

Overview of the Purdue Quantum Science and Engineering Institute

David J. Stewart

April 1 , 2024

About the PQSEI

The Purdue Quantum Science and Engineering Institute was established at Purdue University in order to foster the development of practical and impactful aspects of quantum science. The Institute focuses on discovering and studying new materials and basic physical quantum systems that will be best suited for integration into tomorrow's technology. It encourages interdisciplinary collaboration leading to the design and realization of industry-friendly quantum devices with enhanced functionality and performance close to the fundamental limits in order to produce systems based on these devices that will impact a vast community of users. Finally, we work to train the next generation of quantum scientists and engineers in order to meet the growing quantum workforce demands.

Atomic & Molecular Optics

Study of matter-matter and light-matter interaction on the scale of single atoms or molecules

- Ultra-cold atoms
- Many-body dynamics
- Coherent transient effects in atomic ensembles

Solid-State Quantum Systems

Study of quantum systems built inside a solid state of matter

- Color centers in diamond
- Topological insulators and correlated electron systems
- Quantum dots
- Quantum optomechanics
- 2D materials and graphene

Quantum Nanophotonics *Ultrafast/Nanoscale photonic structures for applications in quantum computation, communication, and sensing*

- SiN non-linear optics and entangled photon generation
- Control of interaction with metamaterials
- Vacuum Fluctuation Effects

Quantum Information & Communication

Study of quantum mechanical systems which can be used for processing, transmitting, and storing information

- Bi-photon pulse shaping
- Quantum algorithms and adiabatic quantum computing

57 Faculty Members: 34 from College of Science, 28 from College of Engineering

Full Name	Position	Department(s)	College(s)
Hany Abdel-Khalik	Professor	NE	COE
Vaneet Aggarwal	Associate Professor	IE	COE
Hadiseh Alaeian	Assistant Professor	ECE	COE
Arnab Banerjee	Assistant Professor	PHYS	COS
Peter Bermel	Professor	ECE	COE
David Bernal	Assistant Professor	CHEME	COE
Sunil Bhawe	Professor	ECE	COE
Rudro Biswas	Assistant Professor	PHYS	COS
Alexandra Boltasseva	Distinguished Professor	ECE	COE
Erica Carlson	Professor	PHYS	COS
Yong Chen	Professor, PQSEI Director	PHYS & ECE	COS & COE
Weng Chew	Distinguished Professor	ECE	COE
Gabor Csathy	Professor	PHYS	COS
Shawn Cui	Associate Professor	MATH & PHYS	COS
Supriyo Datta	Distinguished Professor	ECE	COE
Stephen Durbin	Professor	PHYS	COS
Daniel Elliott	Professor	ECE & PHYS	COE & COS
Chris Greene	Distinguished Professor	PHYS	COS
Jonathan Hood	Assistant Professor	CHEM	COS
Mahdi Hosseini	Associate Professor	ECE	COE
Libai Huang	Professor	CHEM	COS
Chen-Lung Hung	Associate Professor	PHYS	COS
Zubin Jacob	Professor	ECE	COE
Andreas Jung	Associate Professor	PHYS	COS
Sabre Kais	Distinguished Professor	CHEM & ECE	COS & COE
Ralph Kaufmann	Professor	MATH	COS
Birgit Kaufmann	Professor	MATH & PHYS	COS
Alexander Kildishev	Professor	ECE	COE

Young L. Kim	Associate Professor	BME	COE
Gerhard Klimeck	Professor	ECE	COE
Martin Kruczenski	Professor	PHYS	COS
Tillman Kubis	Associate Professor	ECE	COE
Rafael Lang	Professor	PHYS	COS
Nima Lashkari	Assistant Professor	PHYS	COS
Tongcang Li	Professor	PHYS & ECE	COS & COE
Grace Liang	Assistant Professor	PHYS	COS
Yuli Lyanda-Geller	Professor	PHYS	COS
Alex Ma	Assistant Professor	PHYS	COS
Michael Manfra	Distinguished Professor	PHYS,MSE,ECE	COS & COE
Saeed Mohammadi	Professor	ECE	COE
Evgenii Narimanov	Professor	ECE	COE
Laimei Nie	Assistant Professor	PHYS	COS
Minghao Qi	Professor	ECE	COE
Francis Robicheaux	Professor	PHYS	COS
Leonid Rokhinson	Professor	PHYS	COS
Thomas Roth	Assistant Professor	ECE	COE
Eric Samperton	Assistant Professor	CS, MATH	COS
Vlad Shalaev	Distinguished Professor	ECE	COE
Niranjan Shivaram	Assistant Professor	PHYS	COS
Wojciech Szpankowski	Distinguished Professor	CS	COS
Pramey Upadhyaya	Assistant Professor	ECE	COE
Jukka Vayrynen	Assistant Professor	PHYS	COS
Valentin Walther	Assistant Professor	CHEM	COS
Adam Wasserman	Professor	CHEM	COS
Andy Weiner	Distinguished Professor	ECE	COE
Peide Ye	Professor	ECE	COE
Qi Zhou	Professor	PHYS	COS

Department	Faculty
PHYS	27
ECE	24
CHEM	5
MATH	4
CS	2
BME	1
IE	1
MSE	1
NUCL	1
CHEME	1

PQSEI Affiliated Faculty

A very interdisciplinary group across Science & Engineering

57 Faculty Members: 34 from College of Science, 28 from College of Engineering

Department	Faculty
PHYS	27
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<https://www.purdue.edu/dp/quantum>

Significant Growth of Quantum Research/Programs at Purdue in recent years:

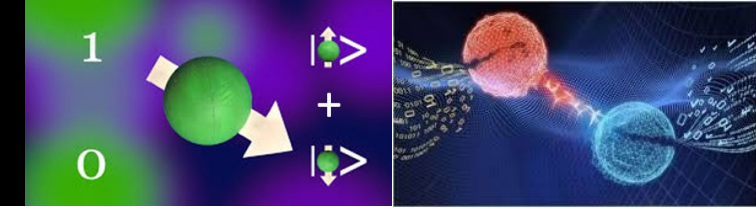
- *~20 new faculty members related to quantum science and technology hired in both COE/COS in past decade – PQSEI grown from ~25 faculty at founding (2019) to 57 today*
- COE Tellabs **Quantum Photonics Preeminent Team**
- COS Atomic Molecular Optical (**AMO**) **Physics Cluster** Initiative
- COS **Quantum Information Science** cluster hiring initiatives

Also leveraging related programs:

- Spintronics Preeminent Team Initiatives
- Engineering Faculty Conversation (EFC) Initiatives on Nano/Quantum
- Condensed matter physics (quantum materials) group
- Microsoft Station Q Purdue (Manfra Group)
- Birck Nanotechnology Center
- NanoHub

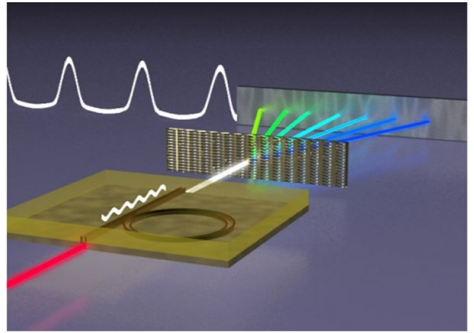
<https://www.purdue.edu/newsroom/releases/2019/Q1/purdue-dives-deeper-into-potentially-game-changing-field-of-quantum-science-and-engineering.html>

PQSEI: Bring people from diverse backgrounds together to pursue collaborative new research/funding/partnerships...

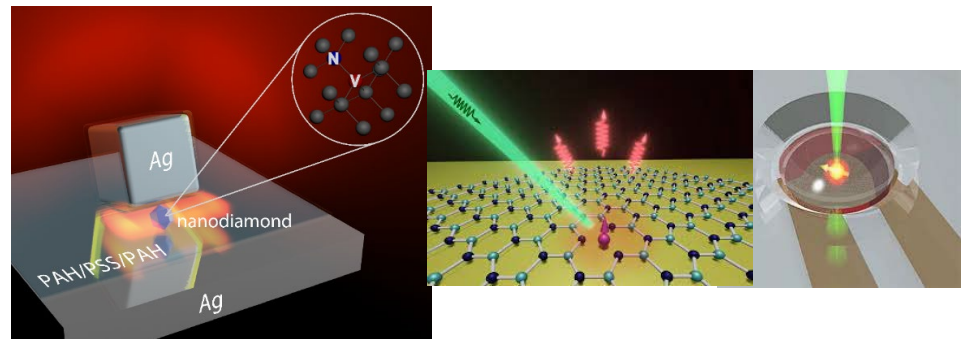


Key Quantum Technologies @ Purdue

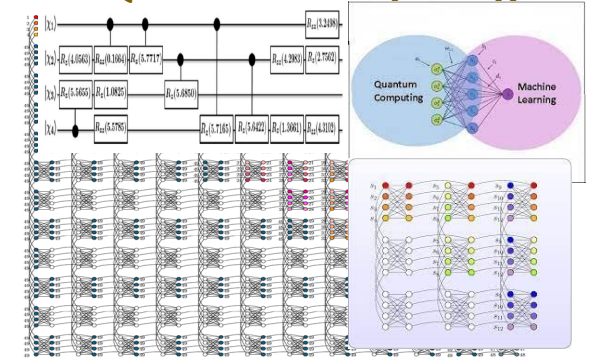
Quantum communications



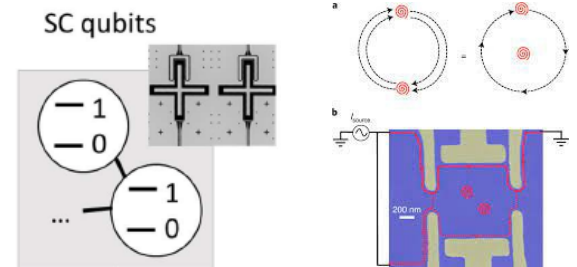
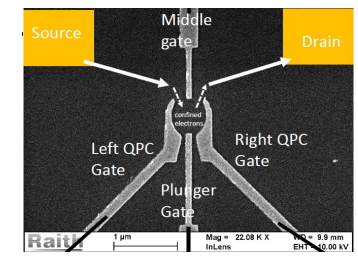
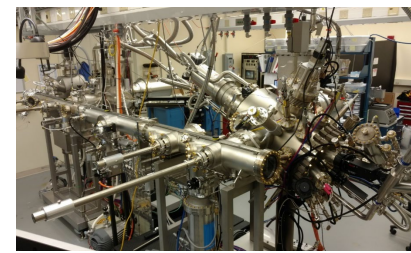
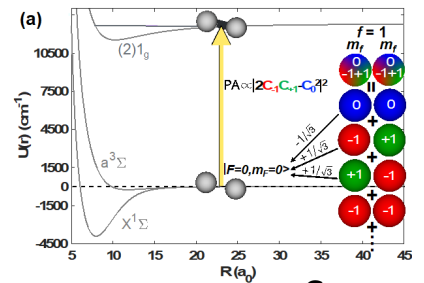
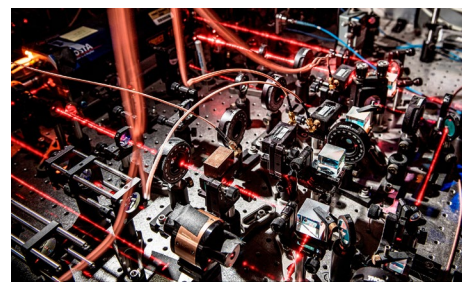
Quantum Sensing



Quantum Computing



Hardware platforms: entangled photons; NVs (and other spin defect centers); spin qubits, superconductor qubits, (towards) topological qubits.

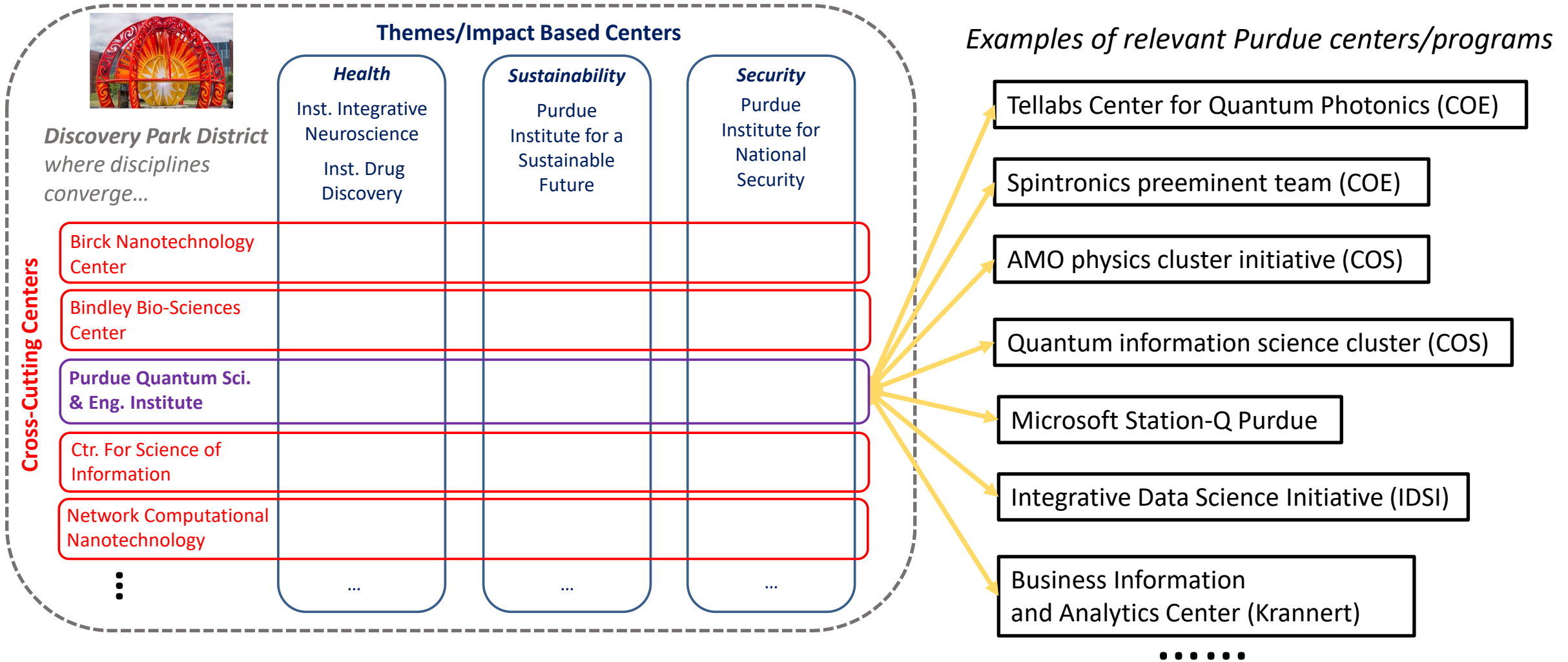


Supported by key **Quantum Sciences** strengths in:

***Atomic-Molecular-Optical Physics & Quantum Photonics** [ultrafast optical q.comm/q.computing, plasmonics speedup]

***Quantum Materials/Devices & Nanoelectronics** [e.g. quantum structures/devices/transport, e.g. quantum Hall, topological/2D materials; nanoelectronics/spintronics; NEMS; "nanoHub"]

Important synergies/connections with other key technologies: **Semiconductors/microelectronics; AI**



Discovery Park District facilitates collaborative research which allows PQSEI and relevant centers/programs to impact tomorrow's technologies across a variety of disciplines!

Birck Nanotechnology Center



- 25,000 sq. ft. of bay-chase cleanroom, with 45% of the bays operating at ISO 3 (Class 1), 40% operating at ISO 4 (Class 10), and the remaining 15% operating at ISO 5 (Class 100)
- Three-level structure consists of a full subfab, the cleanroom level, and an air-handling level above the cleanroom.
- Capabilities include nano- and microscale lithography, wet- and dry-etching, physical vapor deposition, three-tube banks of process furnaces, ultra-pure water system, and pharmaceutical-grade biocleanroom.
- Facility also provides 22,000 sq. ft. of specialized laboratories and offices for 45 resident faculty members, 30 post-docs, 30 staff, and approximately 200 graduate students.

Currently undergoing \$49M upgrade!!

PQSEI Mission & Objectives

Make Purdue a leading Hub for new quantum science & technology

- Create/support major **new/emerging [interdisciplinary] research areas** in quantum science & technology (QST) where Purdue can be a pioneer and a leader
 - Examples: interfacing quantum photonics/AMO physics with spintronics/quantum materials/devices (impacting quantum communication and sensing); novel game-changing applications of quantum sensors and other quantum technologies (quantum materials research, high energy/nuclear physics and even industrial processes); “applied quantum computing” applying quantum algorithms and machine learning to data analytics and optimization (including many industrial or business problems)
- Attract **big projects and center-level funding** (e.g., DOE, NSF, ..) on QST
- Develop **key partnerships** (DoD, national labs, industrial, international) on QST
- Train the next generation quantum workforce.

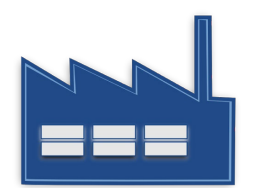
Key PQSEI Initiatives



- Quantum Science Center (QSC) (qscience.org)
 - One of five DOE-funded National Quantum Information Science Research Centers (led by ORNL) – *Purdue is core partner*
 - 3 main goals: develop topological quantum materials, create algorithms that exploit topological systems, and demonstrate new devices and sensors
 - Purdue also leads workforce development efforts of the QSC (Prof. Alexandra Boltasseva)
- Workforce Development
 - Innovation in Quantum Pedagogy, Application and its Relation to Culture (IQ-PARC) – \$2.8 M project from DoD (www.iqparc.com; E. Carlson, M. Hosseini)
 - Quantum Micromasters Program (<https://www.edx.org/micromasters/purdue-quantum-technology-computing>)
 - Quantum Coffeehouse YouTube Channel (<https://www.youtube.com/quantumcoffeehouse>)
 - Contributing to Quantum Economic Development Consortium (QED-C) Workforce Committee
- Midwest Quantum Collaboratory (www.midwestquantum.org)
 - Partnership with U. Michigan and Michigan St. to collaborate on quantum information science grand challenges.
- Quantum Collaborative (quantumcollaborative.org)
 - Led by Arizona State - aims to advance QIST, build workforce, and drive US quantum economy
- Other Projects led by PQSEI Faculty
 - DOE quantum chemistry & quantum materials program (algorithm & experiments, PI: Kais)
 - DOD: DARPA QUEST/DETECT (light-matter interaction/photodetector, PI: Jacob)
 - DOD MURI: Weyl Fermion Optoelectronics (PI: Boltasseva)
 - Elmore Emerging Frontiers Center: Crossroads of Quantum and AI (PI: Boltasseva) (<https://engineering.purdue.edu/Elmore-EFC>)

Center for Quantum Technologies (CQT)

Projects launched May 2023



NSF provides \$ for administrative and management costs

Members provide \$ for research (0% overhead – all member fees go directly to research efforts)

Universities provide infrastructure and people to conduct research

Members gain access to pre-competitive research and highly-skilled workforce

PI & Director
Prof. Sabre Kais
(kais@purdue.edu)

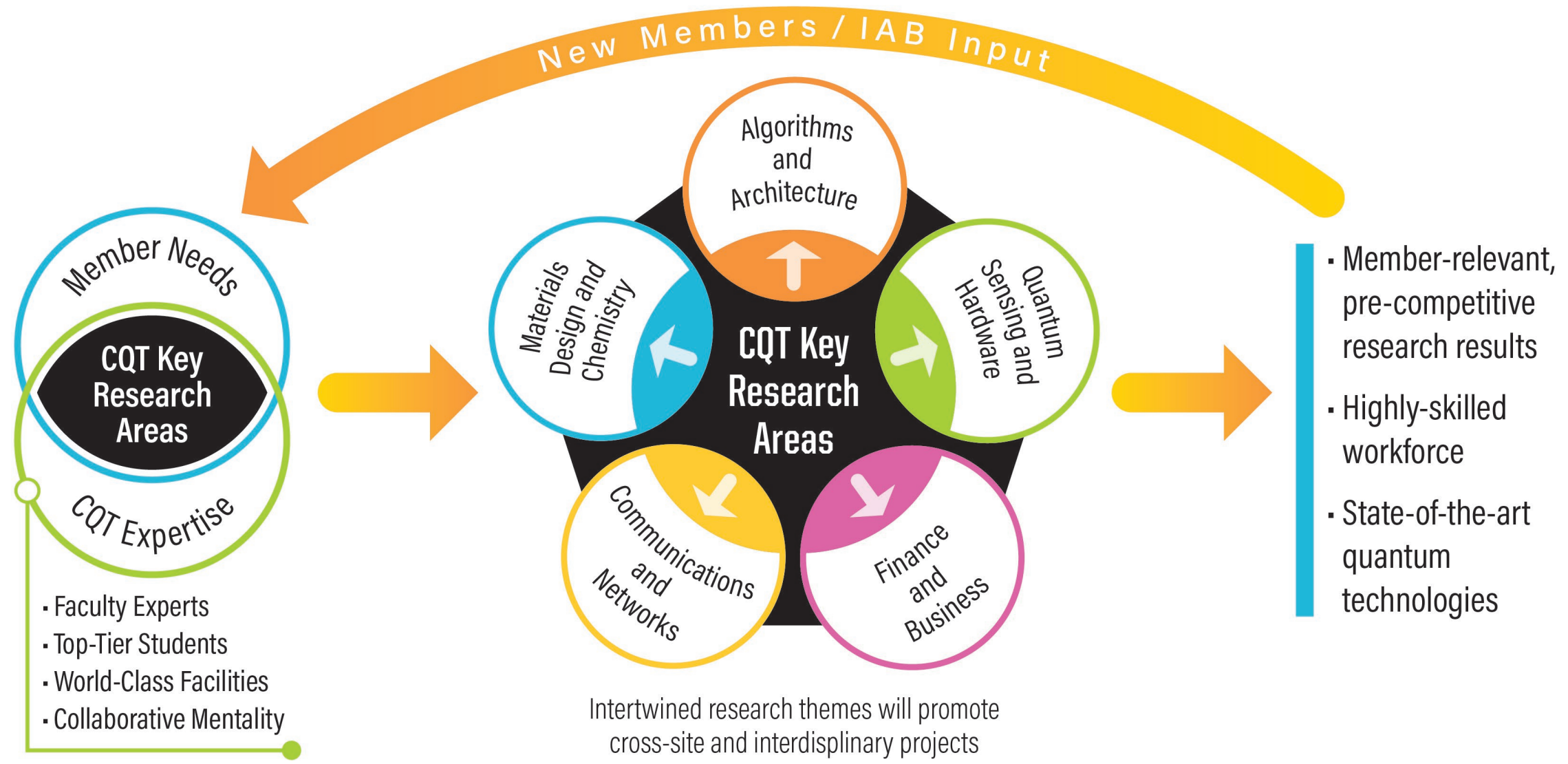
Industry Liaison
Officer/Man. Dir.:
Dr. David Stewart
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- Benefits for Industry/Government Members:**
- All research projects are selected by members
 - Access to talent (students and faculty)
 - Leverage of research dollars (minimum 18:1 leverage on \$50K member fee)
 - Network opportunities with other CQT members
 - Royalty-free, non-exclusive license to center IP
 - R&D risk mitigation – sharing risks with peers

- CQT Members:**
- AFRL
 - AWS
 - Cummins
 - D-Wave
 - Eli Lilly
 - Entanglement, Inc.
 - Hewlett Packard
 - Peraton
 - Quantum Corridor
 - Toyota

CQT Research Roadmap

CQT Projects launched May 2023



CQT Members



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