



U.S. DEPARTMENT OF
ENERGY

Office of
Science

LA-UR-26-27468



Sandia
National
Laboratories



Los Alamos
NATIONAL LABORATORY
EST. 1943

Center for Integrated Nanotechnologies

Strategic Plan 2026-2030



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EXECUTIVE SUMMARY

About to enter its third decade as a U.S. Department of Energy (DOE) **Nanoscale Science Research Center (NSRC)**, the Center for Integrated Nanotechnologies (CINT) continues to enable world-leading nanoscale science that advances the nation's energy, security, and technology frontiers. Since its founding, CINT has provided the research community with open access to the complementary capabilities of its two sites—the Core Facility in Albuquerque and the Gateway Facility in Los Alamos—together with the unique expertise and infrastructure of its host laboratories, Sandia National Laboratories and Los Alamos National Laboratory. These combined assets have established CINT as a premier hub for discovery at the intersection of materials science, physics, chemistry, and nanotechnology.

The **2026–2030 Strategic Plan** outlines CINT's next evolution: transitioning from a traditional user facility into an autonomous, data-centric research ecosystem that seamlessly integrates artificial intelligence (AI), advanced instrumentation, and human expertise. In this vision, synthesis, characterization, modeling, and theory will be linked through AI-driven feedback loops that enable predictive design, real-time control, and accelerated discovery. This transformation will position CINT as a national model for next-generation research infrastructure and will advance DOE missions in AI and Autonomous Science, Quantum Science and Technologies, Microelectronics and Integrated Systems, Advanced Manufacturing and Critical Materials, and Energy Innovation and Extreme Environment Materials.

Guided by this vision, CINT's strategy centers on **five cross-cutting scientific priorities**, summarized below and described in detail in Section 3:

Artificial Intelligence, Machine Learning, and Autonomous Science

CINT will embed AI throughout its research ecosystem to accelerate experimental design, execution, and interpretation. Reinforcement learning, interpretable ML, and digital twins will guide autonomous workflows, while robotic automation and shared data infrastructure will enable continuous, reproducible experimentation. These investments will position CINT to fully leverage DOE's emerging AI resources and drive materials discovery at scale, to help the DOE realize the goals of the Genesis Mission.

Quantum Science and Technologies

CINT will advance quantum information science by uniting quantum materials discovery, nanophotonic integration, and AI-enhanced theory to control coherence and entanglement. Emphasis will be placed on room-temperature quantum materials, integrated photonics, and quantum-enhanced measurement techniques that support scalable sensing, communication,

and computation. Strategic investments in fabrication and cryogenic infrastructure will establish CINT as a national quantum materials and device testbed.

Microelectronics and Integrated Systems

CINT will provide the scientific foundation for next-generation microelectronics through discovery of advanced semiconductors, wafer-scale heterogeneous integration, and AI-enabled characterization. The Collaborative Microelectronics Platform for Accelerated Characterization and Testing (COMPACT) will standardize microelectronics evaluation across the NSRC network, linking synthesis and fabrication parameters to device performance and reliability for energy-efficient and quantum-capable systems.

Advanced Manufacturing and Critical Materials

CINT will expand the frontiers of intelligent, data-rich materials design by combining AI, multimodal data fusion, and autonomous experimentation to reveal mechanisms governing synthesis, processing, and materials resilience. These capabilities will support challenges in microelectronics, energy materials, additive manufacturing, and critical element recovery, enabling predictive and sustainable materials design aligned with DOE priorities.

Energy Innovation and Extreme Environment Materials

CINT will advance materials that maintain performance under extreme thermal, chemical, and radiation conditions. Through operando diagnostics, multimodal microscopy, and AI-accelerated modeling, CINT will uncover atomic-scale mechanisms of degradation and reliability and develop predictive design rules for next-generation energy, nuclear, and defense materials. These efforts will strengthen national security and support resilient energy infrastructures.

1. Strategic Vision and Context

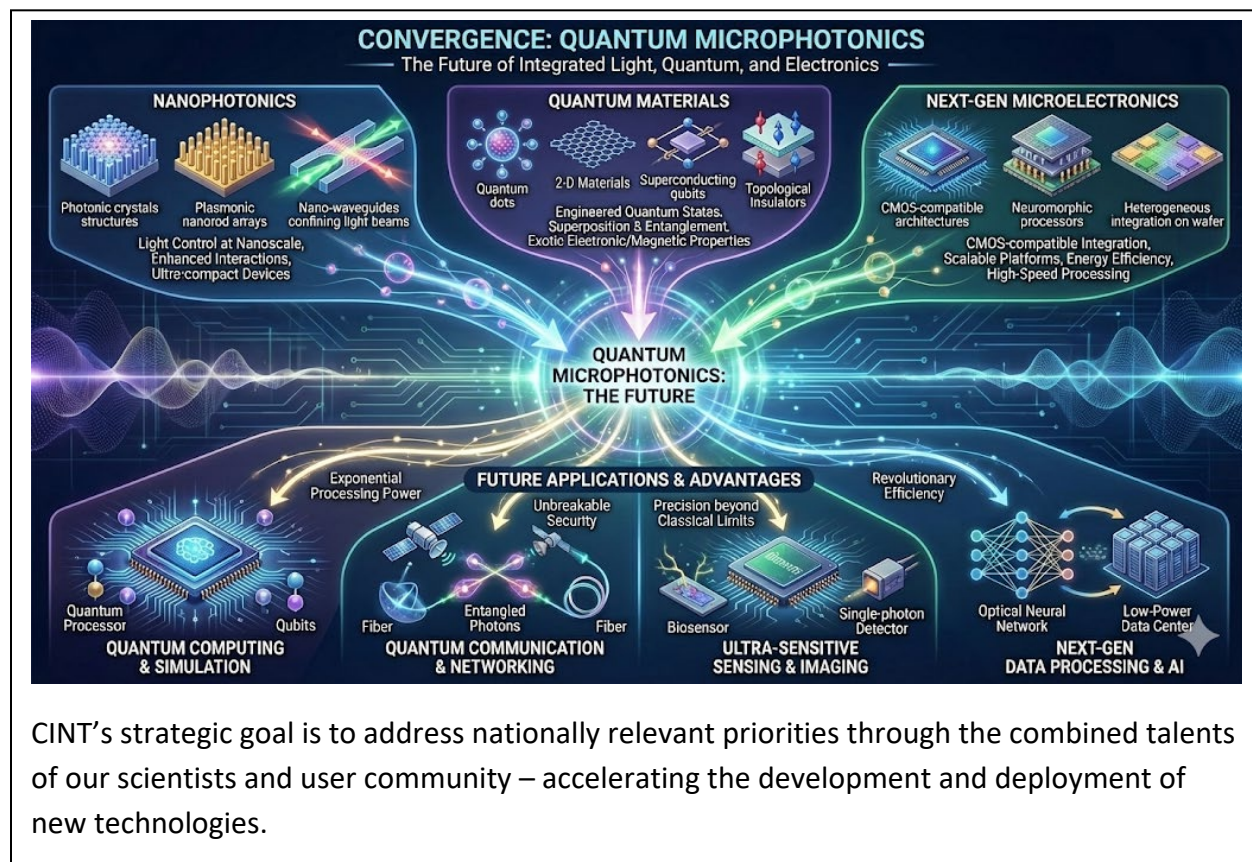
CINT's mission is to provide the scientific foundations necessary to understand, design, and control materials and systems at the nanoscale. As one of the DOE Office of Science Nanoscale Science Research Centers (NSRCs), CINT offers researchers from academia, industry, and national laboratories open access to advanced instrumentation, high-performance computing, and world-class scientific expertise. This combination of capabilities enables high-impact, user-driven research across a broad spectrum of scientific domains critical to national competitiveness.

The **2026–2030 Strategic Plan** builds on CINT's two-decade legacy while charting a course toward an integrated, autonomous research ecosystem. Scientific discovery is increasingly driven by data-rich experimentation, rapid characterization, and predictive modeling. To remain at the forefront of this transformation, CINT will evolve from a collection of exceptional but largely independent capabilities into an **intelligent, interconnected facility** where experiments, simulations, and AI-driven reasoning operate in synergy.

CINT's strategic vision is anchored by three core principles: **unification, automation, and impact**.

- **Unification** underscores CINT's commitment to unify synthesis, characterization, modeling, and theory into cohesive scientific workflows. By linking disciplines, platforms, and length scales, CINT will accelerate the pace at which fundamental insights translate into functional materials and devices.
- **Automation** reflects the facility's transition toward AI-enabled, self-optimizing laboratories that support autonomous planning, execution, and analysis of experiments. These platforms will reduce experimental cycle times, improve reproducibility, and expand access to complex experimental capabilities.
- **Impact** highlights CINT's alignment with DOE priority areas—including quantum information science (QIS), microelectronics and integrated systems, advanced manufacturing and critical materials, and energy innovation—where rapid, predictive, and high-throughput approaches are essential to national needs.

Through targeted investments in workforce, infrastructure, digital ecosystems, and scientific platforms, CINT will establish itself as a model for **next-generation research facilities**. This strategic evolution will strengthen the national research enterprise by enabling broader participation, accelerating cross-disciplinary innovation, and providing the technical foundations required to meet emerging challenges in energy, security, and advanced technology.



CINT's strategic goal is to address nationally relevant priorities through the combined talents of our scientists and user community – accelerating the development and deployment of new technologies.

2. User Program Management

2.1 Outreach

CINT's user program is central to its mission, enabling researchers from across the nation and around the world to access cutting-edge tools, expertise, and scientific infrastructure. To maintain its position as a premier DOE user facility and maximize its scientific impact, CINT will implement a forward-looking outreach strategy focused on four pillars: expanding the user base, deepening industry engagement, strengthening NSRC collaboration, and supporting the STEM pipeline.

User Community Expansion

CINT will broaden its user community through strategic recruitment efforts that combine a strong presence at major international scientific conferences with targeted participation in specialized workshops aligned with CINT's core technical areas. These research areas—AI-enabled materials science, quantum technologies, microelectronics, advanced manufacturing, and extreme environment materials—provide natural entry points for new users. The CINT Annual Meeting will remain a signature venue for highlighting user achievements, facilitating collaboration, and expanding awareness of CINT capabilities.

Industry Engagement

To enhance translational impact and support DOE's growing emphasis on technology maturation, CINT will deepen engagement with industry sectors connected to its scientific priorities, including microelectronics, quantum information science, and AI-driven materials discovery. This engagement will be supported through partnerships with regional and national technology accelerators, economic development organizations, and industry consortia. Increased visibility at technical conferences and industry trade events will expand CINT's reach into commercial research communities.

NSRC Network Collaboration

CINT will strengthen collaboration across the NSRC network by supporting unified branding, shared outreach materials, and coordinated representation at joint user events. Enhanced cross-NSRC communication will facilitate multi-center user projects, support interoperable workflows, and amplify the collective impact of the NSRC complex while maintaining CINT's unique identity. Finally, CINT is committed to working with all NSRCs to stand up a multi-center proposal system allowing users to work across facilities with a single proposal.

STEM Pipeline and Evaluation

CINT will invest in educational partnerships with regional universities, community colleges, and the Bradbury Science Museum to cultivate the next generation of nanoscale focused scientists and engineers. CINT will evaluate the effectiveness of its outreach and education programs through continuous, data-driven assessment of participation, outcomes, and long-term impact, ensuring resources are deployed efficiently and equitably.

2.2 Unifying the User Experience

Although CINT operates across two national laboratory sites, the facility is committed to delivering a seamless, integrated experience that minimizes logistical barriers for users. Over the next five years, CINT will unify its digital and physical infrastructure into a cohesive “one-lab” environment, enabling users to move efficiently from proposal submission to experimentation and publication.

A central component of this transformation is the development of www.cint.science, a unified platform designed to streamline the user experience. This dynamic, mobile-optimized portal will support proposal submission, document routing, peer review, project onboarding, safety and training compliance, and publication tracking. ORCID integration will enable persistent identification of user outputs and reviewer contributions, improving transparency and supporting metrics for DOE reporting.

CINT will modernize onsite operations by integrating Facility Online Management (FOM) software into the “CINTernet,” the facility’s internal high-speed data and control backbone. This integration will provide a centralized interface for instrument scheduling, usage tracking, and reporting, improving facility utilization and staffing efficiency. To complement these digital enhancements, CINT will implement a universal swipe-card access system to streamline secure access to instrumentation and computing resources across both sites.

Through these combined efforts, CINT will ensure that all users—local, national, and remote—experience a unified, efficient, and modernized facility that supports rapid scientific progress and fosters collaborative engagement across disciplines and institutions.

3. Strategic Scientific Priorities

CINT's scientific strategy for 2026–2030 is organized around five cross-cutting priorities that reflect national needs and unify discovery, design, and deployment across disciplines. These priorities position CINT to advance forefront science while enabling technologies central to the nation's energy, security, and economic missions. Together, they define a coordinated framework that integrates synthesis, characterization, modeling, and AI-driven autonomy into coherent scientific workflows.

3.1 Artificial Intelligence, Machine Learning, and Autonomous Science

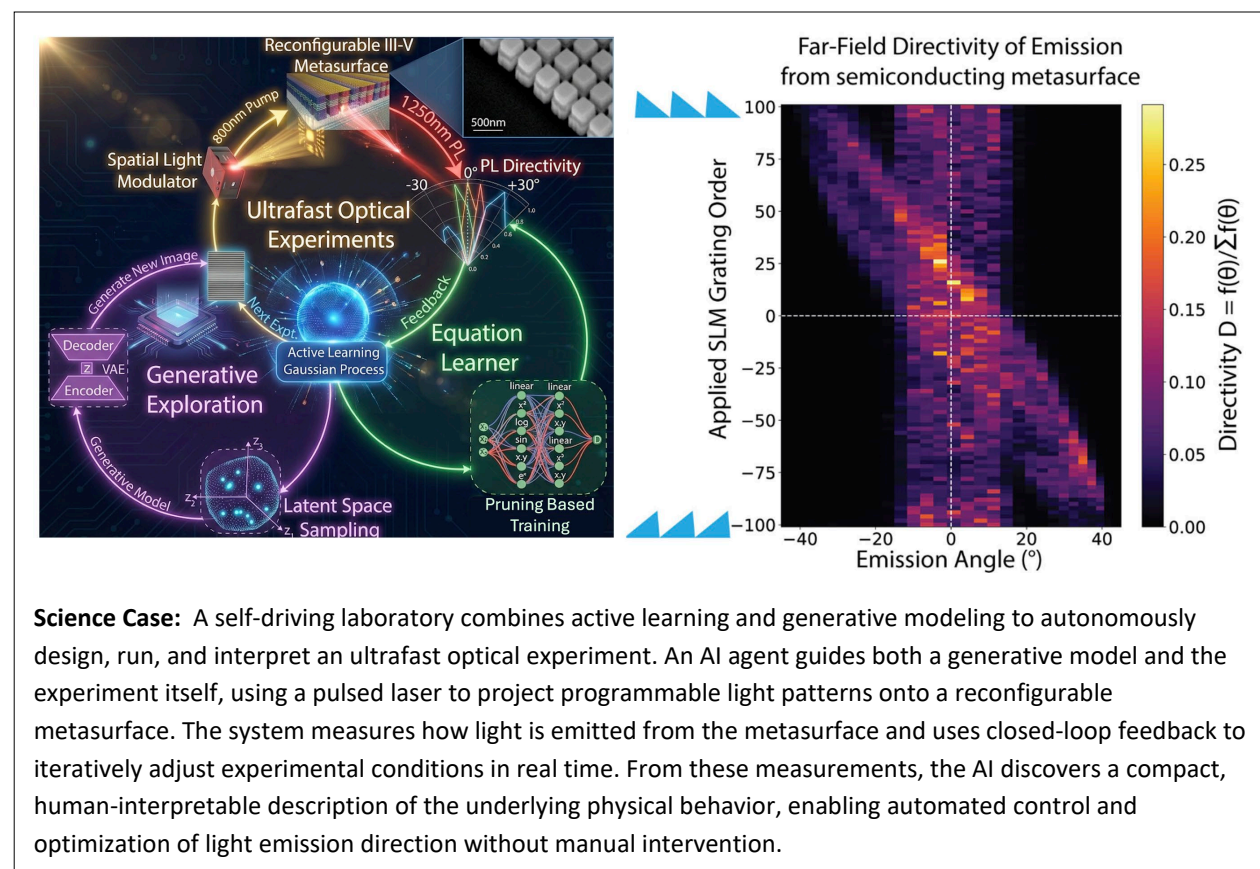
Artificial intelligence (AI) and machine learning (ML) are driving a fundamental transformation in how research is conducted at CINT. Increasingly, data-driven control algorithms are embedded directly into laboratory workflows, enabling experiments to be designed, executed, and analyzed in ways that are faster, more reproducible, and more predictive than traditional approaches. Autonomous experimentation is emerging as a powerful paradigm in which AI agents propose experimental conditions, evaluate results, and refine hypotheses in real time. Through this shift from manual iteration to goal-oriented, machine-driven workflows, CINT is accelerating discovery across all major scientific areas.

In synthesis and materials fabrication, autonomous platforms will carry out high-throughput experimentation by dynamically adjusting reaction conditions under ML guidance. Reinforcement learning strategies and Bayesian optimization methods will explore complex, high-dimensional parameter spaces that would be impractical to traverse manually. These approaches are complemented by instrument-level automation—including robotic sample handling, adaptive alignment, programmable control layers, and environmental monitoring—that will enable systems to operate continuously and self-correct to maintain optimal performance. The emergence of these self-optimizing laboratories marks a significant advance in both reproducibility and scientific agility.

AI is also central to the interpretation of modern scientific data. Nanoscale imaging and spectroscopy generate massive, multidimensional datasets that are increasingly analyzed in real time by deep-learning models. These models enhance signal and resolution in transmission electron microscopy, enable denoising and reconstruction of beam-sensitive materials, and identify subtle spectral or structural features in ultrafast optical, X-ray, and terahertz measurements. Instrument-adjacent edge computing allows such analyses to occur with millisecond latency, enabling closed-loop experimental steering and adaptively evolving measurement strategies.

Beyond experimental control and data processing, AI is reshaping modeling and simulation at CINT. Machine-learned interatomic potentials and neural operators now provide

near-first-principles accuracy at a fraction of the computational cost, enabling studies of long-timescale dynamics, complex chemistries, and large-scale structural evolution. By integrating these models with experimental workflows through digital twins—virtual representations of laboratory systems that predict outcomes, detect anomalies, and guide instrument control—CINT will establish the computational backbone for its autonomous research environment.



CINT's AI strategy also emphasizes interpretability and scientific understanding. The facility is developing physics-informed ML models that embed conservation laws, uncertainty quantification, and causal structure, ensuring that AI not only predicts phenomena but explains the mechanisms that drive them. This commitment to interpretability enhances reproducibility, supports scientific rigor, and provides reliable guidance for autonomous decision-making.

Realizing the full potential of AI-enabled autonomous science requires coordinated investments in infrastructure, instrumentation, and workforce. CINT will expand its suite of instruments with open APIs and programmable control layers, deploying FAIR-compliant (Findable, Accessible, Interoperable, Reusable) data pipelines, and installing edge-computing nodes to support low-latency inference and control. At the same time, CINT is cultivating a workforce of interdisciplinary scientists, engineers, and research software developers who will develop

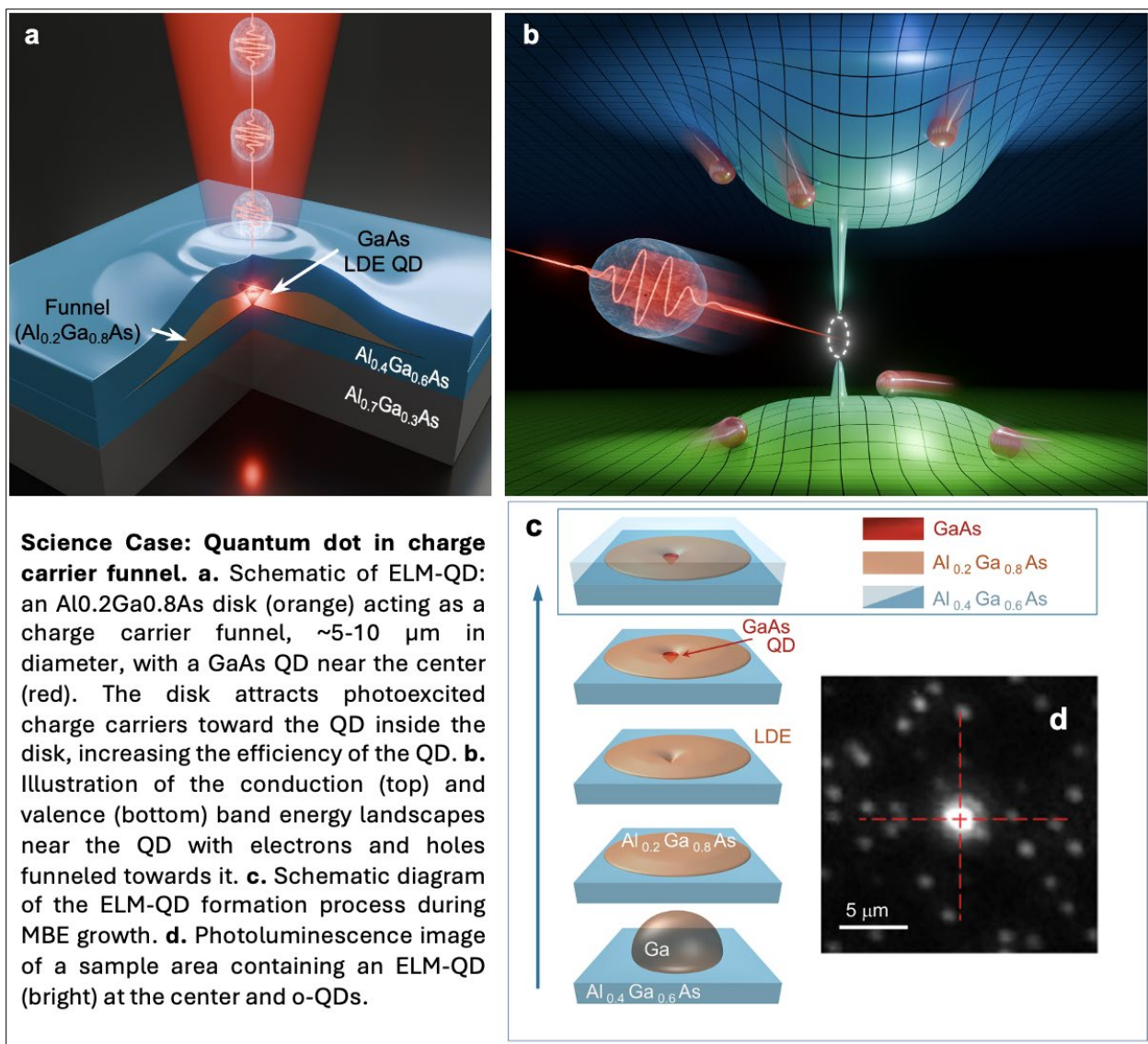
autonomy frameworks, ensure data quality, and govern the ethical operation of AI systems. Through these combined efforts, CINT will establish itself as a national leader in AI-enabled nanoscience and a key contributor to DOE's vision for an integrated, autonomous scientific enterprise.

3.2 Quantum Science and Technologies

Quantum science at CINT centers on the discovery, control, and integration of materials that host quantum states robust enough to support next-generation technologies. Across a diverse class of systems—including wide-bandgap semiconductors, transition-metal dichalcogenides (TMDs), correlated and topological materials, and engineered nanoscale heterostructures—CINT investigates the atomic-level features that give rise to quantum coherence, entanglement, and strong light–matter coupling. Through techniques such as molecular beam epitaxy (MBE), chemical vapor deposition (CVD), and precision 2D stacking, researchers create materials in which defects, strain, composition, and confinement can be tuned to tailor excitonic, spin, and electronic behavior. These efforts underpin the identification of new qubit candidates, quantum sensors, quantum light sources, and material platforms capable of stable operation under realistic environmental conditions.

A major emphasis is the design and control of **quantum defects**—optically addressable spin centers used for sensing, computation, and communication. Through controlled epitaxial growth, ion implantation, and nanoscale patterning, CINT controls defect placement and symmetry to enhance spin coherence, photoluminescence, and environmental stability. These systems enable quantum sensing with nanometer resolution and single-spin sensitivity, while providing deterministic single-photon sources for quantum networks. Complementary studies of correlated oxides and topological materials explore emergent quantum phases that may provide pathways to error-resistant qubits and scalable quantum logic.

Quantum photonics forms a second pillar of CINT's program. By integrating quantum emitters with engineered photonic environments—including metasurfaces, dielectric waveguides, and high-Q cavities—CINT creates platforms that manipulate quantum states of light with exceptional precision. These hybrid architectures enable strong coupling between photons, excitons, magnons, and phonons, allowing controlled generation of entangled photon pairs, chiral emission, and tunable polaritonic states. CINT is advancing integrated quantum photonic circuits that combine emitters, filters, modulators, and detectors on low-loss platforms capable of



scalable routing, interference, and entanglement distribution. Ultrafast photonics extends these capabilities to femtosecond timescales, enabling dynamic control of quantum states and exploration of nonclassical light–matter interactions.

CINT also leads development of **quantum-enhanced imaging, spectroscopy, and communication technologies**. Techniques such as quantum ghost imaging, quantum imaging with undetected photons, and quantum Fourier-transform infrared spectroscopy enable contrast and sensitivity beyond classical limits, allowing samples to be probed at infrared wavelengths while detection occurs in the visible. These capabilities inform quantum-secure communication protocols, long-wavelength photonic channels, and entanglement distribution strategies for future quantum networks.

Advanced multimodal characterization is essential for understanding quantum phenomena. CINT's capabilities in ultrafast optical spectroscopy, cryogenic and aberration-corrected electron microscopy, environmental microscopy, and time-resolved angle-resolved photoemission spectroscopy (TR-ARPES) allow direct observation of coherence decay, defect dynamics, excitonic interactions, and band structure evolution. Planned enhancements—including spin-resolved detection and integrated MBE-ARPES pipelines—will expand these capabilities and support deterministic quantum materials engineering.

Theory, modeling, and AI/ML provide predictive insight into quantum behavior. Machine learning accelerates materials discovery by predicting coherence lifetimes, optimizing defect configurations, and guiding inverse design of photonic structures. Digital twins enable real-time simulation of quantum experiments, allowing researchers to tune control parameters and predict unexpected responses. Together, these capabilities create a closed-loop ecosystem in which experiment and computation continuously reinforce one another.

By integrating quantum materials synthesis, photonic engineering, multimodal measurement, and AI-enhanced modeling, CINT will support the emergence of scalable, hybrid quantum-classical systems for computing, sensing, and secure communications. These efforts directly contribute to DOE's Quantum Information Science mission and will help build the national quantum ecosystem needed to support future technologies.

3.3 Microelectronics and Integrated Systems

Microelectronics underpin nearly every aspect of modern technology—from computation and communication to energy conversion and national defense. As traditional semiconductor scaling approaches fundamental physical and economic limits, progress depends increasingly on innovations in materials, device architectures, heterogeneous integration, and energy-efficient design. CINT's microelectronics program provides the scientific foundation for these advancements by uniting nanoscale materials discovery, wafer-scale processing, device integration, and AI-enabled characterization.

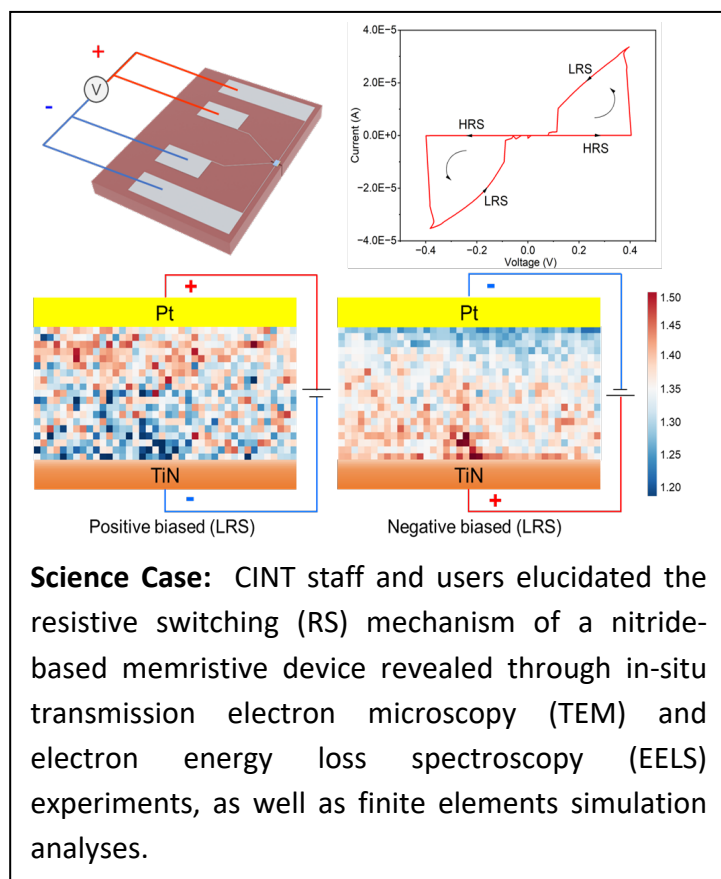
CINT's research spans four interrelated themes. First, the facility discovers new materials that transcend the limits of conventional CMOS technology, including wide-bandgap semiconductors,

ferroelectrics, layered two-dimensional heterostructures, and solution-processible/printable nanoscale metals, semiconductors, dielectrics and polymers that can be assembled to create high mobility electronics or to realize on-chip creation, manipulation or detection of light for ultimate multifunctional behavior. These materials are synthesized using techniques such as MBE, CVD, atomic layer deposition (ALD), chemical synthesis, and advanced additive manufacturing, supported by machine-learning-assisted analysis and in situ diagnostics that ensure reproducibility and accelerate exploration.

Second, CINT advances **heterogeneous and three-dimensional (3D) monolithic integration**, enabling multifunctional device stacks that combine electronic, photonic, and quantum components on shared substrates. Wafer bonding, low-loss dielectric patterning, and precision alignment allow integration of silicon photonics with III–V, III–N and lithium niobate layers or solution-processed electronics for ultrafast modulation, on-chip light sources, and hybrid quantum-optical systems. Through-silicon vias or printed 3D interconnects further reduce latency and improve energy efficiency, supporting next-generation system-on-chip and chiplet architectures.

A third thrust investigates **nanoscale reliability**, recognizing that mechanical, chemical, thermal, and interfacial stability become dominant constraints as devices incorporate diverse materials or

face extreme-environment operation. Using environmental TEM, nanoindentation, multimodal scanning probe methods, and hybrid metrology frameworks that combine electron microscopy, optical interferometry, and X-ray scattering, CINT maps stress evolution, delamination pathways, and thermal response at the nanoscale. These insights inform design strategies that enhance device robustness and yield.



Finally, CINT leads **AI-enabled characterization and design**, accelerating device development through autonomous analysis pipelines and predictive modeling. The **COMPACT** initiative provides a standardized framework for

microelectronics evaluation across the NSRC network, enabling reproducible benchmarking and linking synthesis parameters to electrical performance and long-term reliability.

CINT's microelectronics program aligns closely with DOE missions in microelectronics, AI, and quantum information science. Photonics-enabled interconnects support high-bandwidth communication required by AI workloads, while hybrid quantum–electronic devices bridge quantum materials with classical control systems. Facility investments in wafer-scale integration, programmable control, and autonomous characterization will position CINT as a national hub for microelectronics innovation and workforce development.

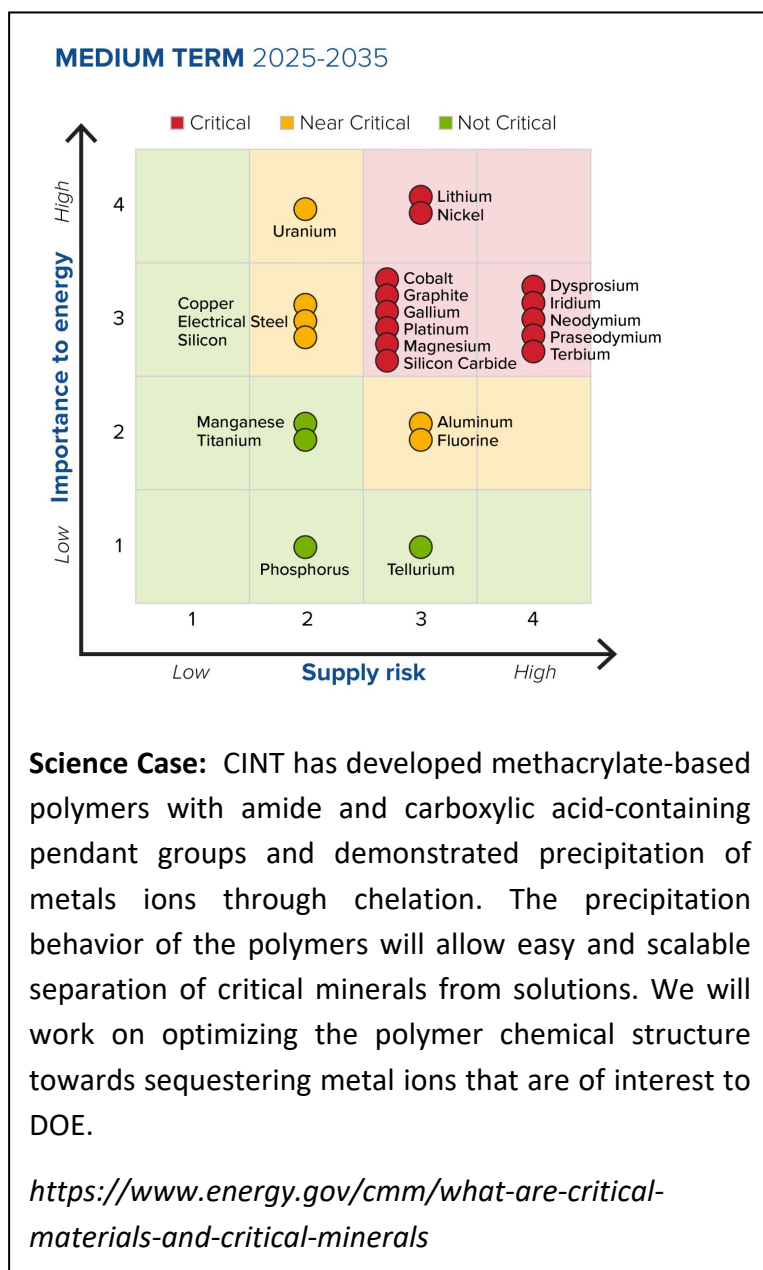
3.4 Advanced Manufacturing and Critical Materials

Advanced manufacturing and critical materials science are deeply interconnected challenges that define the technological competitiveness of future microelectronics, energy systems, and quantum devices. CINT's program in this area leverages its strengths in synthesis, characterization, and process science to develop predictive, scalable, and sustainable approaches to materials design and fabrication. By integrating AI-driven discovery, multimodal data fusion, and autonomous experimentation, CINT uncovers the fundamental principles that govern processing, performance, and resilience in advanced material systems.

CINT's manufacturing research emphasizes discovery of materials with engineered grain structure, controlled porosity, and deterministic interfaces, enabling devices with improved optical, electronic, and mechanical performance. AI-assisted process optimization and in-line diagnostics will shorten development cycles and increase reproducibility.

A central research direction is the design of **metastable and compositionally complex materials**—such as transition-metal nitrides, metastable oxides, and high-entropy alloys—whose unique magnetic, catalytic, or mechanical properties emerge from controlled disorder, strain, or constrained kinetic pathways. AI-guided modeling and autonomous synthesis enable exploration of these complex phase spaces and facilitate discovery of rare-earth-free magnets, durable catalysts, and new functional materials.

CINT also advances the science of **critical materials recovery and sustainability**. Polymer-based ion-capture systems, hybrid membranes, and biomolecular platforms are designed to selectively chelate and separate lithium, cobalt, rare earths, and other strategic elements from industrial waste streams. Studies of polymer–ion interactions, ionic transport, and interfacial structure inform the design of more selective and durable recovery media. Bio-inspired methods, including



engineered fungal and microbial systems for “mycomining,” offer environmentally responsible pathways for extracting critical elements from low-grade ores or waste products.

Multimodal characterization—including cryogenic electron microscopy, X-ray and infrared spectroscopy, environmental TEM, and terahertz spectroscopy—provides insight into structure, chemistry, and dynamics across length scales. Coupled with machine-learning models, these tools accelerate the correlation of synthesis parameters with performance metrics and guide materials optimization.

Through these combined efforts, CINT advances DOE priorities in advanced manufacturing, critical materials, and energy security. The resulting knowledge supports circular materials economies, reduces reliance on geopolitically constrained resources, and

provides the scientific foundation for resilient supply chains and sustainable manufacturing.

3.5 Energy Innovation and Extreme Environment Materials

Energy systems and national security applications increasingly require materials that maintain functionality under severe thermal, chemical, mechanical, and radiation conditions. CINT’s efforts in Energy Innovation and Extreme Environment Materials provides the scientific foundation needed to design, synthesize, and understand materials capable of performing

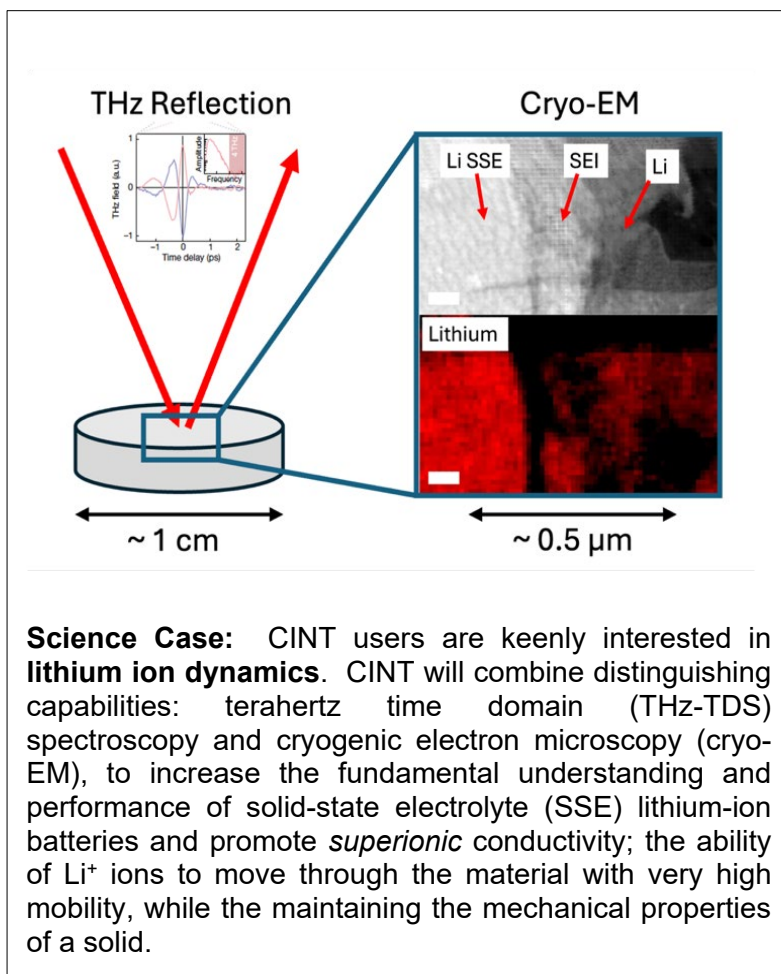
reliably in such environments. By integrating operando diagnostics, multimodal microscopy, and AI-accelerated modeling, CINT uncovers the atomic-scale mechanisms governing degradation, defect evolution, and long-term reliability.

A major focus is investigating radiation effects and defect dynamics in complex alloys, ceramics, and nanostructures. High-entropy alloys and refractory metals offer exceptional resistance to swelling, segregation, and embrittlement due to their compositional disorder, which impedes defect mobility. Using in situ and environmental TEM, ultrafast spectroscopy, and advanced ion-beam platforms, CINT examines defect nucleation,

migration, and annihilation in real time. AI-assisted analysis identifies correlations within these datasets, enabling rational design of microstructures with built-in radiation tolerance.

CINT also develops materials for **electrochemical energy storage**, focusing on solid-state electrolytes (SSEs) and their interfacial stability. Operando cryogenic EM and terahertz spectroscopy reveal nanoscale heterogeneities and solid–electrolyte interphase (SEI) formation that influence ionic conductivity and cycling durability. Integration of these insights with machine-learning models guides the optimization of composition and processing to achieve mechanically robust, high-conductivity SSEs.

Nanostructured coatings and barrier layers for high-temperature, corrosive, and irradiated environments form another pillar of this program. Advanced deposition techniques create films with tailored grain structure, porosity, and adhesion to resist oxidation, corrosion, and spallation. Machine-learning models enable predictive optimization of multilayer architectures for long-term operation.



Soft materials science contributes to understanding ion-conducting polymers and membranes used in fuel cells, water purification, and chemical separations. By combining molecular simulation with NMR and infrared spectroscopy, CINT identifies how nanoscale morphology and functional chemistry influence ion mobility, solvation, and selectivity.

CINT's multimodal diagnostics—including ETEM, ultrafast optics, and X-ray-based techniques—capture dynamic changes in structure and chemistry under operational conditions. Multiscale modeling links atomistic simulations with continuum behavior, enabling predictive control of thermal transport, defect migration, and oxidation kinetics. These insights accelerate materials optimization and support the design of robust systems for next-generation energy production, storage, and conversion.

Through this integrated approach, CINT advances DOE missions in nuclear technology, fusion energy sciences, and national security. The resulting scientific knowledge supports the development of resilient materials essential to the nation's evolving energy and infrastructure needs.

4. Data and Network Infrastructure for AI-Driven Science

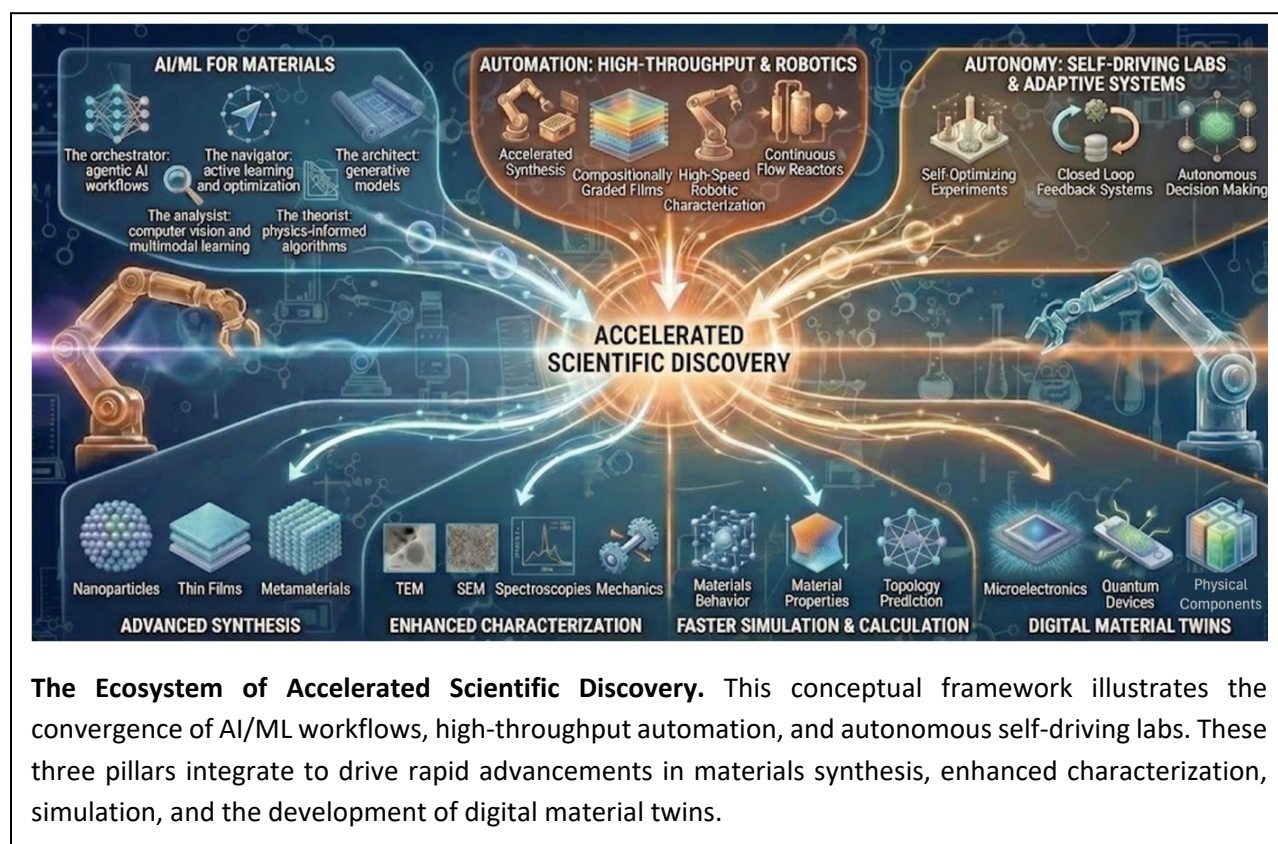
CINT's long-term vision is to create a fully interconnected, AI-ready research environment that enables autonomous science across the entire facility. This digitally integrated ecosystem will allow instruments, simulations, data repositories, and computational resources to operate as coordinated components of a distributed scientific network. The future CINT will be a facility in which every instrument can communicate, every dataset is machine-interpretable, and AI systems can design, execute, and analyze experiments with minimal human intervention. This transformation will ensure CINT remains at the vanguard of DOE's next-generation scientific infrastructure.

4.1 Vision and Objectives

CINT aims to establish a unified digital environment in which experimental platforms, data systems, and computational resources interact seamlessly through standardized interfaces and shared intelligence. This vision rests on four strategic objectives:

1. Enable AI-assisted and fully autonomous operation of synthesis, characterization, and modeling platforms.
2. Ensure interoperability and transparent data exchange across instrumentation, workflows, and user projects.
3. Provide secure, high-bandwidth connectivity to support remote participation and distributed AI computing.
4. Operationalize FAIR (Findable, Accessible, Interoperable, Reusable) data principles across the entire facility.

This approach positions CINT to fully leverage emerging DOE initiatives—including the Genesis Mission, the Integrated Research Infrastructure (IRI), and the High Performance Data Facility (HPDF)—and to serve as a model for autonomous user facilities across the national laboratory system.



4.2 Data Infrastructure and Architecture

Over the next five years, CINT will build a scalable, flexible data architecture designed to support AI-driven and autonomous experimentation. This architecture will combine on-site high-performance computing with distributed edge-computing nodes collocated at major instruments. The edge nodes will perform low-latency inference, initial data reduction, and closed-loop feedback control, enabling real-time adaptive experiments.

All data streams will be automatically enriched with comprehensive metadata describing instrument configuration, environmental conditions, calibration state, and provenance. CINT will deploy a FAIR-compliant data platform with standardized formats, automated metadata capture, and structured APIs to support machine learning (ML) workflows. Automated versioning and provenance tracking will guarantee the reproducibility and transparency of datasets generated by staff, users, or autonomous systems.

To support projected data growth, CINT will implement a hybrid storage model combining high-speed solid-state arrays for active data with large-capacity archival systems for long-term preservation. Integration with DOE computing facilities will allow flexible access to high-

performance computing resources for model training, multimodal data fusion, and simulation-driven inference.

4.3 Network Connectivity and the CINTernet

CINT will expand and modernize its internal network infrastructure—known as the **CINTernet**—to provide the bandwidth, security, and reliability required for autonomous, distributed experimentation. The CINTernet will connect instruments, compute clusters, user platforms, and storage systems through a unified, authenticated framework that supports real-time communication.

This infrastructure will enable remote initiation and monitoring of experiments, high-speed data streaming, and cloud-accessible analysis tools. Low-latency network links and encrypted telemetry will ensure high performance and cybersecurity. As laboratory systems are upgraded with programmable control layers and open APIs, the CINTernet will function as the backbone that transforms CINT’s instruments into intelligent, interconnected nodes in a distributed research environment.

4.4 AI Integration and Workflow Automation

CINT will deploy modular “autonomy stacks” that unify experiment planning, instrument control, data reduction, and analytics into cohesive digital workflows. Each autonomy stack will consist of planning engines that use AI to select experimental conditions, control engines that interface with instruments via open APIs, and real-time analytics layers that interpret results and update learning loops.

These stacks will allow coordinated, multi-instrument experiments to proceed autonomously across laboratories and physical locations. Over time, CINT’s workflows will progress toward fully autonomous operation in which synthesis, characterization, and modeling occur in closed loops guided by AI and human oversight. This architecture will shorten discovery cycles, enhance reproducibility, and maximize the scientific value extracted from every experiment.

4.5 Governance, Security, and Access Control

The increasing use of autonomous systems requires robust governance and cybersecurity frameworks. CINT will implement role-based authentication for instrument access, standardized review pathways for autonomous experiment execution, and formal audit trails for experiment design, data generation, and model decisions.

Governance policies will safeguard data integrity, operational safety, and ethical use of AI. Data sharing will follow DOE security and export-control guidelines while ensuring transparency and accessibility where appropriate. CINT will integrate explainability, uncertainty quantification, and

human-in-the-loop supervision into its AI governance framework to maintain trustworthiness in autonomous operations.

4.6 Strategic Impact

A fully integrated data and network infrastructure will transform CINT from a collection of world-class instruments into a cohesive, intelligent scientific ecosystem capable of autonomous operation. AI systems will be able to design, execute, and interpret experiments across platforms, linking nanoscale synthesis and measurement with predictive modeling in real time. This digital modernization will accelerate discovery, enhance collaboration across the DOE complex, broaden user participation, and ensure that CINT remains at the forefront of data-driven materials science. Through these investments, CINT will provide the infrastructure foundation needed to support the next decade of breakthroughs in quantum technologies, microelectronics, advanced manufacturing, and energy innovation.

5. CINT Implementation Plan: 2026–2030

Overview

Achieving the vision outlined in this Strategic Plan requires coordinated investments in workforce development, facility modernization, digital infrastructure, and strategic partnerships. CINT's implementation plan aligns operational resources with its five cross-cutting priorities—AI and Autonomous Science; Quantum Science and Technologies; Microelectronics and Integrated Systems; Advanced Manufacturing and Critical Materials; and Energy Innovation and Extreme Environment Materials. Through targeted hiring, infrastructure upgrades, integrated research platforms, and strengthened collaborations, CINT will establish the foundation for a next-generation, autonomous user facility that accelerates scientific discovery and broadens national impact.

5.1 Workforce Development and Key Hires

CINT's scientific transformation depends on expanding its interdisciplinary workforce. Over the 2026–2030 period, CINT will recruit staff with expertise in AI-enabled science, quantum technologies, microelectronics, advanced manufacturing, and materials for extreme environments. These hires will support the development and operation of autonomous platforms, deepen technical strength across scientific thrusts, and enhance the user experience.

AI and Autonomous Science

CINT will recruit scientists with AI, data, and control engineering expertise to design, operate, and govern AI-enabled laboratories. These specialists will develop autonomy frameworks, maintain data quality, ensure safe AI–instrument interaction, and build user-facing training programs covering autonomous experimentation, machine-learning model validation, and FAIR data practices.

Quantum Science and Technologies

New staff in quantum materials synthesis, quantum photonics, cryogenic measurement, and device integration will strengthen CINT's role as a national quantum laboratory. These hires will support the development of hybrid quantum–classical testbeds and ensure CINT remains responsive to DOE's Quantum Information Science (QIS) mission.

Microelectronics and Integrated Systems

To meet DOE's microelectronics priorities, CINT will hire experts in semiconductor materials discovery, device physics, materials fabrication and processing, and nanoscale reliability. These staff will support advanced fabrication, 3D integration, and AI-assisted characterization. Cross-

disciplinary short courses will train staff and users in fabrication, process control, and autonomous device evaluation.

Advanced Manufacturing and Critical Materials

CINT will add chemists and materials scientists to strengthen intelligent manufacturing, metastable materials discovery, and sustainable critical materials recovery. These researchers will support AI-guided design, high-throughput synthesis, and circular materials workflows.

Energy Innovation and Extreme Environment Materials

New hires in radiation materials science, electrochemistry, and computational materials science will expand CINT's capability to investigate materials under extreme thermal, chemical, and radiation conditions, advancing DOE missions in nuclear, fusion, and grid-scale energy systems.

Collectively, these workforce expansions will enable CINT to design, operate, and sustain autonomous, AI-enabled research platforms, ensuring high-impact outcomes for the user community and the nation.

5.2 Scientific Investments

CINT will execute a multi-year modernization program to expand cleanroom capabilities, upgrade instrumentation, deploy digital infrastructure, and integrate autonomous laboratory systems.

CINT has always utilized a bottom-up investment decision strategy wherein new investment concepts originate with the scientific staff who work directly with, and hence best understand the needs of the user community. Need is also conveyed by the Science Advisory Committee and User Executive Committee. CINT is organized around four scientific thrusts as described at [CINT.lanl.gov](https://cint.lanl.gov), and the leaders of those scientific thrusts form a senior staff group that leads the scientific investment strategy and provides recommendations to the Director and Co-Director. The Thrust Leaders, as a group, therefore represent the totality of CINT's scientific workforce. Investment decisions, whether hiring or capability, are always considered by the Thrust Leaders prior to enactment. Individual details (e.g. model, options, re-assessment of need) regarding the investments described below will be considered by the Thrust Leaders at the time of investment.

Facility Modernization

CINT will upgrade its cleanrooms and integration laboratories to support advanced environmental control, 4-inch wafer-scale processing, and hybrid photonic–electronic integration. New fabrication capabilities—including atomic layer etching (ALE), ion-beam deposition and milling (IBE/IBD), and multiphoton additive manufacturing—will enable precise control of interfaces, microstructures, and extended 3D architectures.

Computational Infrastructure

CINT will deploy a distributed computing architecture that integrates instrument-adjacent edge processors with high-performance clusters for simulation, digital twin operation, data fusion, and large-scale AI model training. FAIR-compliant data systems will ensure consistent metadata capture, automated provenance tracking, and data interoperability across the facility.

Digital Twins and Process Design Kits (PDKs)

CINT will develop digital twins for key synthesis, characterization, and fabrication processes, enabling predictive process control and autonomous optimization. Process Design Kits will standardize device and fabrication models across DOE user facilities, enabling reproducible design and enhanced cross-center collaboration.

CINeternet Expansion

The internal “CINeternet” will be expanded to support high-bandwidth, secure, low-latency connectivity linking instruments, data systems, and compute resources. This backbone will enable remote experiment execution, distributed AI workflows, and real-time data streaming for autonomous platforms.

Characterization and Metrology Enhancements

CINT will invest in advanced multimodal characterization tools, including electron microscopy with remote and autonomous operation capabilities, ultrafast spectroscopy, time-resolved angle-resolved photoemission spectroscopy (TR-ARPES), and quantum-enhanced measurement systems. These capabilities will support in situ and operando analysis of microelectronics, quantum devices, and extreme-environment materials.

5.3 Partnerships and Collaboration

CINT will strengthen partnerships across national laboratories, academia, and industry to expand scientific impact and accelerate technology readiness.

National Laboratory Collaborations

CINT will deepen coordination with DOE user facilities and national centers to advance data interoperability, AI infrastructure, microelectronics testing, and quantum device integration.

University Engagement

Joint appointments, graduate internships, and postdoctoral programs will expand training opportunities in AI-enabled science, quantum technologies, microelectronics, and sustainable materials. Co-located projects will strengthen shared scientific agendas.

Industry Partnerships

Engagement with semiconductor, energy, quantum technology, and advanced manufacturing sectors will accelerate translation of CINT discoveries and ensure alignment with national industrial priorities.

Workshops and Consortia

CINT will host annual cross-cutting workshops to engage the broader research community, align efforts with DOE initiatives, and strengthen collaboration across scientific, academic, and industrial partners.

5.4 Implementation Timeline (2026–2030)

2026–2027: Foundation and Pilot Deployments

CINT will initiate the transition to an autonomous, data-centric research environment by launching foundational infrastructure upgrades and workforce expansion. Early tasks include recruiting key personnel in AI/ML, quantum science, microelectronics, and advanced manufacturing to build the interdisciplinary expertise required for next-generation research platforms. Cleanroom modernization and laboratory enhancements will begin, including improved environmental control and preparation for expanded wafer-scale processing.

Pilot FAIR data systems will be deployed to standardize metadata capture across major instruments, accompanied by the installation of the first edge-computing nodes to support low-latency experiment feedback. CINT will establish high-speed internal network links between major characterization and synthesis laboratories, laying the groundwork for the CINTernet. Initial autonomy stacks—software frameworks to coordinate experiment planning, control, and analysis—will be deployed in selected synthesis and microscopy platforms. Together, these early activities will create the technical and operational foundation for autonomous workflows across the facility.

2027–2028: Integrated Platforms and Data Interoperability

CINT will expand autonomous and data-centric capabilities across its research programs. The CINTernet 1.0 infrastructure will be launched, enabling authenticated remote access to instruments, unified application programming interfaces (APIs), and high-bandwidth data streaming. A facility-wide expansion of FAIR data systems will ensure interoperability across synthesis, characterization, and computational workflows.

Major instrumentation upgrades will be commissioned, including additive nanomanufacturing tools, new wafer-scale fabrication capabilities, and enhanced cryogenic and spectroscopic platforms. COMPACT 2.0 will be launched, providing standardized microelectronics

benchmarking across the NSRC network. During this period, autonomy stacks will be integrated into multiple laboratories, enabling multi-instrument coordination and early closed-loop experiments. These advancements will facilitate seamless data movement, cross-instrument orchestration, and scalable user access.

2028–2029: Autonomous, Multi-Instrument Workflows and Quantum Testbeds

CINT will establish integrated autonomous workflows with advanced device fabrication, characterization, and modeling. New capabilities for quantum integration will be operational, combining cryogenic measurement, integrated photonics, and superconducting or semiconductor-based device platforms.

Distributed computing clusters will be expanded to support large-scale AI model training and simulation-driven inference, with direct interoperability to DOE high-performance computing (HPC) centers. Hybrid metrology platforms—including environmental TEM, ultrafast optical spectroscopy, and multimodal imaging—will be expanded to support real-time, AI-driven data fusion. Multi-instrument autonomous workflows will become routine, creating new capabilities for coordinated synthesis–characterization–modeling campaigns.

2029–2030: Facility-Wide Autonomy and Digital Twin Integration

CINT will achieve its goal of laboratory autonomous experimentation, in which synthesis, characterization, and modeling operate through coordinated autonomy stacks and seamless data infrastructure. Digital twin ecosystems—virtual replicas of key synthesis tools, fabrication processes, and characterization platforms—will be deployed across the facility to enable predictive instrument control, anomaly detection, accelerated hypothesis testing, and optimized experimental planning.

The CINTernet will reach its full operational capability, supporting remote experiment initiation, cross-center collaboration, and distributed AI workflows. CINT will conduct a comprehensive evaluation of scientific, operational, and workforce metrics, assessing the performance of autonomous systems, data platforms, and user program enhancements. These assessments will inform planning for the next strategic period and ensure that CINT remains aligned with DOE mission needs, national scientific priorities, and the evolving research landscape.

5.5 Performance and Oversight

CINT leadership will conduct annual implementation reviews to assess progress across scientific priorities, infrastructure modernization, autonomy adoption, and user program metrics. A Strategic Operations Committee—composed of facility leadership, technical leads, and DOE representatives—will provide oversight, evaluate performance, and ensure alignment with

evolving national priorities. This governance model will maintain accountability, ensure resource optimization, and guide continuous improvement across all aspects of CINT's mission.

6. Summary

The 2026–2030 Strategic Plan positions the Center for Integrated Nanotechnologies (CINT) to lead a new era of discovery in which autonomous experimentation, advanced characterization, and predictive modeling operate in concert to accelerate progress across the quantum, microelectronics, energy, and materials sciences. Through coordinated investments in AI-enabled infrastructure, multimodal measurement platforms, high-performance computing, and workforce development, CINT will evolve into an intelligent, fully integrated research ecosystem. This transformation will strengthen CINT’s role as a national model for next-generation scientific facilities—supporting rapid, data-rich discovery and expanding the facility’s reach across the DOE research community.

CINT’s five cross-cutting scientific priorities—AI and Autonomous Science; Quantum Science and Technologies; Microelectronics and Integrated Systems; Advanced Manufacturing and Critical Materials; and Energy Innovation and Extreme Environment Materials—provide a unified framework that links fundamental science to national mission needs. These priorities leverage CINT’s strengths in synthesis, characterization, and theory, while creating new opportunities for interdisciplinary collaboration and translation. By integrating autonomous platforms with advanced materials discovery and scalable device integration, CINT will contribute the scientific foundations needed for next-generation computing, resilient energy systems, sustainable materials cycles, and secure technological infrastructures.

Looking ahead, CINT’s commitment to autonomous research platforms, FAIR data practices, and cross-disciplinary workforce development will ensure that the facility remains at the forefront of scientific innovation. By deepening integration across its two sites, expanding partnerships within the NSRC network, and strengthening ties to academia and industry, CINT will broaden participation and accelerate scientific impact. Through these efforts, CINT will continue to advance U.S. leadership in nanoscale science and deliver transformative contributions to the nation’s energy, security, and technology frontiers.

This work was produced by the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA-0003525. Los Alamos National Laboratory is managed by Triad National Security, LLC, for the U.S. Department of Energy’s NNSA under contract 89233218CNA000001.