QNFCF

Quantum Nano Fabrication
and Characterization Facility

Quantum Nano Fabrication and Characterization Facility
Core Scientific Research Platform
Annual update: Fiscal Year 2025 – (May 2024 – April 2025)

Nicki Shaw leading a tour of the JEOL F200 S/TEM at the Transmission Electron Microscopy Open House (October 2024)

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1. INTRODUCTION

The operational milestones and data for the Quantum-Nano Fabrication and Characterization Facility (QNFCF) for fiscal year 2025 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 (QNFCF) is an ever-evolving resource which changes to meet the needs of our community of lab members. Some operational highlights for the 2024/25 year include:

- **May 2024**: The QNFCF transitioned to our new NEMO lab management software on May 1st 2024. Dr. Greg Holloway led this project, deploying and configuring NEMO to ensure the continuity of user accounts, accounting workflows and the integrity of the lab activity data gathered. NEMO boasts a simpler and more modern user interface, which is more easily accessible on tablet and mobile devices. By hosting NEMO locally, using QNFCF and UWaterloo IST resources, the annual cost of operations has been drastically reduced compared with the cost of Badger, the previous lab management software.
- **June 2024**: An open house event was held to celebrate the opening of the Inert Atmosphere Fabrication Lab. This event was co-presented by the QNFCF and Transformative Quantum Technologies (TQT), with sponsorship from JEOL. More than 60 community members visited the RAC1 facility for lectures and lab tours. The University Relations group reported on the event and the article is included in the link below: https://uwaterloo.ca/news/taking-quantum-community

Figure 1: Photo of Professor Wei Tsen providing a lecture on 2D heterostructure devices at the Inert Atmosphere Fabrication Lab open house.

- **October 2024**: An open house event was held to celebrate the first year of operations for the QNFCF's JEOL F200 S/TEM, this event drew more than 90 attendees. This event was co-presented by the QNFCF and TQT, with sponsorship from JEOL. The event featured lectures from the equipment vendors JEOL and Gatan, as well as from QNFCF team members Dr. Greg Holloway and Nicki Shaw. After the technical sessions, attendees had the opportunity to visit the S/TEM, FIB/SEM and dry sample preparation labs. The University Relations group also published a news article on the S/TEM that coincided with the event:
  https://uwaterloo.ca/news/unlocking-atomic-world-reveals-new-research-possibilities

Figure 2: Dr. Greg Holloway discussing TEM sample preparation using FIB/SEM during the TEM open house.

- **January 2025**: The QNFCF and TQT co-hosted an introductory seminar on physical vapour deposition (PVD) techniques. This seminar was delivered by Dr. Mike Miller from Angstrom Engineering, a local PVD equipment manufacturer. This event drew more than 50 attendees and summarized standard PVD techniques including evaporation and sputtering, and discussed the operational mechanisms, advantages and disadvantages of each of the sub-techniques.

Figure 3: Dr. Mike Miller from Angstrom Engineering delivered an introductory seminar on PVD techniques.

- **April 2025**: The QNFCF and TQT co-hosted a follow-up seminar on physical vapour deposition (PVD) techniques, once again drawing upon Dr. Mike Miller's expertise. Dr. Mike Miller is the Director of Business Development at Angstrom Engineering. This event drew more than 40 participants and covered various topics, including film characterization methods, testing and analytical techniques, and deposition process control. Following the lecture, Dr. Miller and several attendees discussed advanced topics such as sample surface preparation and the integration of ion sources to enable ion-assisted film depositions.

Figure 4: Dr. Mike Miller and Professor Na Young Kim discussed PVD techniques after the follow-up seminar.

During the past year, the QNFCF assumed responsibility for several pieces of existing equipment from the Transformative Quantum Technologies (TQT) group. The list of equipment is included below:

1. AJA Sputter/E-beam deposition tool
2. X-ray diffractometer
3. Omicron UHV Scanning tunneling microscope (STM)
4. Adixen mobile He vacuum leak checker
5. Edwards mobile turbomolecular pump station
6. Janis cryostat

These tools are located in various QNFCF labs within the RAC1 and RAC2 buildings and are available for use by all trained members of the QNFCF community.

In terms of staffing, the following personnel changes occurred in the 2025 fiscal year.

- **Jandira Oliveira** joined the QNFCF as a Facility Microscopist for a 6 month appointment term, from September 2024 to March 2025. Jandira was primarily responsible for conducting training and equipment operator services on the JEOL F200 S/TEM.

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 active users who register *at least one* instance of equipment use within the fiscal year. For the 2025 fiscal year, the QNFCF registered 265 active lab users, reflecting a 21% increase from the previous fiscal year. The graph below represents this trend over time:

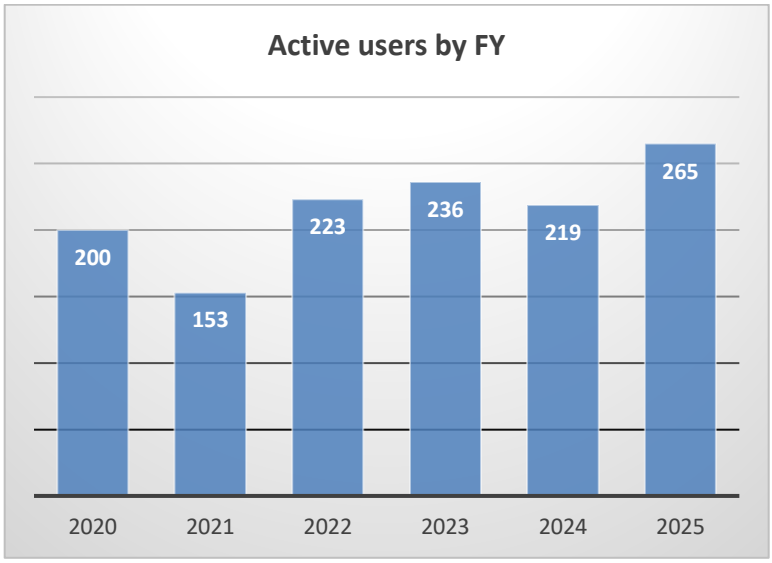

Figure 5: Number of active QNFCF lab users per year.

If we investigate the data for the 2025 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:

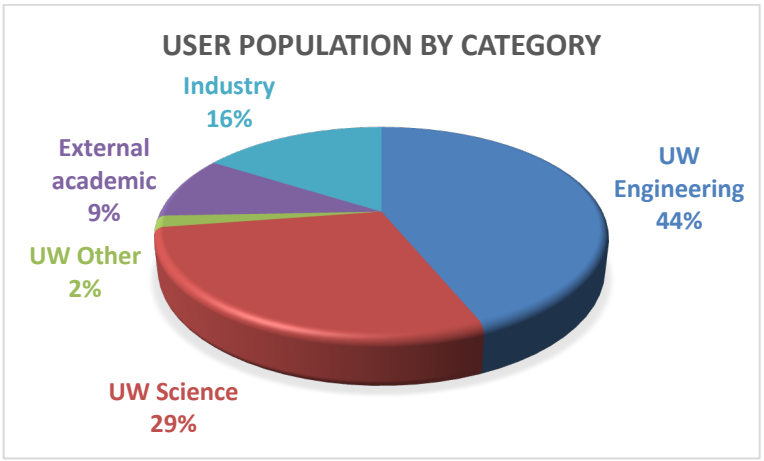

Figure 6: Pie chart of the users grouped into the affiliation categories.

All user accounts within the QNFCF are associated with an account holder, the principal investigator (PI). The population of principal investigators showed a modest increase during the year, from 87 in the previous year to 101 in the current year. A graph of this population over time is included below:

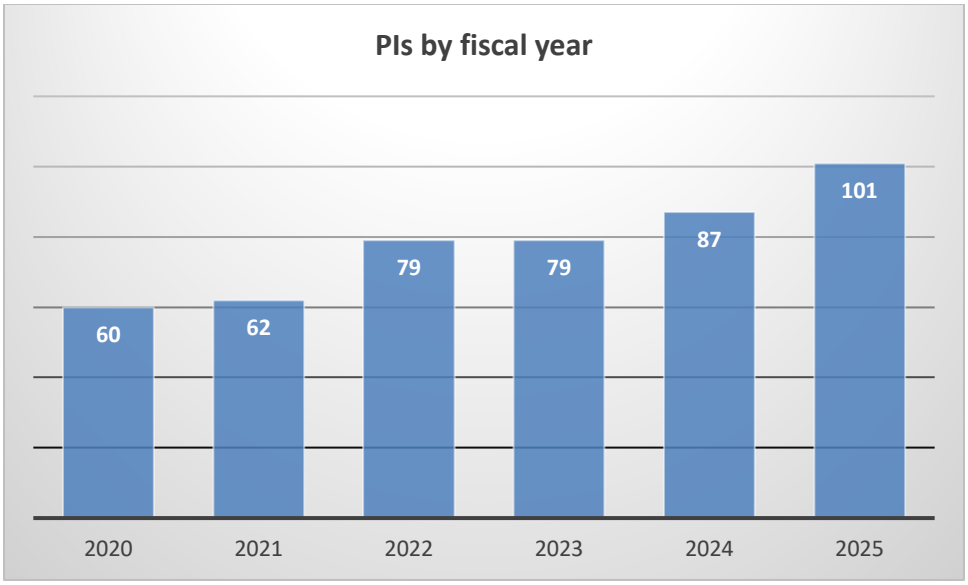

Figure 7: Number of active PIs per year.

If we investigate the data for the 2025 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:

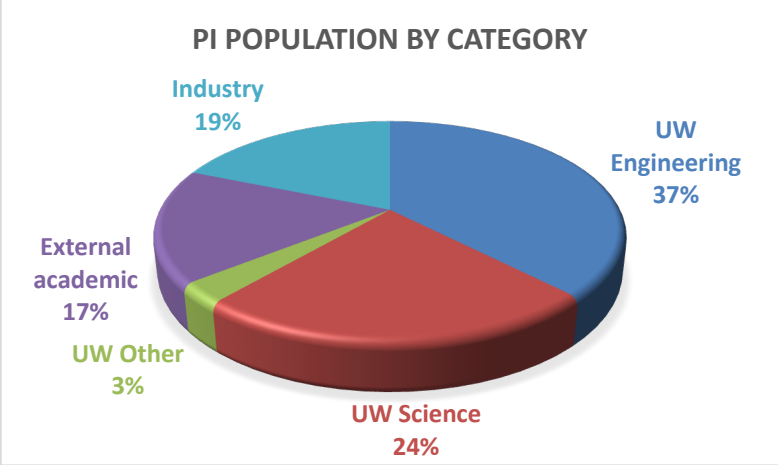

Figure 8: Pie chart of the PIs grouped into the affiliation categories.

Brief comments regarding the QNFCF lab demographics for the 2025 fiscal year:

This year's growth in PI population appears to be attributable to the continued impact of the JEOL F200 S/TEM which was installed in late 2023. This is a continuation of a trend which was highlighted in last year's annual report. The JEOL F200 S/TEM attracts a broad cohort of

researchers who were not previously QNFCF members, and this has increased the number of PIs and users for the year. Within the past year there have been 56 individual users that are associated with 33 PIs, who have accessed the JEOL F200 S/TEM. Anecdotally, the relatively steep learning curve associated with training on this tool has driven many researchers to access it through the staff operator service option. This observation is aligned with our NEMO training records, which indicate that only 27 of the 56 users in 2025 had received training on this instrument. Additionally, staff operator services across the lab have jumped by 229% (from 171 hours to 563 hours) since the installation of the JEOL S/TEM in late 2023. In summary, the JEOL S/TEM has significantly contributed to the increase of the user and PI populations and has also had a dramatic effect on the staff operator service hours.

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 use is a key performance indicator demonstrating the impact of the QNFCF on the University of Waterloo community. To measure the usage of the QNFCF equipment, we rely on our NEMO lab management software. It is important to note that NEMO features both equipment reservation tracking and equipment use tracking. The graphs in this report are based exclusively on the equipment use data that indicate actual activity on our toolset and are not based on the equipment reservations that tend to be higher due to missed appointments or other 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 in the beginning of this fiscal year. Extensive work was undertaken in configuring and testing the NEMO system to ensure that the equipment usage data was measured through the same methodologies that had been employed by the Badger system. We are confident in the integrity of the year-over-year comparisons across these platforms.

A figure representing the number of equipment use hours that have been invoiced per fiscal year is included below. The 2025 fiscal year represents a new record for the QNFCF, surpassing the previous years. The volume of equipment use has increased by 13% compared with the previous year.

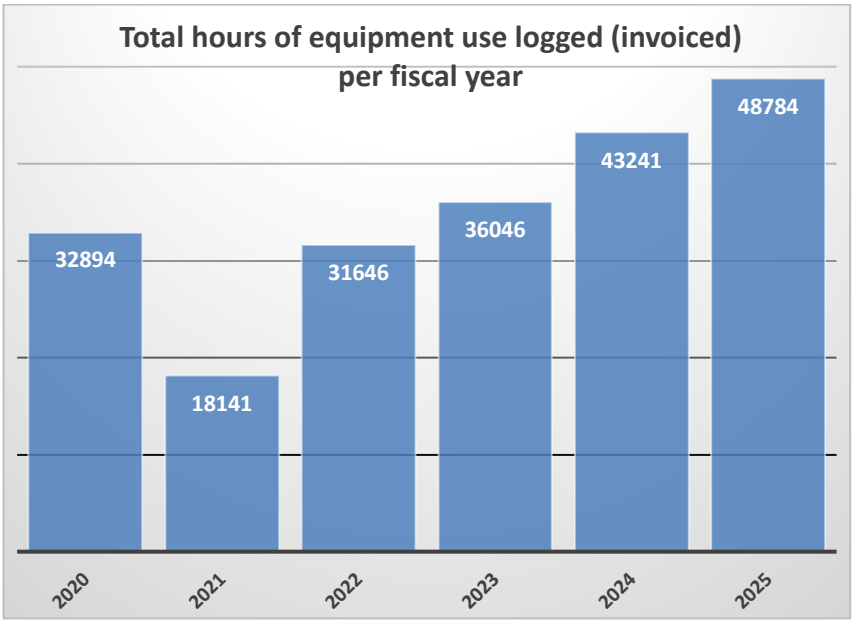

Figure 9: Hours of equipment use logged per fiscal year.

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

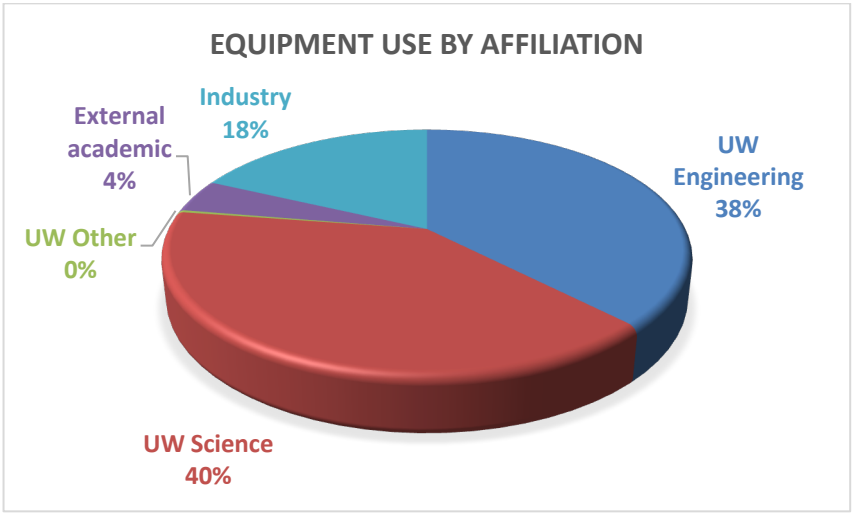

Figure 10: QNFCF equipment use hours grouped by the affiliation categories.

If we compare the pie chart of equipment use in Figure 10 with the lab user population data in Figure 6, we observe that the UW Science population is responsible for a disproportionately higher amount of equipment usage time per capita, relative to the other demographic groups.

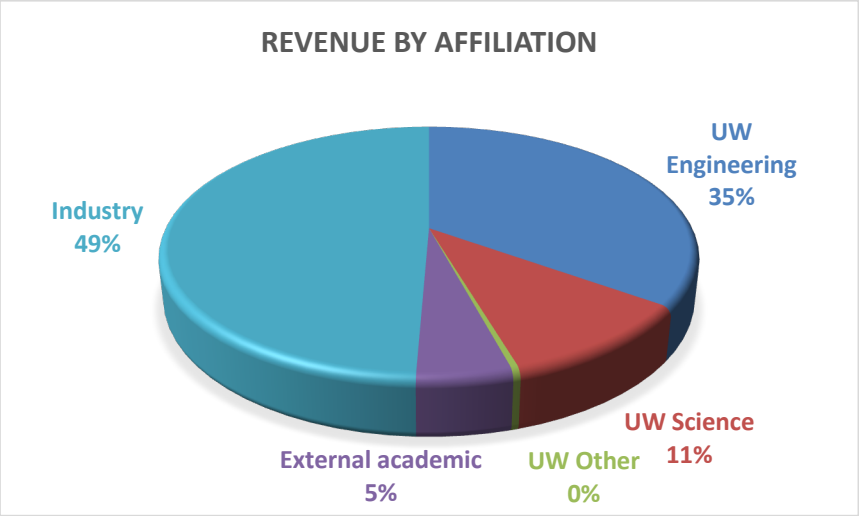

Figure 11: QNFCF invoiced equipment revenue grouped by the affiliation categories.

Figure 11 represents the components of the equipment revenue as a function of the affiliation categories. The pie chart above shows stark differences when compared with the pie charts that represent the equipment use in Figure 10 and the user population in Figure 6. It is evident from Figure 11 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 10 with the equipment revenue by affiliation category in Figure 11 demonstrates that the UW Engineering users represented 38% of all lab use, and this lab usage constitutes 35% of the total lab revenues. In contrast, the UW Science users represented 40% of all lab use, and this lab usage constitutes 11% 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 2025 fiscal year:

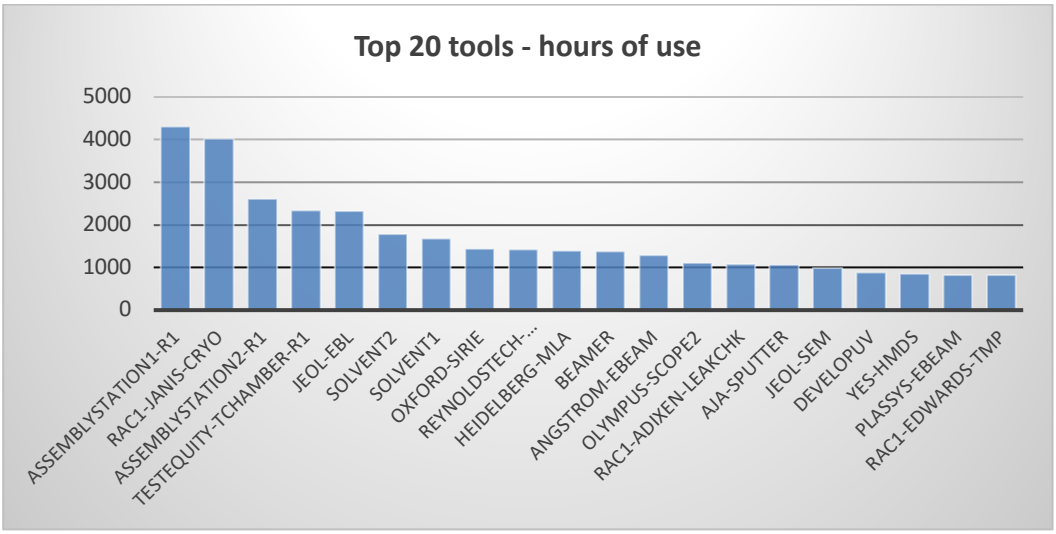

Figure 12: The top 20 tools in the QNFCF, based on the hours of use in the 2025 fiscal year.

Figure 12 demonstrates that the most popular tools in terms of use, are split between the "workhorse" types of tools that might be found in many microelectronic 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). Notably, the newly transferred RAC1-JANIS-CRYO, RAC1-ADIXEN-LEAKCHK and RAC1-EDWARDS-TMP tools are also included in this list of highly used equipment.

The following figure represents the top 20 pieces of equipment in terms of the invoiced revenue in the 2025 fiscal year:

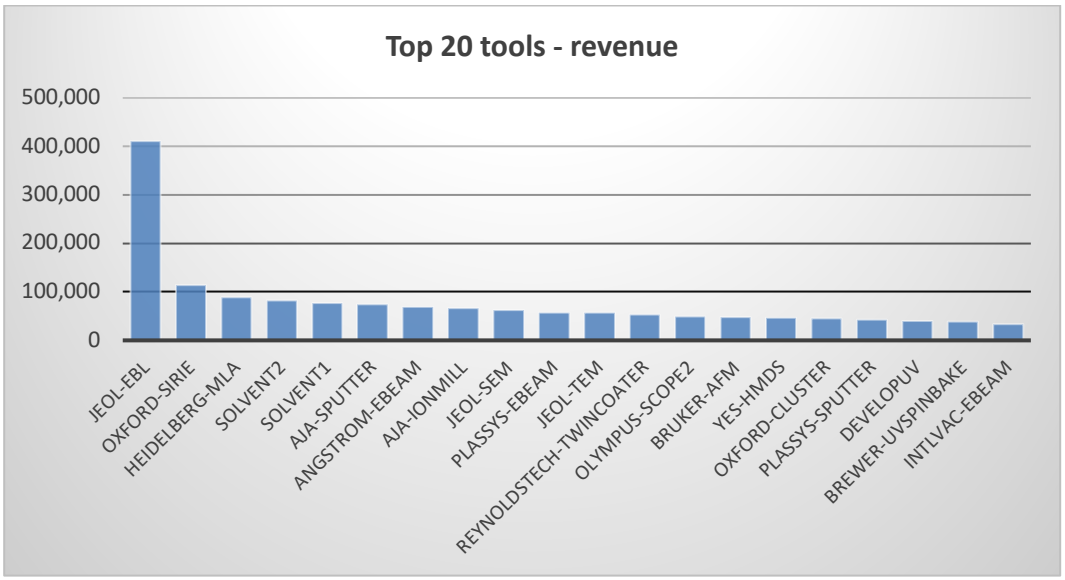

Figure 13: The top 20 tools in the QNFCF based on the invoiced revenue in the 2025 fiscal year.

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. The QNFCF maintains service agreements for seven pieces of equipment, and

six of these pieces of equipment (the Oxford, JEOL and Heidelberg tools) are included in this graph. 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.

Brief comments regarding the QNFCF equipment usage hours for the 2025 fiscal year:

The 2025 fiscal year showed a 13% increase in equipment use hours compared with the 2024 year. It is important to recall that there were a significant number of new tools that were added to the QNFCF's toolset in the beginning of this year. If the impacts of this new equipment and the Inert Atmosphere Fabrication Lab which came online in the end of the 2024 year were removed from the comparison, the revised total would be 40,546 hours of logged equipment time for the year. This new total would represent a reduction of approximately 6% from the 2024 fiscal year. The minor reduction of annual activity for the existing toolset may be indicative of increased tool downtime on the popular but ageing equipment.

The OXFORD-MetalRIE plasma etch tool was notably absent from both the top 20 most active tools and the top 20 highest revenue tools. This tool has averaged over 1,400 hours of use and over $82,000 of revenue per year for the previous 5 fiscal years (2020-2024), consistently placing it near the top of both lists. This system has suffered from a grounding issue that has been difficult to isolate and has perplexed staff members from both Oxford Instruments and the QNFCF, causing the tool to be unavailable for nearly all of the 2025 fiscal year. It is not clear whether it will be possible for the tool to return to an operational state. The unavailability of a major plasma etch resource has presented a major hurdle for many projects since there are no comparable tools available at other university nanofabrication labs in southern Ontario.

5. TRAINING

To benefit our stakeholder community 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 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.

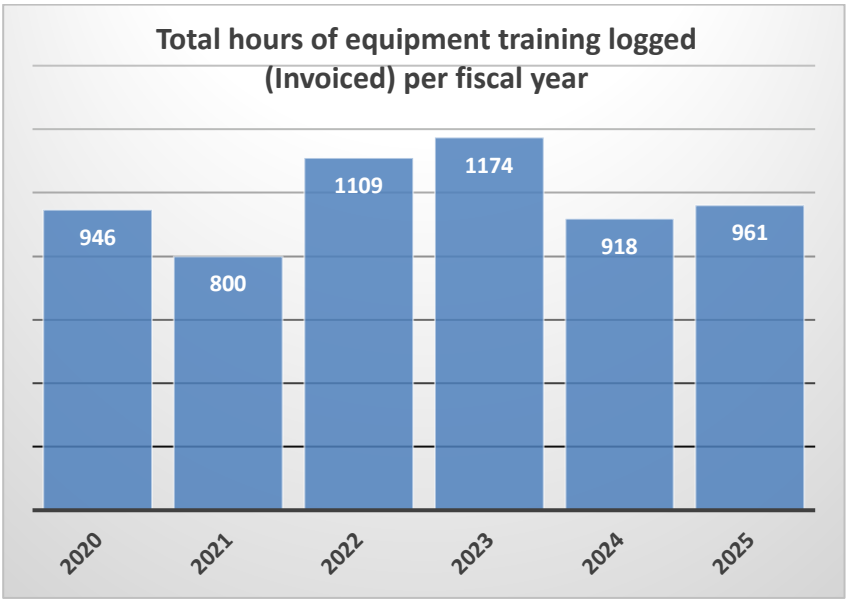

Figure 14: Total hours of equipment training per fiscal year.

The graph of the total equipment training hours shows that for the 2025 fiscal year, the equipment training hours were approximately aligned with the average from the previous 5 years which was 989 hours. It would be reasonable to expect that the volume of equipment training hours would scale proportionately with the number of active equipment users. This has not been the case for the 2025 fiscal year, where the number of active equipment users was 29% above the average from the previous 5 years and the equipment training hours were 3% below the average for the same period. As discussed at the end of section 3, there has been a partial decoupling, where some of the activities for the SEM-FIB and S/TEM will attract new users who access these resources through the staff operator service and not through hands on equipment training. Furthermore, the XRD, STM and new deposition tools that were transferred from the TQT group have a previously established, trained cohort of users who are generating incremental lab activity with a relatively low amount of incremental training requirements.

The QNFCF has not reported staff operator service hours in the past, as this work had been relatively infrequent. There has been a marked increase in the staff operator services across the QNFCF labs in the past few years, as shown in Figure 15 below.

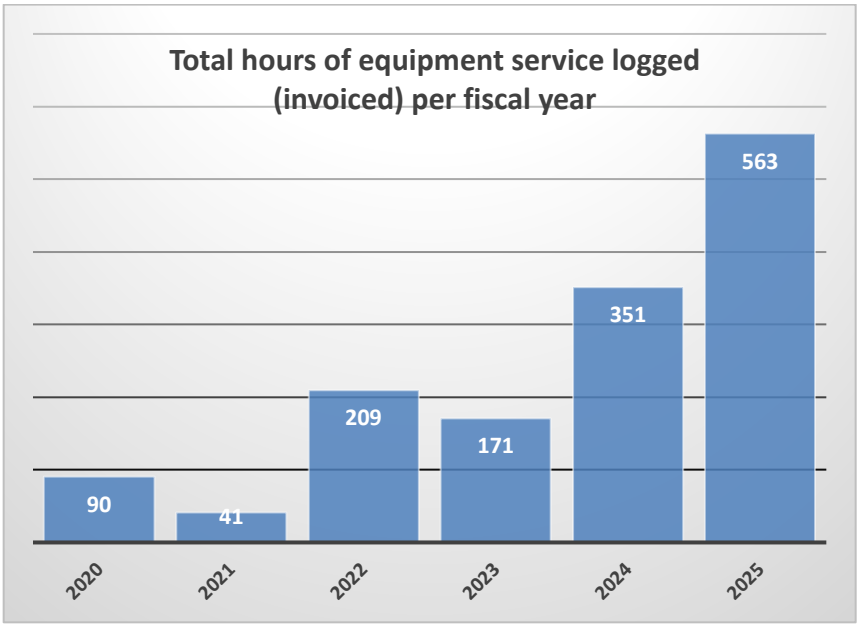

Figure 15: The total hours of staff equipment service charges per fiscal year.

The staff operator services rose by 105%, between the 2023 and 2024 fiscal years and continued to rise by an additional 60% to 563 hours, between the 2024 and 2025 fiscal years. The current level of staff equipment service hours has risen dramatically above the average for the previous 5 years which was 172 hours. Unfortunately, the new NEMO lab management software reports do not attribute staff equipment service charges to specific pieces of equipment so it is difficult to conclusively identify which tools are driving this trend. The timing of this dramatic increase coincides with an increase in the activity of the newly commissioned JEOL F200 S/TEM and corresponding TEM sample preparation activity on the Zeiss FIB/SEM. We can infer that activity on these two tools is a large part of the story behind the increase in staff equipment service hours.

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 of the 2025 fiscal year is included below:

	2020	2021	2022	2023	2024	2025
Salaries	$ 1,625,255	$ 1,681,851	$ 1,690,106	$ 1,360,802	$ 1,441,602	$ 1,580,573
Supplies, Maintenance & Repairs	$ 1,254,116	$ 1,034,485	$ 1,082,626	$ 1,307,433	$ 1,545,732	$ 1,458,638
Total Expenses	$ 2,879,371	$ 2,716,336	$ 2,772,732	$ 2,668,235	$ 2,987,334	$ 3,039,211
User fees	$ 1,763,769	$ 877,024	$ 1,320,204	$ 1,522,381	$ 2,060,129	$ 2,238,727
Funds from CFREF-TQT	$ 694,699	$ 605,646	$ 589,698	$ 769,324	$ 829,005	$ 802,663
Funds from IQC	$ 257,177	$ 259,412	$ 321,377	$ -	$ -	$ -
Funds from CFI-IOF	$ 694,187	$ 661,320	$ 312,465	$ -	$ -	$ 50,908
Ongoing operating budget - Nitrogen	$ 140,194	$ 142,998	$ 145,858	$ 122,474	$ 93,873	$ 81,213
Ongoing operating budget - Salaries	$ 178,103	$ 181,271	$ 183,814	$ 235,037	$ 292,655	$ 236,131
Total Revenue	$ 3,728,130	$ 2,727,671	$ 2,873,416	$ 2,649,216	$ 3,275,663	$ 3,409,643
Net Cash Flow	$ 848,759	$ 11,335	$ 100,684	$ (19,020)	$ 288,328	$ 370,432
% of contributions						
User fees	47%	32%	46%	57%	63%	66%
Funds from CFREF-TQT	19%	22%	21%	29%	25%	24%
Funds from IQC	7%	10%	11%	0%	0%	0%
Funds from CFI-IOF	19%	24%	11%	0%	0%	1%
Ongoing operating budget - Nitrogen	4%	5%	5%	5%	3%	2%
Ongoing operating budget - Salaries	5%	7%	6%	9%	9%	7%

Figure 16: Annual financial summary of the QNFCF laboratories.

In the 2025 fiscal year, the overall expenses for the QNFCF have increased by a modest 1.7%. The total expenses have been categorized by *Salaries,* which have increased by 9.6%, and *Supplies, Maintenance & Repairs,* which have decreased by 5.6%.

The most significant factors that have contributed to the increase in the *Salaries* expenses for the 2025 fiscal year were associated with the annual salary increases that were announced by the Provost's Advisory Committee on Staff Compensation on July 25th 2024, as well as two QNFCF staff positions that were vacant for a portion of the 2024 year.

The decrease of 5.6% in *Supplies, Maintenance & Repair* costs has been a positive development, and particularly notable considering the increased volume of equipment use, the increased lab user population and the general ageing of the equipment. The reduction of the expenses has primarily been attributed to the decision to discontinue the QNFCF's annual subscription to Badger lab management software, identifying lower cost suppliers for cleanroom consumables, and a one-time discount for the Heidelberg equipment service contract. The remaining reductions in *Supplies, Maintenance & Repair* costs were partially attributable to favourable timing of equipment failures within the laboratories.

The *User Fees* that were invoiced by the QNFCF have increased by 8.7% compared with the prior year and are aligned with the increased equipment usage in the labs (the invoiced equipment hours were up by 13%). The QNFCF's *User Fee* revenue for the 2025 fiscal year reached the highest level in the lab's history. The 2025 *User Fee* revenue represented approximately 66% 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 average of 49% for the previous 5 fiscal years.

A comparison of the QNFCF's *User Fee* revenue to the *Total Expenses* demonstrates that the revenue has grown to offset 74% of the *Total Expenses* in the 2025 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. INFRASTRUCTURE RECAPITALIZATION, LONG-TERM OPPORTUNITIES AND RISKS

The QNFCF began operations in 2009, with its first group of major equipment installations taking place in the RAC1 cleanroom space throughout 2010 and 2011. The equipment acquired during this time was relocated to the QNC cleanroom, once the operations began in 2014. This toolset includes many heavily used and essential systems for which there is no practical alternative or equivalent within the other facilities at the University of Waterloo. A subset of these ageing, unique tools is included below:

- OXFORD-metalRIE – Cl chemistry ICP reactive ion etch tool
- OXFORD-SiRIE – F chemistry ICP reactive ion etch tool
- OXFORD-cluster – PECVD and plasma assisted ALD capability
- INTLVAC-Ebeam – Ion assisted E-beam deposition tool

Each of the systems above had equipment usage hours between 688 and 1,430 hours in the 2025 fiscal year, except for the OXFORD-metalRIE which has been out of service for most of the year. All of these systems are more than 15 years old and the majority are at the vendor-defined "end of life" stage, where many of the subcomponents are no longer manufactured and vendor support is available on a "best effort" basis. In the next 5 years, it is probable that several of these tools may succumb to a failure that will no longer be repairable. This is perhaps the first time in the QNFCF's history when the toolset requires a significant, multi-million dollar infrastructure investment to maintain its existing capabilities.

Semiconductor and quantum device fabrication processes are essentially sequential and when one process is unavailable, there are often no alternative process or equipment which may be substituted. The potential failure of these tools presents a risk to the research productivity of many groups, as there are no local alternatives. Additionally, the QNFCF is primarily funded by equipment use and while the academic researchers may tolerate some interruption in their access to these tools, the industrial groups who account for 49% of the QNFCF's revenue may choose to relocate to other facilities within Canada. Consequently, a loss of these core capabilities would represent a significant financial risk to QNFCF revenues and therefore to the facility's overall operations.

In summary, there is a wide array of highly used equipment within the QNFCF that are likely to require replacement within the next 5 years. All of the tools that are highlighted in this section are unique, with no practical equivalents at the University of Waterloo. A loss of these core capabilities would be significant in terms of the research productivity of the QNFCF's customer groups and in terms of the financial and operational stability of the QNFCF. The scale of the capital investments requires that proactive actions be taken, since smaller and more expedient infrastructure funding opportunities would likely be insufficient for these recapitalization initiatives.

8. CONCLUSIONS AND KEY TAKE AWAYS

The 2025 fiscal year was an eventful year for the Quantum-Nano Fabrication and Characterization Facility, with many community building events and continued improvements in majority of the metrics that are recorded by the lab. This year, the QNFCF set new records for the number of **active users and PIs**, as well as the **volume of invoiced hours of equipment use**. A point form summary of the performance metrics is included below:

- Lab user population (active users per year) increased by 21% to 265, a new all-time high.
- PI population (the number of different research groups) increased by 14 to 101, a new all-time high.
- Logged equipment hours increased to over 48,000 hours, which is a **new all-time high**. This increase is attributable to the transfer of multiple pieces of equipment from the Transformative Quantum Technologies group, as well as new equipment usage from the Inert Atmosphere Fabrication Lab in RAC1.
- The cost of operations has increased by 1.7% relative to the prior year, which is a positive development considering the ageing toolset and the increased laboratory activity.
- The user fee revenue for the QNFCF has increased by 8.7% to $2.24M CAD, representing 66% 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 acknowledge 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