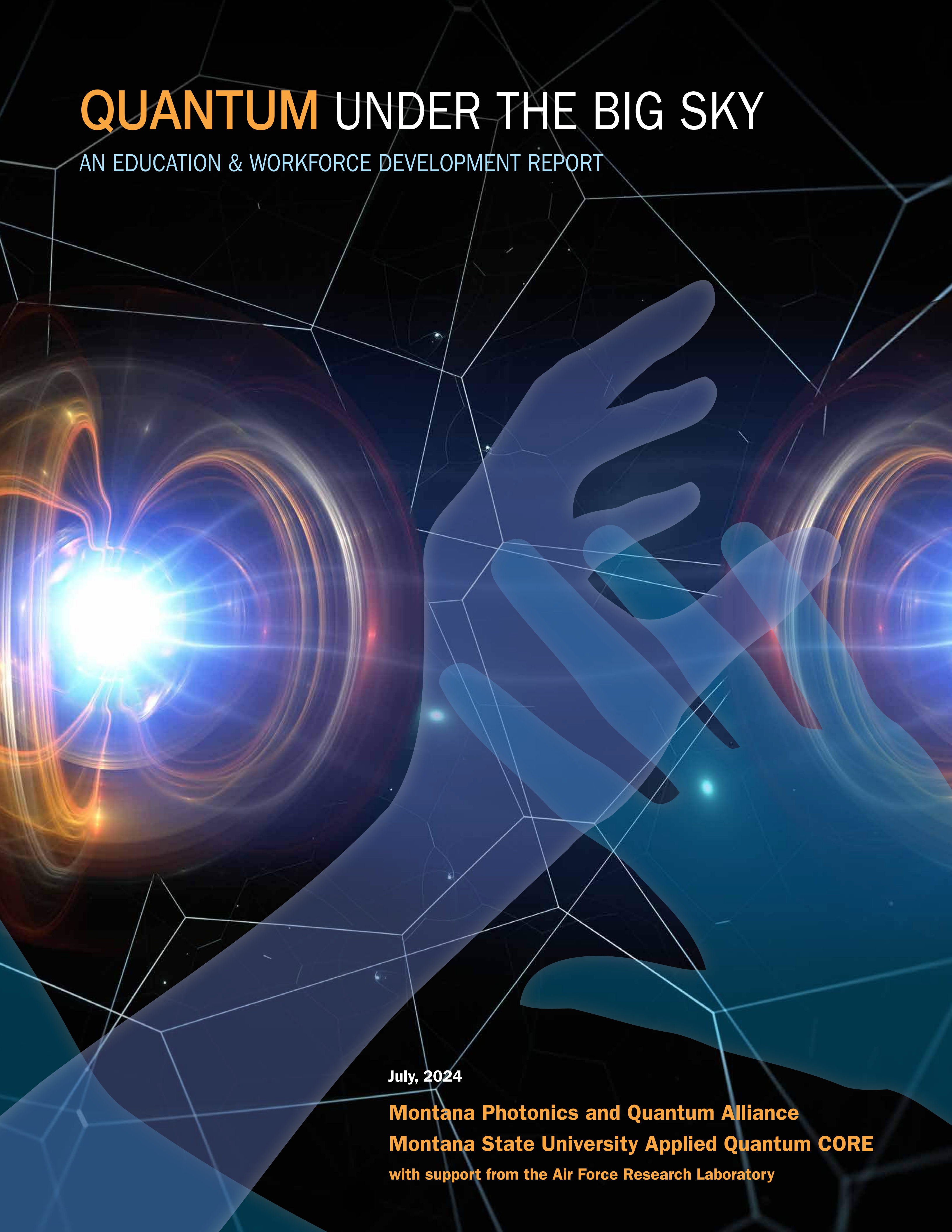
QUANTUM UNDER THE BIG SKY

AN EDUCATION & WORKFORCE DEVELOPMENT REPORT



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Montana Photonics and Quantum Alliance
Montana State University Applied Quantum CORE

with support from the Air Force Research Laboratory

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An Education & Workforce Development Report

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The race has already begun

As this report is being written, the world eagerly anticipates this summer's 2024 Olympic Games. But while the world watches races and events, another global race is happening behind the scenes. This is the quantum race, and China has already announced its intent to win with a strategic initiative for global quantum dominance by 2049. As with any race, the situation is changing rapidly; this report is a real-time snapshot of this race.

What is quantum? We have all heard the term in the news and media, but often, it seems like something from the far future or a science fiction movie. Quantum finds its roots in the word *quantized* and refers to a discrete quantity of energy proportional in magnitude to the frequency of the radiation it represents. Quantum scientists and engineers study extremely small particles – the size of those found inside an atom. These particles often exhibit unusual properties that differ from what classical physics would describe, and we are discovering how to manipulate these particles to create faster, more sensitive and more precise systems in electronics, including sensors, location systems, computers, and medical equipment. To quote Neils Bohr, "If you aren't confused by quantum mechanics, you haven't really understood it." The following report will seek to answer the question of what quantum is, where quantum will be seen in real-world applications, the gaps and opportunities in the workforce, and what roles quantum technology will play in the future of the great state of Montana.

QUANTUM SECTORS

The most well-known quantum sector is quantum computing. However, this nascent industry includes many other areas, such as quantum sensing, quantum materials, and quantum communications, all of which are important to Montana's growing quantum ecosystem.

Quantum computing is a rapidly emerging technology that harnesses the laws of quantum mechanics to solve problems too complex for classical computers (*What Is Quantum Computing? | IBM*, n.d.). While classical computers process information in digital bits (0s and 1s), quantum computers deploy quantum bits or "qubits" to store quantum information in values between 0 and 1. This essentially offers infinite states instead of just two, analogous to a household light switch with a dimmer – rather than be only on or off, the dimmer switch (like a quantum qubit) can be *between* on and off.

Quantum sensing is an advanced sensor technology that detects changes in motion and electric and magnetic fields by collecting data at the atomic level (*What Is Quantum Sensing?,* n.d.). These measurements are significantly more sensitive than what is achievable with classical sensors. Quantum imaging, for instance, covers the entire optical spectrum from infrared to ultraviolet in microscopic systems, enabling us to make objects visible even at wavelengths that have been invisible to date.

Quantum materials are optical, electrical, and magnetic materials that exhibit behaviors that can create, store, transport, and/or manipulate light and matter quantum states (*Quantum Resources - Montana Photonics & Quantum Alliance,* n.d.).

At sufficiently small dimensions, materials present new properties. 2D materials are often single-atom layers that have been reassembled in novel orientations, producing previously unseen properties. For example, with a minor shift between the orientation of two atomic layers, graphene — a form of carbon — can be reassembled to form a high-temperature superconductor.

Quantum communications takes advantage of quantum's fundamental properties by transferring data via qubits to protect transmitted data. From a cybersecurity perspective, the beauty of qubits is that if a hacker tries to observe them in transit, their super-fragile quantum state "collapses" to either 1 or 0 (*Giles, 2020*). This makes it impossible to intercept a quantum communication without being detected.

National Overview

The United States has prioritized quantum as a critical technology and actively participates in the global quantum race. To help develop a US strategy for advancing quantum technology, the National Quantum Initiative (NQI) Act was passed on Dec. 13, 2018 and "provides for the continued leadership of the United States in Quantum Information Sciences (QIS) and its technology applications. It calls for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States" (National Quantum Coordination Office, 2021). The NQI funded quantum efforts across the US for several years, spending $2.6 billion, but said funds have now expired. Efforts to reauthorize the NQI in 2024 are underway to include an additional $1 billion. The National Science Foundation, National Photonics Initiative, the Quantum Economic Development Consortium (QED-C), and photonics organizations like Optica and the Society of Photo-Optical Instrumentation Engineers (SPIE) lead these efforts. The quantum capabilities funded by the NQI have evolved across the country's regional clusters, including Washington, Colorado, Illinois, Maryland, and Montana, and have rapidly developed and entered the global race.

QED-C and the MonArk Quantum Foundry

Montana Overview

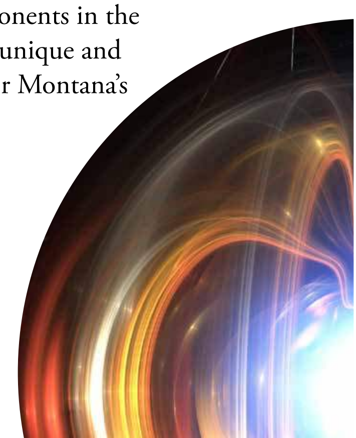
Montana State University (MSU) has played a vital role in developing Montana's quantum community, including fundamental research, workforce development, and startup creation. Montana's quantum origins can be traced back to work done in the early 2000s. For example, work on extremely cold temperatures by Krishna Rupavatharam and Charles Thiel, who remain as MSU scientists to this day, was critical to enabling today's quantum industry. Most quantum processes require temperatures near absolute zero, so cryogenics plays a vital role in the hardware necessary to develop a quantum technology.

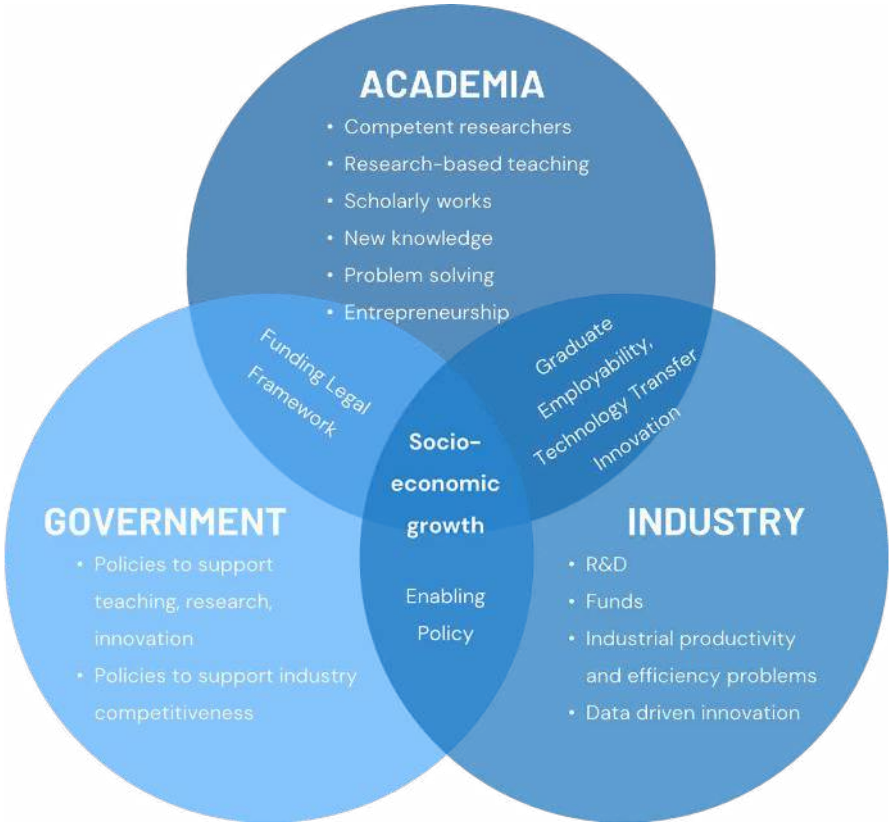
Since that time, Montana has continued developing key enabling technologies in the quantum supply chain, thus filling in the key base layers in the Quantum Stack diagram above (developed by MonArk Quantum Foundry, QED-C, Luke Mauritsen, and NQI to highlight all the necessary layers from core quantum technologies to end-users).

As Montana solidifies its position in the Quantum Supply Chain, its strengths have evolved into three core technologies: quantum materials, cryogenics for quantum, and quantum communications.

In fact, during a recent visit, a neutral-atom quantum computer manufacturer said that if another pandemic struck the world, the one place in the US where we could build a quantum computer would be in Bozeman because of the many Montana companies embedded in the quantum supply chain.

Dr. Yves Idzerda, the Dean of the College of Letters & Science at MSU, recently compared Montana's quantum industry with California's gold rush in 1848. While some miners found gold nuggets and made it big, others just made a decent living, and many more ended up broke and destitute. However, the suppliers who provided the picks and shovels to the miners simultaneously made a fortune. While Montana companies may or may not strike it rich with quantum computers, Montana's strengths in the quantum supply chain are the metaphorical picks and shovels, the core components in the Quantum Stack and a unique and strategic positioning for Montana's growing industry.





Montana Quantum Landscape

Montana's world-leading photonics ecosystem, primarily located in Bozeman, is growing rapidly and enabling Montana's nascent quantum community. Thousands of new jobs are anticipated statewide. Most of this growth has been in the Gallatin Valley, but this is beginning to change. Examples include Maztech Industry in the Bitterroot Valley, Four Nine Design in Billings, and VACOM in Lewistown. VACOM is forecasting 1,000 new jobs in the coming years on its Lewistown campus, which is currently under construction.

Photonics, the science and technology of light, is an adjacent technology to quantum, and the two industries are fundamentally entangled. Montana photonics' origins date back over 40 years. One of the first photonics companies in Montana was Scientific Materials, founded by Ralph Hutchinson. Ralph grew the ruby crystal Theodore Maiman used in the first laser ever made back in 1960. This company is still thriving in Montana after nearly 35 years and is now part of Teledyne/FLIR, which still grows laser crystals today. This industry has seen exponential growth and is now estimated to employ over 1,000 Montanans directly and another 5,500 indirectly. (*McKinsey et al., 2023*)

Montana's photonics ecosystem, with high-functioning relationships among the region's academic, government, and industry members, is a key differentiator and crucial asset.

ACADEMIC ASSETS

Academic Assets include MSU's **Optical Technology Center** (OpTeC) and **Spectrum Lab**. MSU also hosts one of two Quantum foundries in the US, the **MonArk Quantum Foundry**. MSU has received over $85 million in federal funding for quantum research and development and plans to apply in 2024 for another $200 million. These include a $40 million proposal to the US Air Force Research Lab to develop quantum communications. This project is referred to as the QCORE project. Even larger proposals will be submitted to the National Science Foundation (NSF) for a $160 million Engines award. If won, these funds will dramatically increase the development of Montana's quantum community.

INDUSTRY ASSETS

Industry Assets include the Montana Photonics & Quantum Alliance (MPQA), which is one of only six photonic clusters in the US and serves as a hub for Montana's optics, photonics, and quantum companies, entrepreneurs, laboratories, and universities to commercialize, grow, and sustain globally leading organizations that create high-quality jobs and economic opportunity in Montana. This non-profit photonics cluster, founded in 2013, now has 53 members across the state, and it has core technologies, including remote sensing, quantum materials and cryogenics, laser manufacturing, designators, and photonic materials. In 2023, MPQA member Shadowridge Analytics won a Small Business Administration Innovation Cluster award. This multi-year, multi-million dollar award is focused on helping Montana's smaller photonics and quantum companies grow.

Several Montana companies are focused on quantum-enabled technologies; others are quantum-adjacent and well-positioned for developments in the industry. Below are some examples:

Quantum Materials:

Scientific Materials - a division of **Teledyne/FLIR** - optical quantum materials (Y2SiO5)

AdvR - solid-state waveguides for atom cooling

Quantum Cryogenics:

Montana Instruments - optical cryostats; recently acquired by Atlas Copco

S2 - Corporation - cryostats and extreme bandwidth analyzers

Quantum Coax - coaxial cable assemblies for cryogenic quantum applications

Four Nine Design - cryogenic system designs for scientific research and industrial applications

Quantum Strategix - commercialized cryogenic system

GOVERNMENT SUPPORT

Local: The City of Bozeman has ardently supported Montana's photonics and quantum industry. As a founding sponsor of the MPQA, the city continues to play a pivotal role in promoting this industry.

State: Montana Governor Greg Gianforte has highlighted photonics as one of the key industries for Montana's future. A photonics delegation was included in the Governor's first trade mission to Taiwan. This precipitated Montana hosting over 25 senior photonics leaders from Taiwan during the Select USA spinoff event in June 2024. Additionally, for more than a decade, the Montana Department of Commerce has participated in the Montana reception at Photonics West in San Francisco, the leading global conference and marketplace for the industry.

Federal: Senator Steve Daines co-chairs the **Congressional Caucus for Optics and Photonics**. Under Senator Jon Tester's leadership, Montana was designated by the Economic Development Administration (EDA) as the **Montana Headwaters Tech Hub** (HTH). This designation allowed Montana to apply for $75 million. In February of 2024, a proposal was submitted with eight components, a total of 75 million dollars, and seeks to create 25,000 new jobs in Montana over the next ten years. "The Montana Headwaters Tech Hub will develop smart photonic sensing systems that can be deployed in autonomous systems and applied to critical defense, resource management, and disaster prevention applications." (Headwaters Tech Hub, n.d.) The Montana Hub was among only 12 hubs selected for funding on July 2, 2024. Montana will receive $41 million over the next five years.

Montana Photonics & Quantum Workforce Overview

Workforce development is integral to the success of the developing quantum industry, and many MPQA members report that finding enough talented employees is one of their biggest challenges. The most common jobs in this industry typically require a bachelor's degree, often in engineering or physics, though many technician and support jobs are also necessary.

Below is a snapshot of job openings at Montana quantum-specific companies when writing this report.

Job Openings:

- Technicians: Technician in Training, Photonics Technician
- Developers: Full Stack Developer, Algorithm Developer
- Engineers: Mechanical Design Engineer entry-level, Optical/ Electrical/Processing Engineer, Computer Engineer, Microwave Photonics Engineer, Photonics Engineer, RF Engineer, Software Engineer
- Scientist: Optical Scientist
- Senior Management: Director of Operations

Interviews with Montana employers in the industry yielded the following list of sought-after job skills.

Skills:

- Fundamentals of electronics and optics
- Good lab practices
- Basic understanding of mechanical and electrical components
- Experience with computer-aided design (CAD), assembly, and drawings, such as SolidWorks

Montana employers specifically mentioned manufacturing experience as a high-demand skill, a nod to Montana's dominance in the Quantum Supply Chain:

- Experience working in a manufacturing company
- Proven track record of manufacturing leadership and competency in a growing production environment, preferably within the high-tech manufacturing industry
- Deep understanding of manufacturing operations and principles
- Direct experience building manufacturing teams and increasing production capacities

Additionally, employers emphasized the importance of non-technical skills and behaviors in potential employees.

Behaviors:

- Self-motivated
- Proactive attitude
- Organized
- Strong interpersonal and communication skills, with the ability to engage and influence team members, customers, and suppliers.
- Strong time management skills with the ability to prioritize tasks effectively,
- Excellent attention to detail and precision in task execution
- Motivated 'lead from the front' servant leader with a strong bias toward action, results-driven with a focus on achieving goals and exceeding expectations,
- Passion for driving innovation in people, processes, and products,
- Passion for personal growth.
- Passion for growing organizations aligns with company core values: Hard work, Integrity, Humility, Productivity, and Innovation.
- Willingness to support the team at any level to get the job done

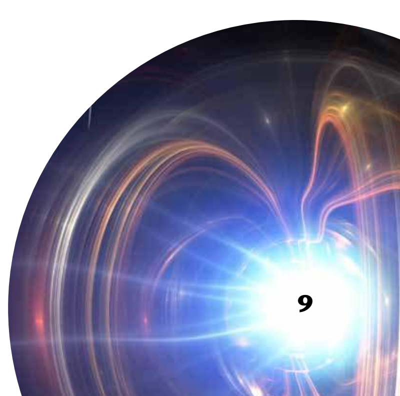
Quantum-adjacent and support positions

Any growing high-tech industry needs not just skilled scientists, engineers and technicians, but all the accompanying support positions. In fact, a recent marketing report from the MPQA stated that six non-technical jobs are needed for every one new tech job.

In 2022, the MPQA surveyed adjacent and support positions in the Montana photonics and optics industry. The most common open positions were:

- sales and marketing
- customer service, and
- bookkeeping.

While these positions are often standard across industries, the sales and marketing function is unique in emerging technology industries because it requires meaningfully translating technically advanced products and their value for customers. This position also requires developing trust-based relationships in a high-risk industry.



Montana Education Pathways: K-12 to Higher Education

Program	Description & Focus	Workforce
Gallatin College: Photonics & Laser Technician	100% placement of graduates locally since its inception in 2016	Associate Degree (Two years)
Optical Technology Center (MSU)	Focuses on quantum adjacent technologies with mostly Master's, PhD	Primarily Advanced Graduate Degrees
Spectrum Lab (MSU)	Seeks to advance technologies, including quantum, into real-world applications, mostly Master's, PhD	Primarily Advanced Graduate Degrees
MonArk Quantum Foundry (MSU)	Manufacturing 2D Quantum materials, mostly Masters, PhD	Primarily Advanced Graduate Degrees
Accelerate Montana: Electro-Optic Assembler	Currently being developed with a targeted launch date of August 2024	Micro-credentials

The spectrum of quantum educational pathways is diverse, ranging from roles requiring little to minimal necessary training to those requiring an advanced graduate degree.

At the time of writing this report, only a few undergraduate degrees in photonics are offered in the US, and none are offered in Montana, leaving an academic gap. Plans are currently underway at Montana State University to create a four-year photonics degree, and this received funding from the EDA Tech Hub Program in July 2024.

Gallatin College in Bozeman offers a 2-year associate degree of applied science (AAS) degree in Photonics and Laser Technology. Students learn the scientific principles of optics, fiber-optics, and lasers and are instructed on the processes and equipment for incorporating these devices in electronic and electro-optics systems. Hands-on training prepares students to become entry-level technicians who work on products or devices in manufacturing, communications, defense, homeland security, medical, information technology, energy, environmental monitoring, lighting, displays, and entertainment.

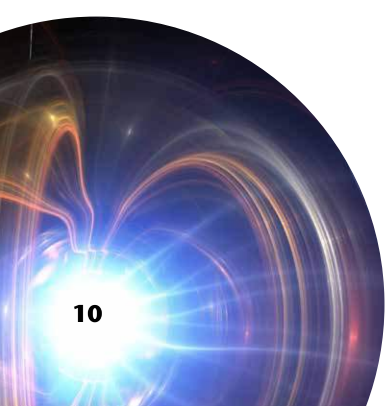
MPQA worked closely with Gallatin College to create the curriculum, which was developed by and for industry and continues to include MPQA board members as instructors. Graduates of the program are well-positioned to enter the workforce and pursue further education if desired. Since the program's inception in 2016, 36 students have graduated and have experienced a 100% placement into industry positions. Some students have gone on to 4-year and graduate degrees.

Montana State University offers a Master of Science (M.S.) degree in Optics and Photonics. In this interdisciplinary program in the departments of Physics, Electrical and Computer Engineering, and Chemistry and Biochemistry, students learn to harness the power of light to prepare for in-demand jobs or research careers in laser engineering, remote sensing, and more.

MSU also offers PhD studies in Optics and Photonics, which can be pursued through Electrical Engineering, Physics, Chemistry and Biochemistry or Materials Science. PhD students often earn the Optics & Photonics master's degree enroute to their PhD. While the master's degree can be earned through any of the participating departments, the Electrical Engineering PhD offers a particularly seamless path.

In Summer 2024, **Accelerate Montana** and the MPQA will offer a 12-week technician program ideal for photonics and quantum companies, further expanding the spectrum of workforce development pathways to include electro-optic assembler training.

An overview of Montana's quantum-based higher education programs are highlighted in the table above.



HIGH SCHOOL PREPARATION

Academic and industry experts recommend that high school students who are interested in photonics and quantum —like any emerging technology field – should take as many math and science courses as are available.

Suggested High School Coursework

- Algebra I & II, Geometry (suggested preparation for associate's degree)
- Physics, Calculus, Trigonometry/ Geometry, Statistics (suggested preparation for undergraduate degree)

In some Montana schools these classes are offered as Advanced Placement and/or Dual Enrollment, reducing the cost of higher education and exposing students to an advanced curriculum.

Additionally, academic extracurriculars and hobbies can prepare students for careers in the field. Examples include: Robotics Club, Science Olympiad, Hands-On Instrumentation, Coding.

K-12 Early Awareness and Teacher Professional Development

Teachers' professional development is critical to raising students' awareness, particularly in emerging fields such as quantum. Quantum awareness for teachers can include facility tours, job shadowing, lectures and workshops, and extended research experiences.

For example:

- The MPQA and MSU Optics and Photonics Society hosted an International Day of Light event in May 2024. More than a dozen regional middle and high school teachers, counselors and students attended and learned about educational and career pathways in optics, photonics and quantum.
- Montana's Work-based Learning Collaborative, a partnership of Reach Higher Montana and the Montana Manufacturing Extension Center, offers externships for teachers – placing them in three-day, hands-on experiences in Montana companies, including those in emerging technology areas.
- The Science Math Resource Center at MSU hosted Montana's first-ever World Quantum Day celebration in April 2024. It distributed hands-on kits and live virtual training to educators across the state, ranging from 4-H leaders to high school physics teachers.
- MSU's Research Experience for Teachers program places elementary teachers in university engineering laboratories, one of which involves the teachers in creating 2D quantum materials.

Students of all ages can grow their curiosity and exposure to emerging technology fields such as quantum through STEM experiences such as science and robotic clubs, STEM-related activities, lectures, and education and outreach opportunities such as those below:

- The Montana Science Center in Bozeman hosts a Light Lab exhibit, which features hands-on demonstrations of lasers, holograms, and prisms and is ideal for young children.
- The American Computer & Robotics Museum, also in Bozeman, offers a quantum computing exhibit and field trip programs for students and educators interested in quantum and other emerging technologies.
- The Montana World Affairs Council offers the EconoQuest program, which highlights photonics. This program educates students on global affairs and economics through a software platform and competition, and students have several opportunities to hear and interact with consul generals and state officials.
- Spark Alpha, a curriculum series focused on photonics, is supported by the MPQA, the Montana Chamber Foundation, and Spark Photonics to bring photonics to Montana's high schools and middle schools.

Montana Education Pathways: Opportunities and Gaps

Montana's two-year tribal and community colleges present a significant opportunity to address the state's future workforce needs. Community-based colleges typically offer highly localized STEM programs, such as forestry, animal science or agriculture rather than emerging technologies such as quantum, data science or AI. However, the wide swath of opportunities presented by quantum sensors, communications and computers as well as Montana's strengths in traditional and high-tech manufacturing could be interwoven into existing STEM programs.

Additionally, students in hands-on two-year technical programs such as electronics, machining, etc. would be uniquely positioned to enter 2+2 programs (a two-year associate's degree that leads directly to a four-year bachelor's degree).

That said, STEM teacher shortages and low teacher pay continue to create recruitment and retention issues across Montana's tribal/community college landscape as well as the K-12 system. ZipRecruiter's most recent data ranked Montana 42nd out of the 50 states for the lowest teacher pay, and a July 2024 search showed more than 100 open K-12 STEM teaching jobs in Montana schools, including many that have been unfilled for several months.

Teachers at all levels K-14 report the difficulty of incorporating new STEM content into their already extensive curricular requirements, and experiential learning opportunities such as field trips are often beyond the shrinking budgets of many schools.

Conclusion

As the quantum race continues to build momentum, the lack of end-use applications has prevented, to some extent, the rapid scaling of the industry, as the finish line is still hazy. As a result, the specific skills required for the quantum industry remain challenging to define, and thus, quantum jobs are filled by employees with skill sets that "mostly" fit the need.

Across the nation, quantum workforce development programs are often only offered to those with advanced graduate degrees. Similarly, Montana does not yet have a specific quantum higher education program outside of graduate programs and lab experiences. This leaves a large gap in the spectrum of industries' needs for both undergraduate and technician-level jobs.

Today's most common approach to a quantum career is using adjacent pathways in existing photonics-related programs, such as engineering and physics. Montana is well-positioned here to utilize its existing and growing photonics workforce development programs to prepare students for future careers in quantum. Additionally, Montana's strong role in the quantum supply chain, which is heavily weighted toward manufacturing, offers many good-paying jobs in the state.

Above all, we recommend creating quantum awareness at all levels of education so a quantum-ready workforce can be developed rapidly. By focusing on quantum awareness among students, their educators, and families; by helping students and workers develop a broad base of technical and non-technical skills for emerging industries; and by creating close working relationships with industry, Montana's educational pathways can be primed to meet the workforce needs of the state's future quantum industry and position Montana well to compete in the global quantum race.

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