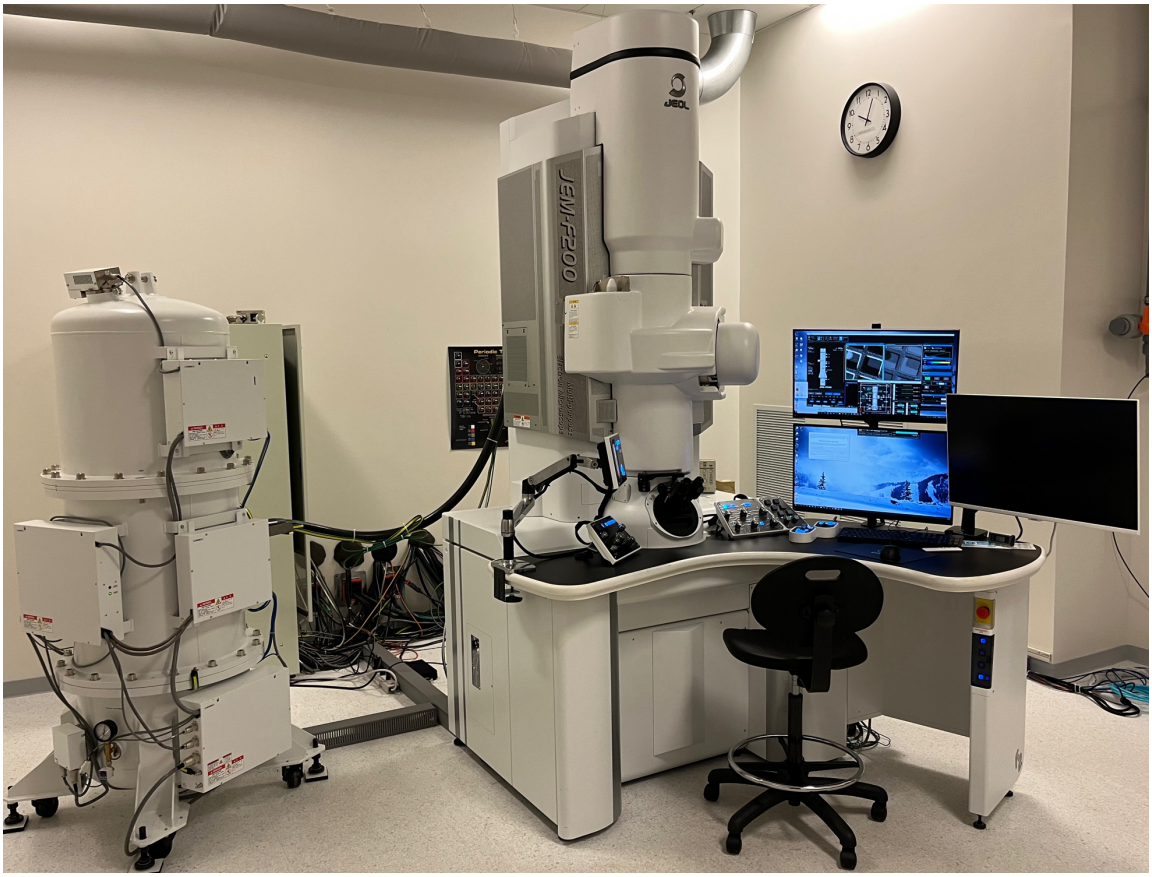
QNFCF
Quantum Nano Fabrication
and Characterization Facility

Quantum Nano Fabrication and Characterization Facility
Core Scientific Research Platform
Annual update: Fiscal Year 2023 – (May 2022 – April 2023)



Picture of newly commissioned JEOL F200 S/TEM system – March 2023

Nathan Nelson-Fitzpatrick
Director, Quantum-Nano Fabrication and Characterization Facility

1. INTRODUCTION

This document is intended as a brief summary of operational milestones and data for the Quantum-Nano Fabrication and Characterization Facility for the fiscal year 2022/23. For more background information about 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 year 2022/23 include:

- **June 2022**: QNFCF received the initial shipments for the new JEOL JEM-F200 Transmission Electron Microscope (TEM). This microscope is a state-of-the-art analytical TEM equipped with both EELS and EDS elemental spectroscopy detectors. Installation activities associated with this microscope would last through most of 2022/23 with final acceptance taking place on March 16th 2023.
- **August 2022**: The QNFCF's founding director, Vito Logiudice retired, and Nathan Nelson-Fitzpatrick was named the new director.
- **August 2022**: A new JEOL IT-510LV SEM was installed in the RAC 2003 "inert atmosphere" lab. This SEM is equipped with an NPGS pattern generator. The system is intended to be integrated in a multi-glovebox assembly to enable electron lithography in an inert environment. This project is ongoing.
- **Fall 2022/Winter 2023**: The QNFCF participated in several Quantum Colaboratory activities including a visit to the University of Waterloo from staff at the UBC and Sherbrooke nodes of the Quantum Colaboratory in November 2022. Additionally, a workshop on the growth of superconducting thin films was held in December 2022 and the first general user meeting of the Quantum Colaboratory was held in January 2023.
- **March 2023**: A contest was held soliciting designs for a new logo for the facility.
- **March 2023**: The QNFCF's SUSS SB6 wafer bonder was commissioned and released to the user community. The wafer bonder had been successfully installed by technicians from SUSS in November 2022.
- **March 2023:** VueReal, a member of our community received $10.5 million dollars in federal and provincial support to scale up their MicroLED manufacturing. At the announcement VueReal mentioned how the University of Waterloo and in particular the QNFCF had been essential in the growth of their business.

3. LAB DEMOGRAPHICS AND TRENDS

This section summarizes the population and makeup of QNFCF community lab members. The population of lab members in this discussion refers to the number of unique users who register *at least one* instance of equipment use within the fiscal year. For fiscal year 2022/23, QNFCF registered 236 unique lab users, an approximately 6% increase from fiscal year 2021/22. The graph below shows this trend over time.

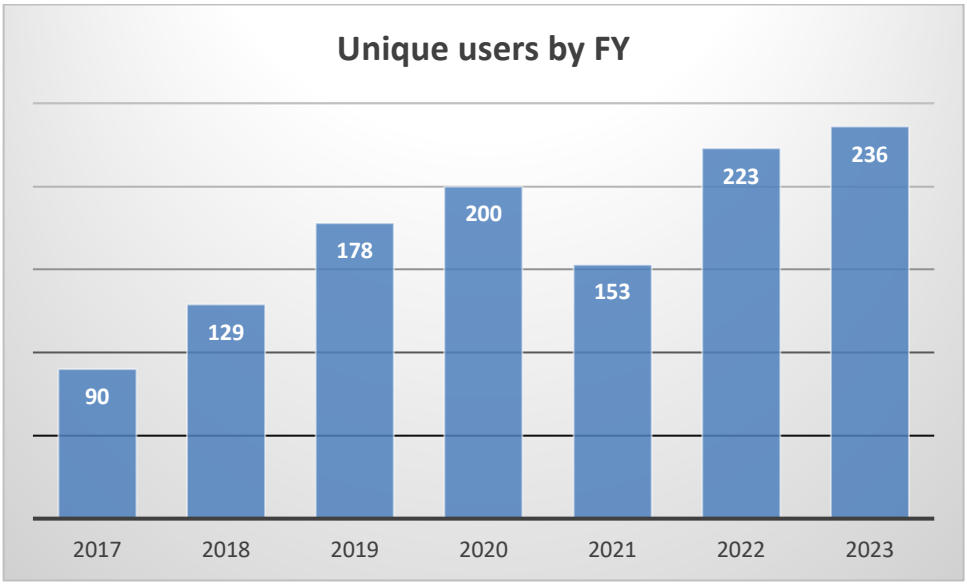


Figure 1: Number of unique QNFCF lab users per year

If we investigate the data for fiscal year 2022/23, the QNFCF user population can be broken down by affiliation. We typically group lab users by faculty if within the University of Waterloo or into the categories of "*external academic*" and "*external industrial*" users. The following pie chart provides an overview of QNFCF's user population by affiliation:

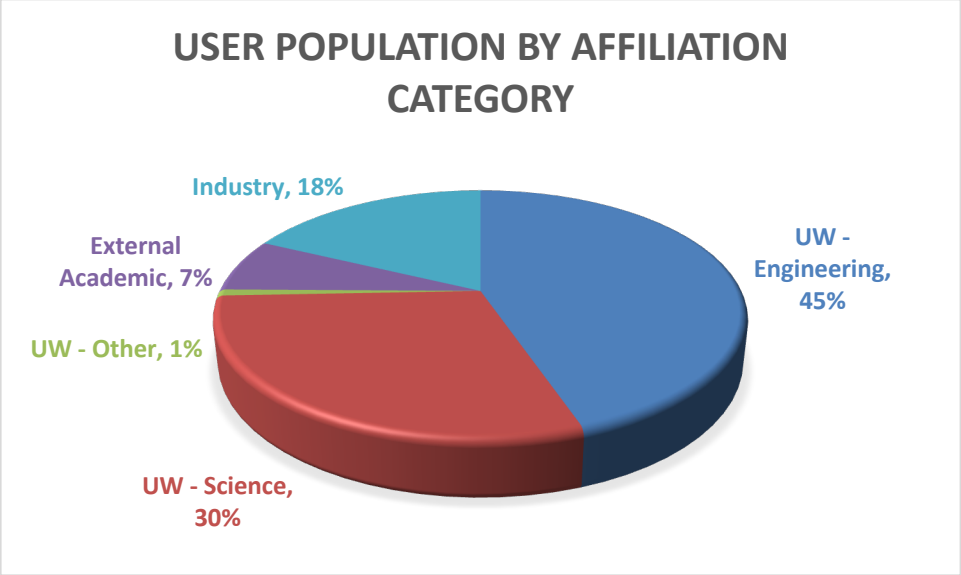


Figure 2: Pie chart of users grouped into affiliation categories

Within the QNFCF all user accounts are tied to an account holder, the principal investigator (PI). The population of principal investigators is relatively stable, having decreased by one in fiscal year 2022/23 to 78 PIs. A graph of this population over time is provided below:

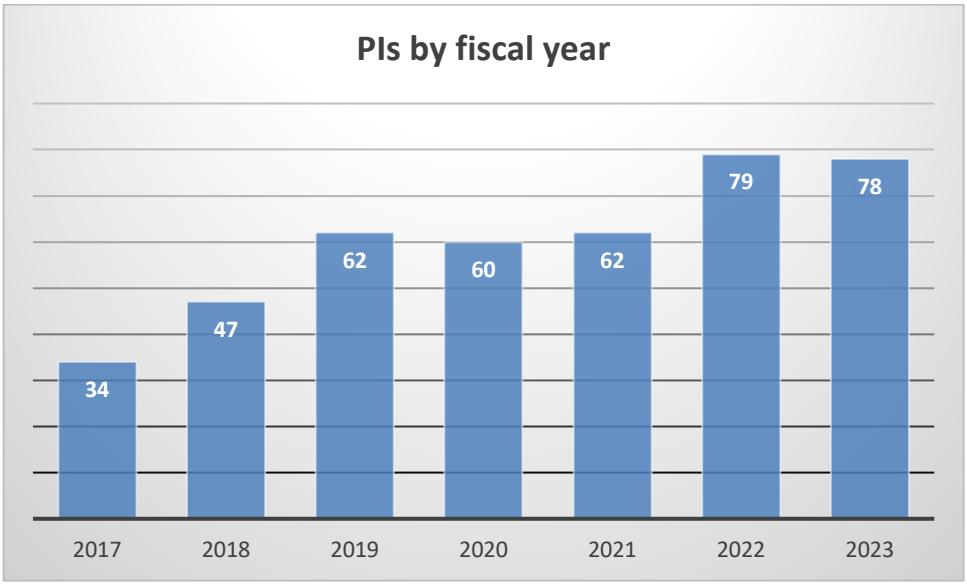


Figure 3: Number of unique PIs per year

If we investigate the data for fiscal year 2023, we can apply the same affiliation categories to PIs as we did previously to users. The following pie chart provides an overview of QNFCF's PI population by affiliation:

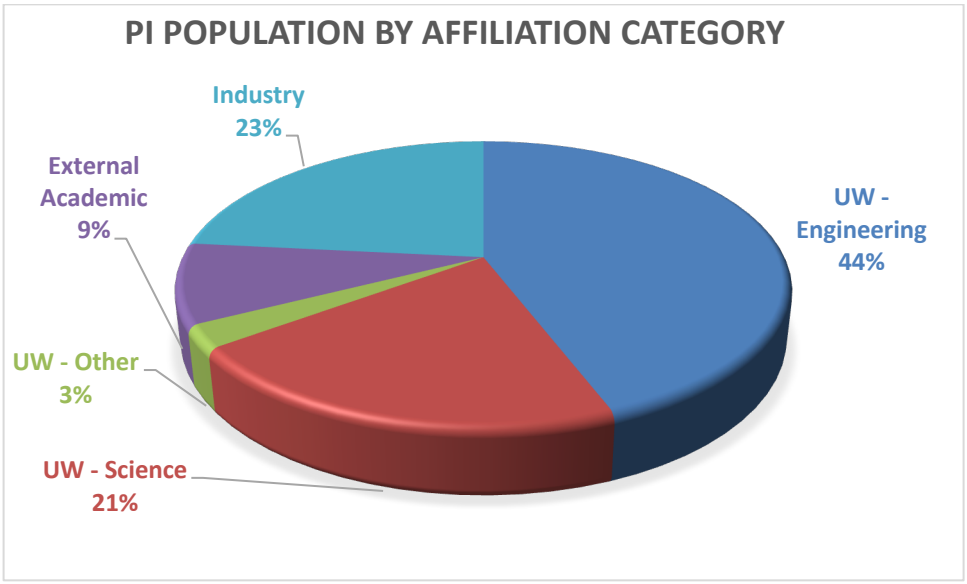


Figure 4: PIs grouped by affiliation categories.

Comparing the pie charts for user and PI populations we can note that "*UW – Science*" groups tend to have a higher-than-average number of users per PI whereas "*Industrial*" and "*External academic*" groups tend to have fewer users per PI.

4. EQUIPMENT USE TRENDS

The mandate of the QNFCF is to provide a world-class nanofabrication and characterization facility to our stakeholders in the University of Waterloo community. A highly useful quantification of QNFCF's impact to the University of Waterloo community is the annual volume of equipment use. To measure the use of QNFCF equipment we rely on our Badger lab management software which is enabled to measure every user interaction with a piece of equipment. It's important to note that Badger features both equipment reservation tracking and equipment use tracking. For this report we worked exclusively with the equipment use data since it is a true measure of the volume of interactions with our toolset.

Below is a figure showing the number of hours of equipment use which has been invoiced per fiscal year. You'll note that 2022/23 represents a new high-water mark for QNFCF with just over 36000 hours invoiced. This is the first year where we have surpassed our pre-COVID high, set in fiscal year 2019/20. This volume of equipment use is a 13.9% increase over the previous fiscal year (2021/22).

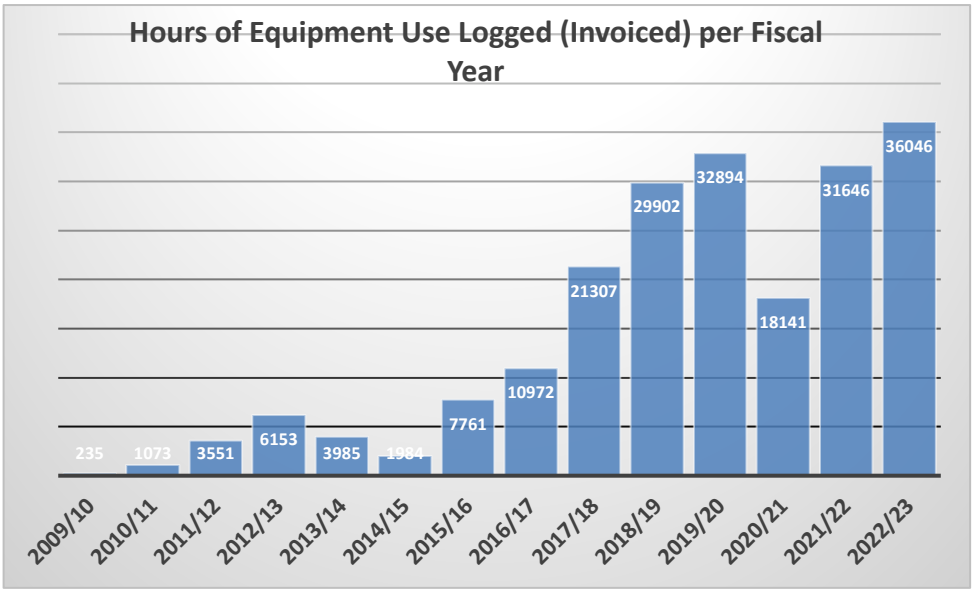


Figure 5: Hours of equipment use logged per fiscal year.

The following pie chart breaks down equipment use as a function of affiliation.

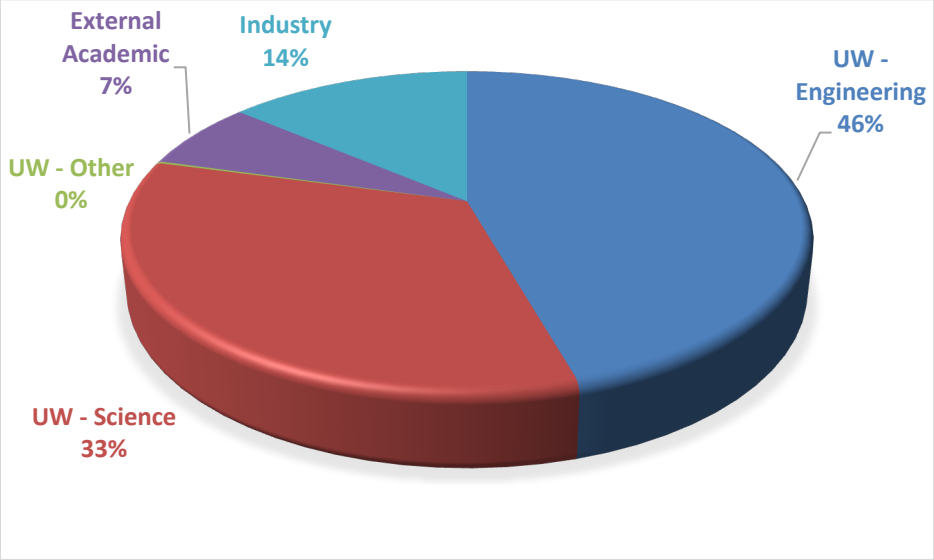


Figure 6: QNFCF equipment hours broken down by affiliation categories.

The pie chart of equipment use broken down by affiliation (figure 6) is remarkably similar to the pie chart of user population broken down by affiliation (figure 2). It's fair to state that equipment use "intensity" does not vary meaningfully across demographic groups except for the "UW – Other" category. The "UW – Other" category captures work for many special projects such as IQC's USEQIP summer school. Such projects are typically low in volume and as a result this category is rounded down to zero in figure 6.

The following figure is a chart showing the top 20 pieces of equipment in terms of equipment use in fiscal year 2022/23:

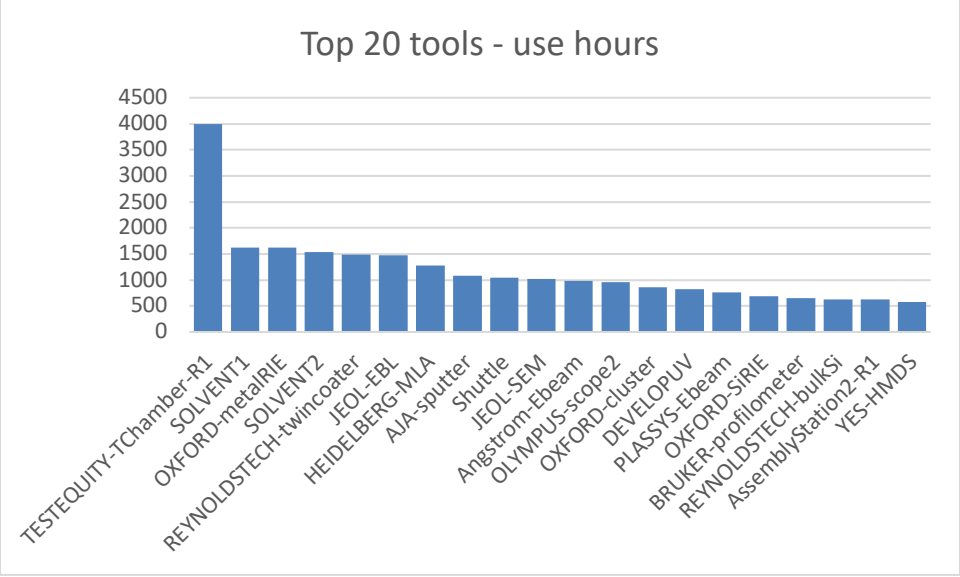


Figure 7: The top 20 tools in QNFCF in terms of hours of use in fiscal year 2022/23

Figure 7 shows that the most popular tools in terms of use are largely "workhorse" type that might be found in many microelectronics cleanroom labs. The exceptions to this are the lab

shuttle, the clean assembly tools at RAC1 (TESTEQUITY oven, clean assembly workstation 2) and the Plassys superconducting Al deposition tool all of which tend to have a handful of qualified users who may use the equipment very intensively.

The following figure is a chart showing the top 20 pieces of equipment in terms of revenue invoiced in fiscal year 2022/23:

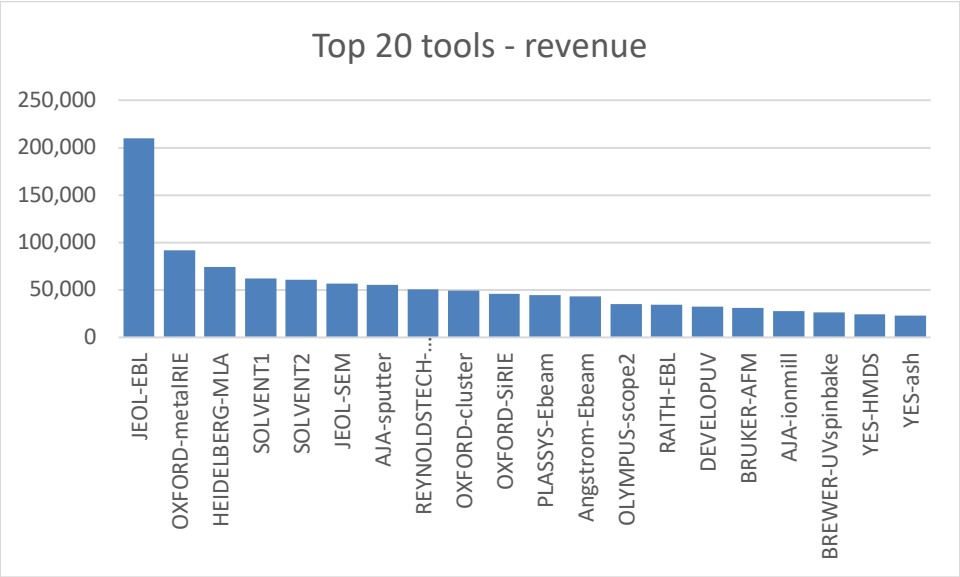


Figure 1: The top 20 tools in QNFCF in terms of invoiced revenue in fiscal year 2022/23

The breakdown of high revenue equipment in QNFCF shows mainly equipment in the QNC cleanroom and is heavily biased towards equipment that has a very high cost of operations. Notably, every piece of equipment that carries a service contract from the vendor (JEOL EBL and SEM tools, Oxford Instruments tools and Heidelberg MLA) is represented on this graph. The simpler tools on this list (Solvent and development wetbenches, resist spinners, optical microscopes) may have low costs to maintain in terms of equipment hardware but their use factors heavily into pre- and post-lithography processing of samples. UV and Electron beam lithography processes rely on expensive and proprietary chemicals the cost of which must be borne by these relatively simpler tools so their presence on this list is appropriate.

5. TRAINING

To further benefit our stakeholders at the University of Waterloo, the Quantum-Nano Fabrication and Characterization Facility has always had a strong focus on training our lab members to operate fabrication and characterization equipment themselves. We pride ourselves on generating helpful standard operating procedure manuals (SOPs) for every piece of equipment and conducting one-on-one, hands-on training on almost every piece of equipment in our labs. We hope that this focus on training of highly qualified personnel will contribute to the success of the University of Waterloo's researchers as well as the success of the Waterloo technology ecosystem. The following graph shows a breakdown of logged equipment training hours broken down by fiscal year.

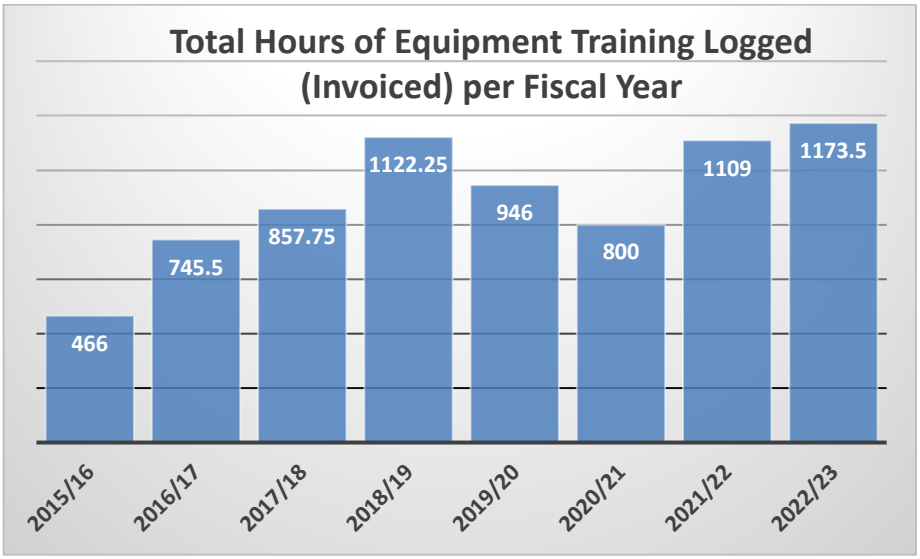


Figure 9: Total hours of equipment training per fiscal year

The graph of total equipment training hours shows that QNFCF reached a pre-COVID high of training hours in 2018/19 which corresponds roughly with when we reached the current level of technical staffing thanks to support from the CFREF-TQT program. Fiscal years 2019/20 and 2020/21 were impacted by COVID and show a reduced level of training. Training recovered in 2021/22 and grown slightly in 2022/23 to the new record level of 1173 hours.

If we look at training hours on a tool-by-tool basis we see that the following tools had the highest amount of training logged in 2022/23.

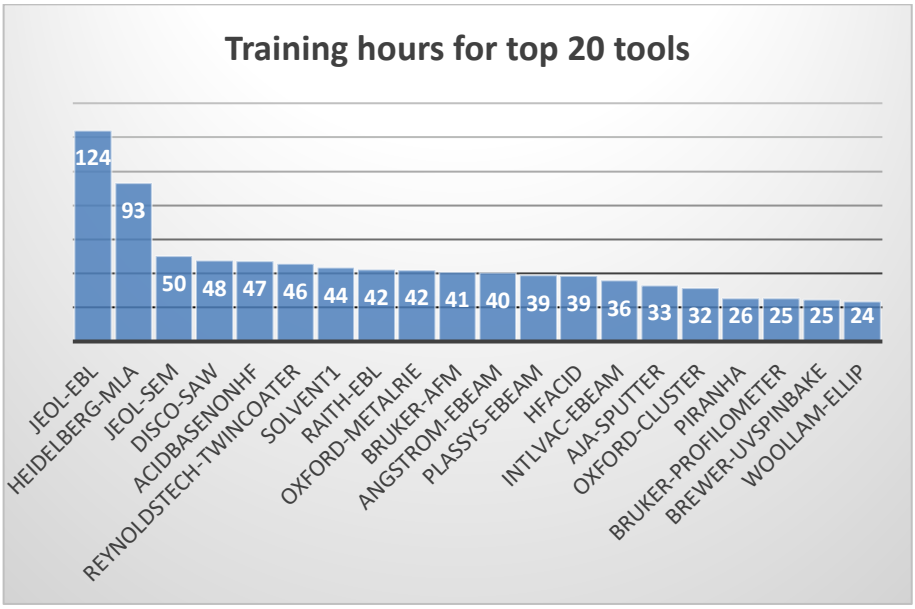


Figure 10: Top 20 tools for logged training in 2022/23

Equipment on this list runs the gamut from very simple and widely used tools like our BRUKER-profilometer for measuring step heights to very specialized tools like our PLASSYS-Ebeam Al Josephson junction deposition tool which has a limited group of highly dedicated users. It's important to note that many highly specialized tools require multiple training sessions for a prospective user to be qualified to operate the equipment (JEOL-EBL, HEIDELBERG-MLA, JEOL-SEM, RAITH-EBL, PLASSYS-Ebeam) and that this increases their relative position on this list.

6. FINANCIAL SUMMARY

For more than 10 years, the Quantum-Nano Fabrication and Characterization Facility (QNFCF) has published a financial summary to report lab expenses and revenues through user fees, an updated table with fiscal year 2022/23 data is below:

	2019	2020	2021	2022	2023
Salaries	$ 1,512,080	$ 1,625,255	$ 1,681,851	$ 1,690,106	$ 1,360,802
Supplies, Maintenance & Repairs	$ 1,279,675	$ 1,254,116	$ 1,034,485	$ 1,082,626	$ 1,307,433
Total Expenses	$ 2,791,755	$ 2,879,371	$ 2,716,336	$ 2,772,732	$ 2,668,235
User fees	$ 1,323,489	$ 1,763,769	$ 877,024	$ 1,320,204	$ 1,522,381
Funds from CFREF-TQT	$ 358,602	$ 694,699	$ 605,646	$ 589,698	$ 769,324
Funds from IQC	$ 776,187	$ 257,177	$ 259,412	$ 321,377	$ 19,020
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
Ongoing operating budget - Salaries	$ 221,205	$ 178,103	$ 181,271	$ 183,814	$ 235,037
Total Revenue	$ 3,457,716	$ 3,728,130	$ 2,727,671	$ 2,873,416	$ 2,668,235
Net Cash Flow	$ 665,961	$ 848,759	$ 11,335	$ 100,684	$ -
% of contributions					
User fees	38%	47%	32%	46%	57%
Funds from CFREF-TQT	10%	19%	22%	21%	29%
Funds from IQC	22%	7%	10%	11%	1%
Funds from CFI-IOF	18%	19%	24%	11%	0%
Ongoing operating budget - Nitrogen	4%	4%	5%	5%	5%
Ongoing operating budget - Salaries	6%	5%	7%	6%	9%

Figure 11: Financial summary table for QNFCF labs

For fiscal year 2022/23 the QNFCF operation saw a notable decrease in "*Salaries & Benefits*" expenses (down 24%) which was balanced against increases in "*Supplies, Maintenance & Repair*" expenses (up 21%). The most significant contributors to the decrease in "*Salaries & Benefits*" expenses for 2022/23 are the reduction in cost due to vacancies in the QNFCF staff following the retirement of Vito Logiudice as well as a reduction in co-op hiring post-COVID. Much of the increase in "*Supplies, Maintenance & Repair*" can be attributed to increased use of the lab (invoiced hours were up 14%). The rest of the increase in "*Supplies, Maintenance & Repair*" expenses can be attributed anecdotally to inflation related increases in the cost of various cleanroom supplies and services and to increased maintenance demands of ageing equipment. Overall, the total cost of operations for the QNFCF in fiscal year 2022/23 is in line with the running average for the past three years and in line with the cost of operations for the previous year (2021/22).

User fees invoiced by the QNFCF increased (revenue up 15%) in line with the increased equipment use in the labs (invoiced hours up 14%). QNFCF's revenue for fiscal year 2022/23 was the second highest in the lab's history behind fiscal year 2019/20. The 2022/23 revenue represented approximately 57% of the cost to operate the lab which is a new record for this performance metric. This percentage of operational cost is also well above the 5-year rolling average of 44%.

The gap between QNFCF's user fee revenue and our lab expenses has historically been bridged by robust support from many partners across the University of Waterloo, effectively subsidizing the cost of the operation to the benefit of our community. Major ongoing sources of support for the QNFCF come from the Canada First Research Excellence Fund – Transformative Quantum Technologies program, the Office of the Vice-President, Academic and Provost, the Office of Vice-President, Research and International, and the Institute for Quantum Computing.

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

7. CONCLUSIONS AND KEY TAKE AWAYS

The Quantum-Nano Fabrication and Characterization Facility's fiscal year 2022/23 was an eventful year with new equipment acquisitions and installs as well as continued improvement in most metrics recorded by the lab. This year QNFCF set new records for the number of **unique lab users**, as well as **volume of invoiced hours on equipment** and the number of **hours of training delivered** by staff. A point form summary of these metrics of performance follows:

- Lab user population (unique users per year) increased by 6% to 236. This is a **new all-time high**.
- PI population (number of different research groups) decreased by one to 78.
- Logged equipment hours increased 14% to over 36000 hours, which is a **new all-time high**.
- Training hours delivered by QNFCF staff increased by 6% to 1173 hours. This is a **new all time high**.
- Cost of operations is similar to last year (down 2.5% from 2021/22) and in line with a 3-year running average for this figure.
- Revenue for QNFCF was up 15% to $1.52M CAD, representing a recovery of 57% of the total operational cost for the lab. In terms of percentage of cost recovered this is a **new all time high.**

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 Vice-President, Research and International
- The Institute for Quantum Computing
- The Canada Foundation for Innovation, projects 39548 and 38914