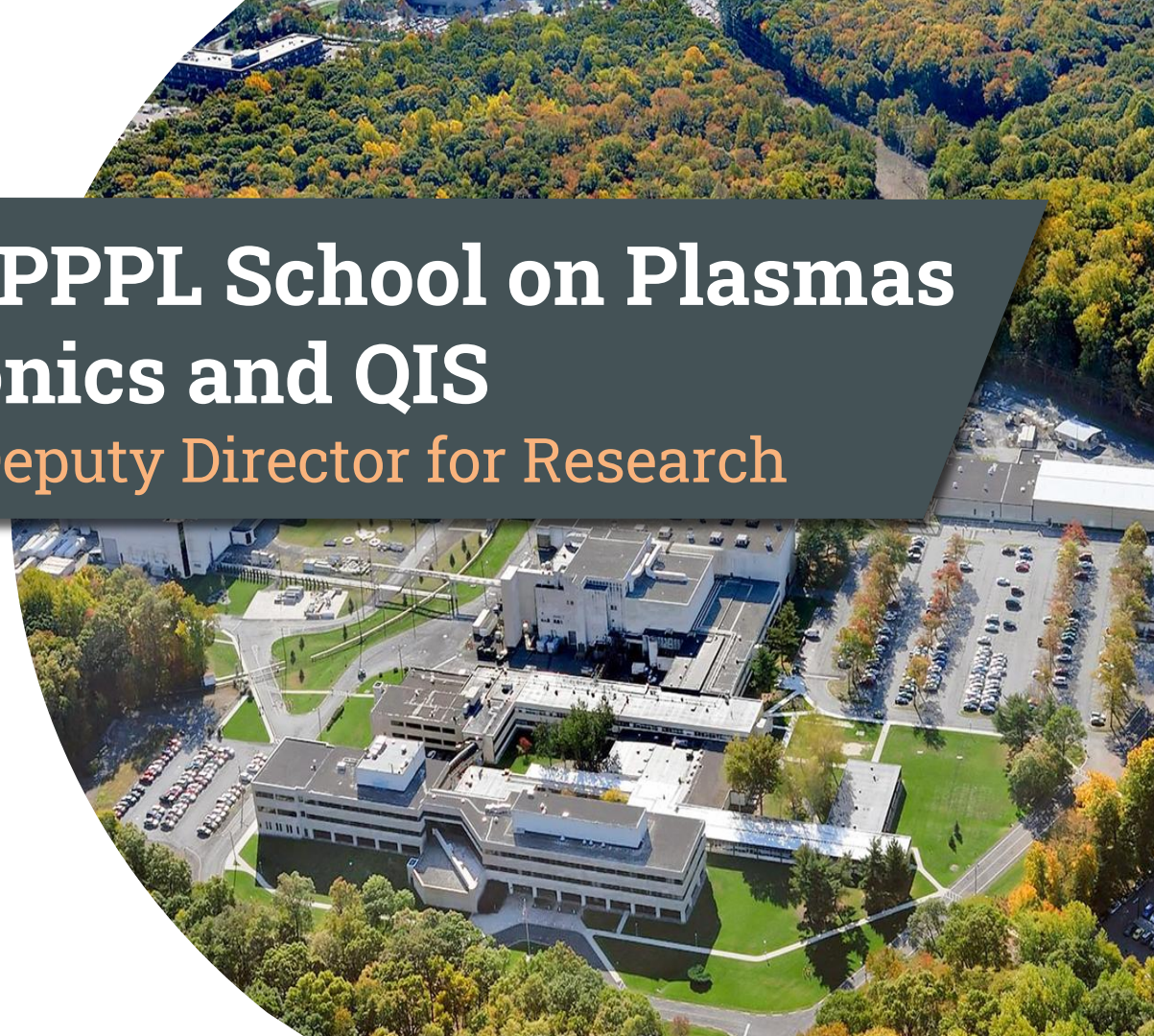
PPPL PRINCETON PLASMA PHYSICS LABORATORY

Welcome to the PPPL School on Plasmas for Microelectronics and QIS

Jon Menard – PPPL Deputy Director for Research



A few PPPL stats

U.S. DEPARTMENT OF ENERGY

One of 17 Dept. of Energy **National Labs**

Managed by PRINCETON UNIVERSITY

700+
Lab employees

$200+ million
government funding

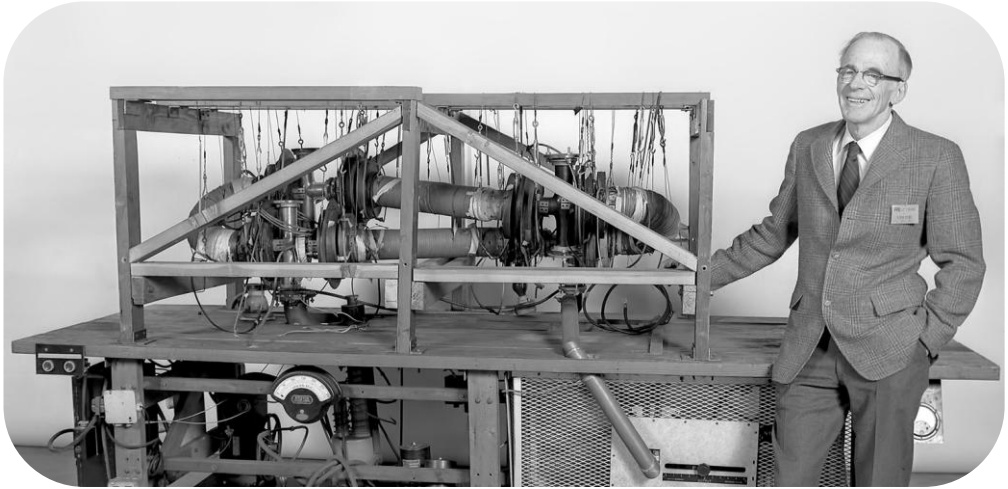
90 acres
Princeton, NJ campus

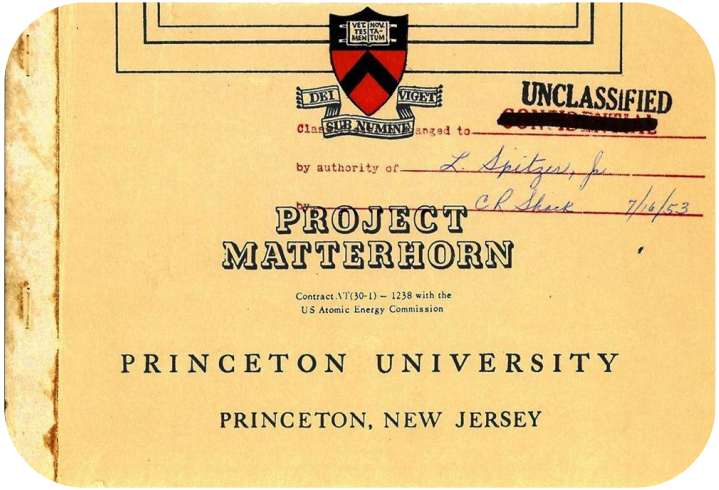
300+
annual research publications

**FY25 figures*

PPPL History

Magnetic fusion research at Princeton began as a classified government project in 1951 under renowned physicist **Lyman Spitzer Jr.**, using the code name “Project Matterhorn.”





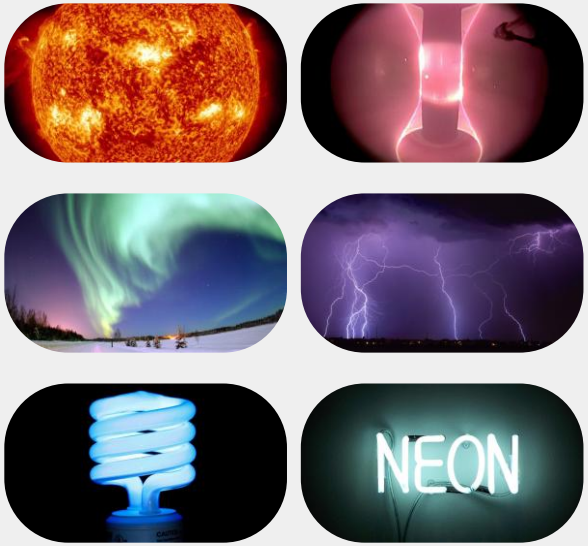
PPPL mission:

Tackling the world's toughest science & technology challenges using **plasma**, the fourth state of matter.

So, what is plasma?

- Plasma is the **fourth state of matter**, making up 99.9% of the visible universe.
- Plasma is a **soup of atomic particles** some of which have net-electric charge.
- Plasma fuels **fusion reactions**, which we can use to create clean, safe, limitless energy.

Examples of plasma:



PPPL Core Strengths

Plasma Science

Engineering

Computational Sciences

Diagnostics & Analysis

PPPL Leads Major Plasma Facilities and R&D

LOCATED AT PPPL:

NSTX-U

National Spherical Torus Experiment-Upgrade

FLARE

Facility for Laboratory Reconnection Experiment

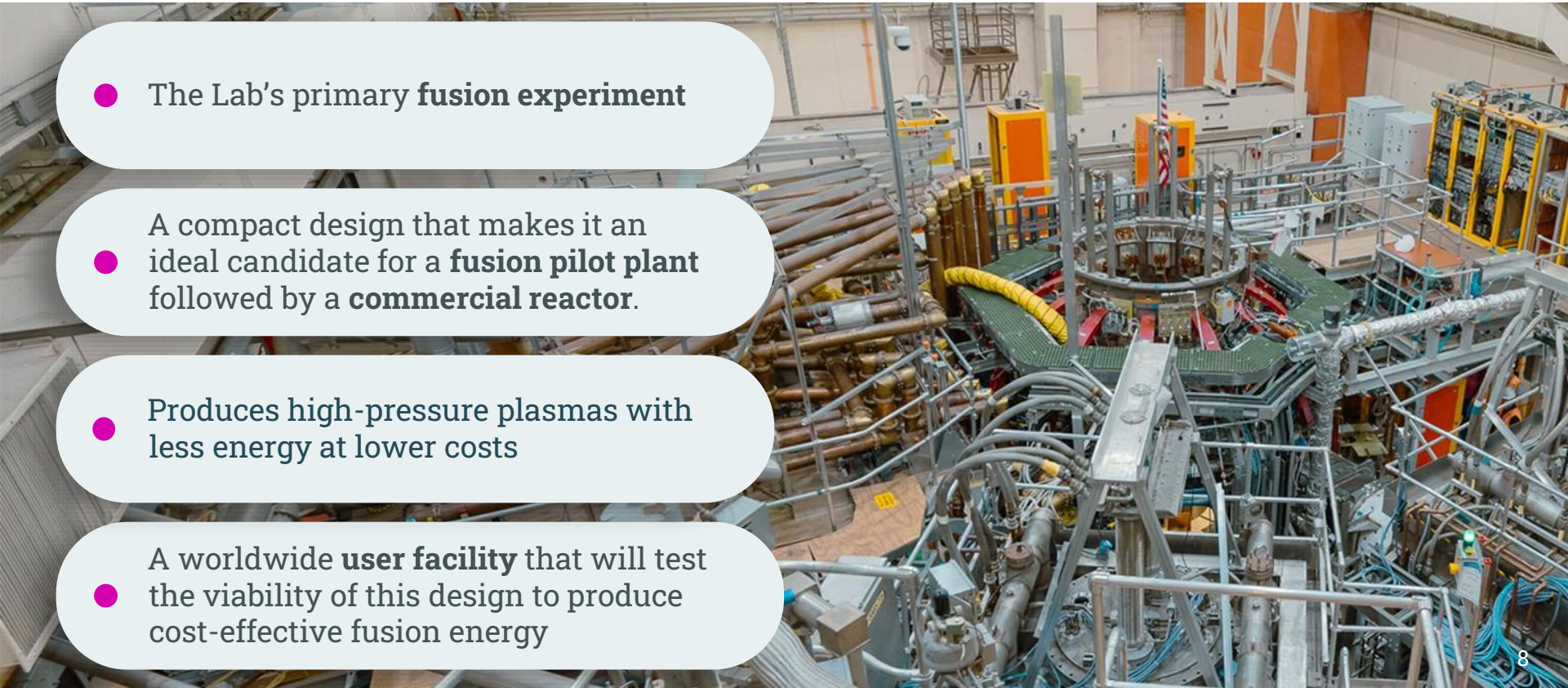
INTERNATIONAL PARTNER:

U.S. ITER

PPPL is designing and building diagnostic equipment and developing scientific data and software coding for the international facility.

NSTX-U

National Spherical Torus Experiment-Upgrade



- The Lab's primary **fusion experiment**
- A compact design that makes it an ideal candidate for a **fusion pilot plant** followed by a **commercial reactor**.
- Produces high-pressure plasmas with less energy at lower costs
- A worldwide **user facility** that will test the viability of this design to produce cost-effective fusion energy

One Decisive Step

| On the road to a ST fusion pilot plant

NSTX-U Results

- **STAR** — *PPPL*
- **ST-E1** — *Tokamak Energy (U.K.)*
- **STEP** — *U.K. Atomic Energy Authority*
- **FAST** — *Japan*

Commercial reactors 2045….?

2026 — *First plasma*

- *Validate the physics of the spherical tokamak*
- *Liquid lithium campaign*

2031 — *Fusion pilot plant design*

2035 — *Fusion pilot plant operation*

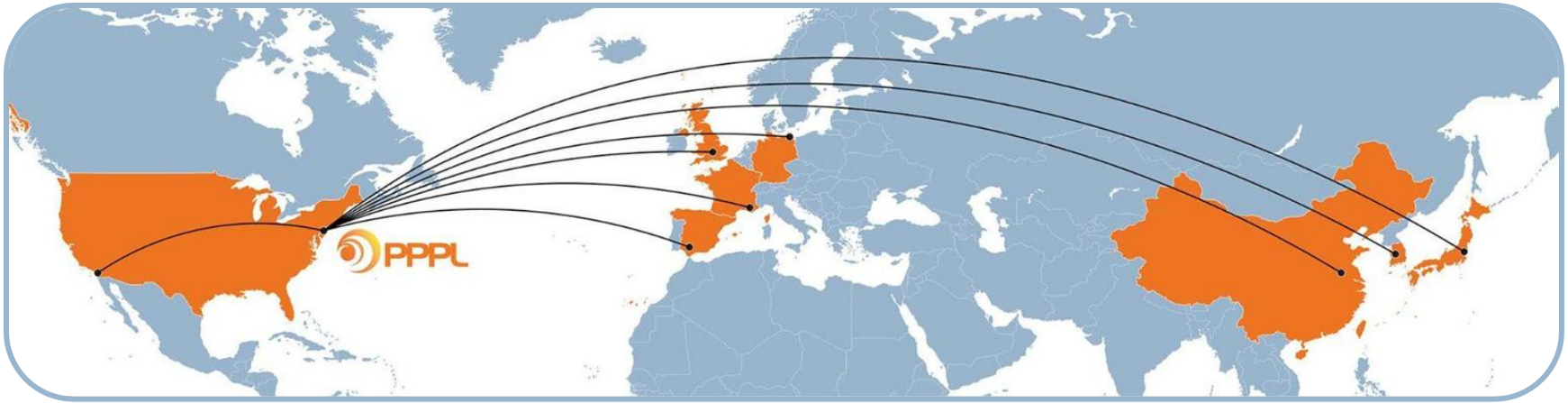
2040

2045

Worldwide Fusion Facilities

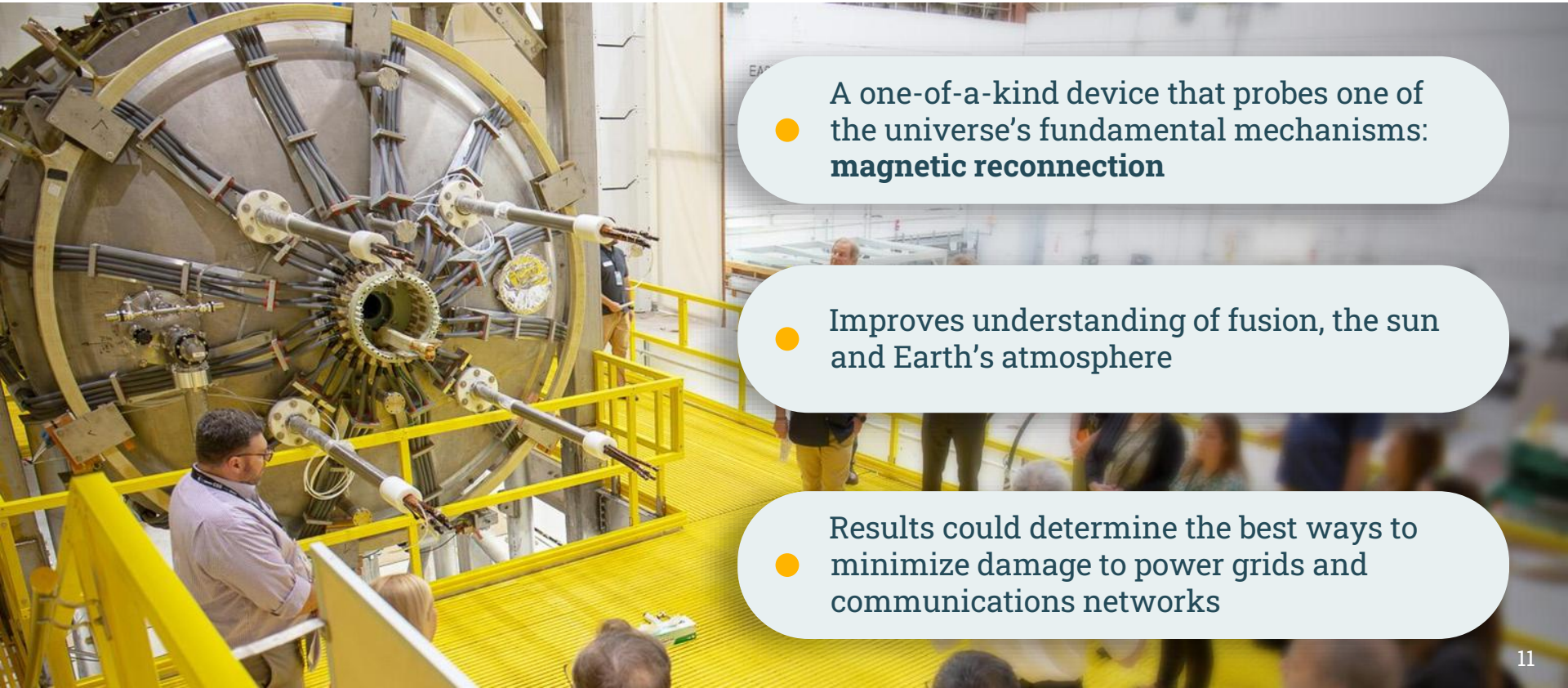
We collaborate with experimental fusion facilities around the world, contributing to **global scientific discovery.**

- **DIII-D** | San Diego, CA
- **EAST** | Hefei, China
- **ITER** | Cadarache, France
- **JET** | Oxfordshire, UK
- **JT0-60SA** | Ibaraki, Japan
- **K-STAR** | Daejeon, South Korea
- **LHD** | Toki, Japan
- **MAST-U** | Oxfordshire, UK
- **SMART** | Seville, Spain
- **ST40** | Oxford, UK
- **W7-X** | Greifswald, Germany
- **WEST** | Cadarache, France



FLARE

Facility for Laboratory Reconnection Experiments



- A one-of-a-kind device that probes one of the universe's fundamental mechanisms: **magnetic reconnection**
- Improves understanding of fusion, the sun and Earth's atmosphere
- Results could determine the best ways to minimize damage to power grids and communications networks

Science Education & Public Engagement

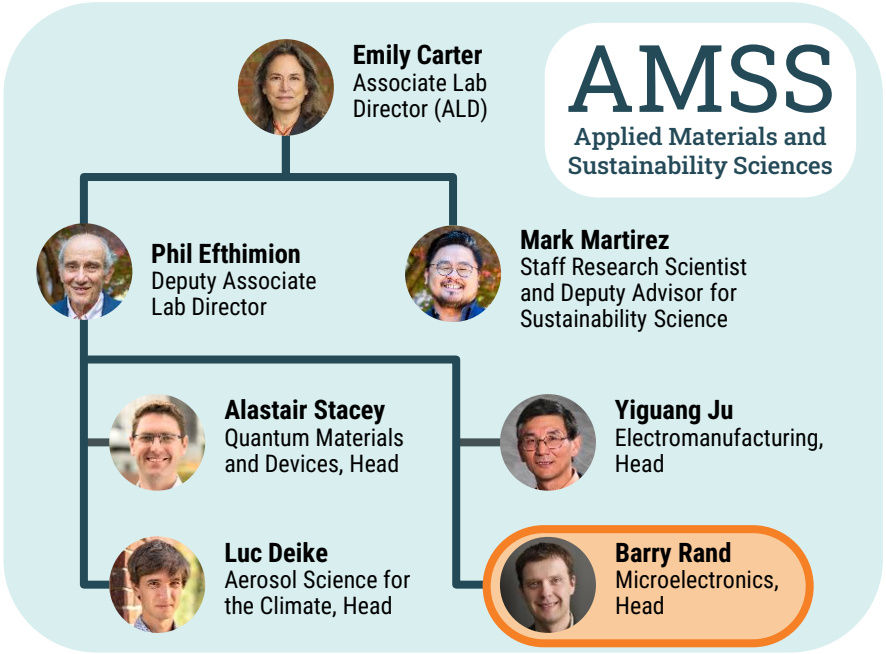
Public Engagement & Outreach

- Plasma Network for Engagement and Training
- APS Division of Plasma Physics
- Young Women in STEM Conference
- Regional Science Bowl Competition
- Ronald E. Hatcher Science on Saturday Series
- Plasma Demonstrations at Local Schools

Academic Programs

- Science Undergraduate Laboratory Internships (SULI)
- Community College Internships (CCI)
- Visiting Faculty Program
- Science Graduate Student Research Program
- Plasma & Fusion Undergraduate Research Opportunities
- High School Internships
- National GEM Consortium Fellowship
- Lab-wide Internship Programs

Increased Emphasis on Research Diversification:
Applied Materials and Sustainability Sciences (AMSS)



- Established Associated Faculty Program with PU
- Six current appointments:
  - Yiguang Ju
  - Luc Deike
  - Marissa Weichman
  - Nathalie de Leon
  - David Graves
  - Barry Rand

Completed: Two PU-PPPL reports to enhance collaborations

Growing AMSS portfolio in Microelectronics R&D

- Science of plasma etching and deposition
- Developing collaborations with **Samsung**; extended agreements with **Applied Materials** and **Lam Research**
  - Advanced laser-based diagnostics on **AMAT** etch system
- Developed novel, patented diagnostics for processing control
- PPPL-led **microelectronics science research centers (MSRCs)**: 2D materials processing, diamond extreme electronics, next-gen EUV sources ***TWO selected and initiated!***
- Invited co-PI with INL-led team: Radiation-hardened GaN sensors
- Teaming in CHIPS Manufacturing USA Institute for diamond materials and digital twins


Luis Delgado-Aparicio


Ahmed Diallo


David Graves


Igor Kaganovich

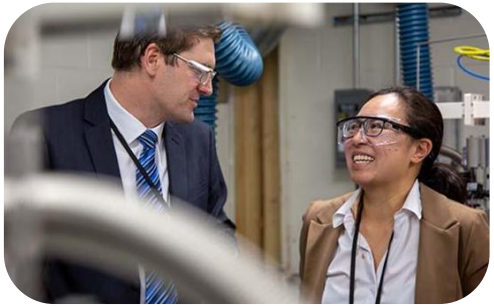

Yevgeny Raitses


Barry Rand

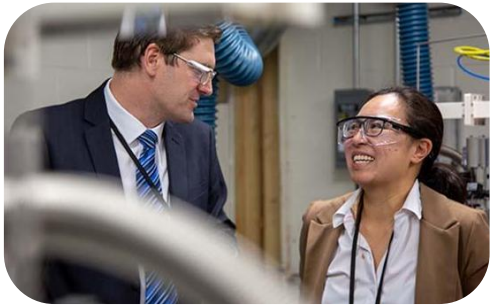

Alastair Stacey

Growing AMSS portfolio in Quantum Materials and Devices

- Quantum diamond lab opened in March 2024
- Operational; initial science started
- PU providing $1.3 million to complete construction
- DOD interest: DARPA funding diamond wafers; teaming with DOD Microelectronics Commons – NORDTECH Hub
- Increasing interest in quantum sensing for fusion
- Working toward a collaborative research facility



Growing AMSS portfolio in Quantum Materials and Devices



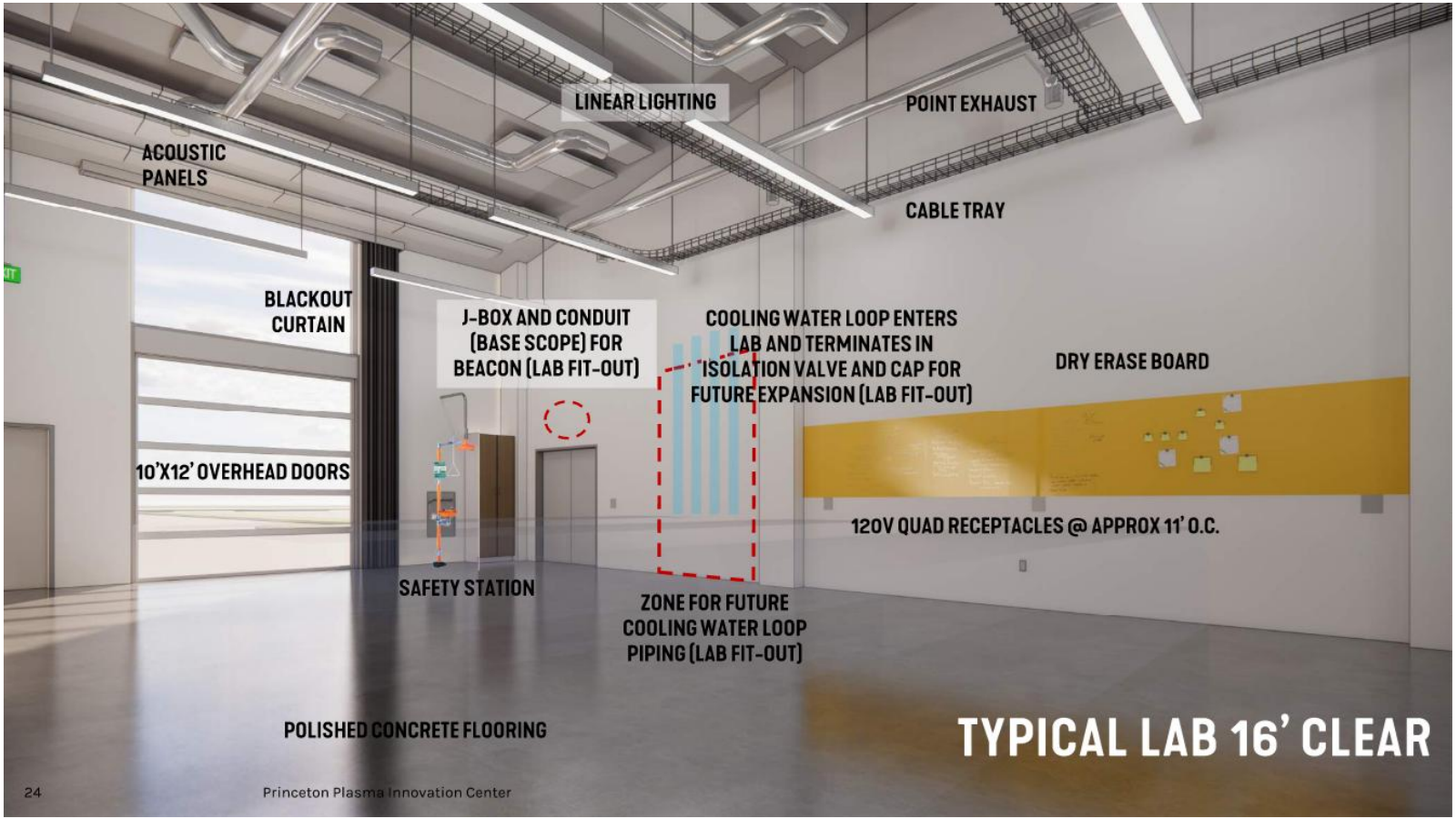
- Element Six (E6) reactor completed **Delivered Dec. 17!**
- Unique partnership with E6 to use and enhance world-leading Q-diamond synthesis tools - lab setup underway

New PPIC Building On Track to Open in 2027

Princeton Plasma Innovation Center (PPIC)

An International Hub of Fusion Research and Plasma Science and Technology

New Medium Bay Labs Enable Growth in ME, QIS

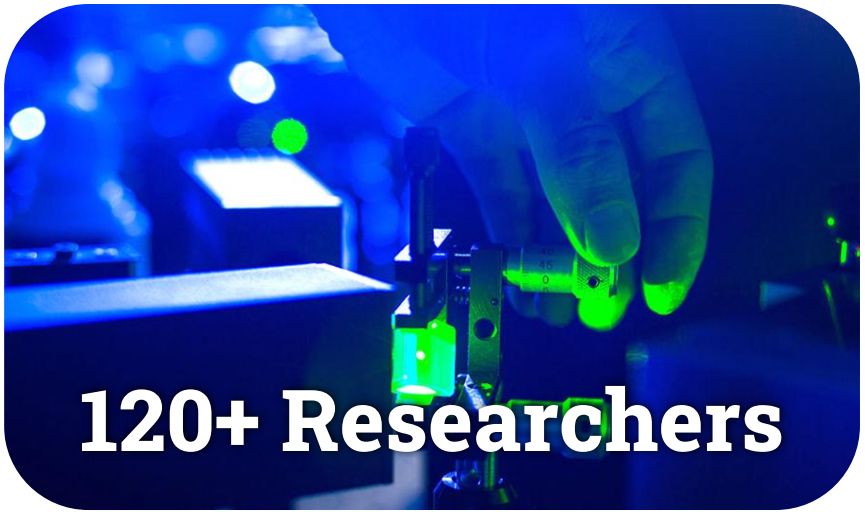


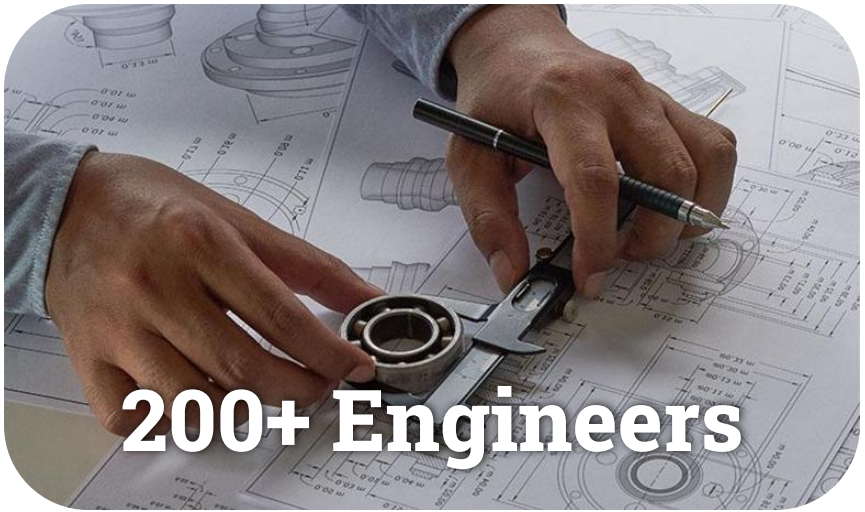
Thank you for participating!

And enjoy the summer school

Backup

Stellar Science Meets Precision Engineering





*FY22 figures

Lab Leadership

Executive Management Team

Steve Cowley
Laboratory Director

Laura Berzak Hopkins
Associate Laboratory Director for Strategy and Partnerships, Deputy Chief Research Officer

Emily Carter
Associate Laboratory Director for Applied Materials and Sustainability Sciences & Senior Strategic Advisor

Kristen Fischer
Chief Financial Officer and Head of Business Operations

Mike Ford
Associate Laboratory Director for Engineering

Michelle Heintz
Chief Human Resources Officer

Jon Menard
Deputy Director for Research and Chief Research Officer

Tim Meyer
Deputy Director for Operations and Chief Operating Officer

Public-Private Partnerships

We believe public-private partnerships are key to advancing commercial fusion. We're partnering with a number of private companies through the Department of Energy's **Milestone-Based Fusion Development Program.**

Fusion Research and Technology Hub (FuRTH)

Largest space for fusion experiments in the U.S. & among the largest in the world
Impressive infrastructure & utility
Ideal platform for private industry partnerships
Can easily support multiple fusion experiments