenues and usage activity experienced throughout the year. The higher costs are aligned with the 3-year rolling average.
- The user fee revenue for the QNFCF increased by 35% to \$2.1M CAD, representing 63% of the total revenue. This is a **new all-time high**, in terms of the percentage of the total contributions.

Acknowledgements:

The Quantum-Nano Fabrication and Characterization Facility gratefully acknowledges contributions to our operations from the following partners:

- The Canada First Research Excellence Fund – Transformative Quantum Technologies program
- The University of Waterloo Office of the Vice-President, Academic and Provost
- The University of Waterloo Office of the Vice-President, Research and International
- The Institute for Quantum Computing
- The Canada Foundation for Innovation, projects 39548 and 38914