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DEPARTMENT OF ENERGY (DOE)

Laying a Foundation to Revolutionize Microelectronics

Chris Fall
DOE Office of Science

DARPA ERI Summit
15 July 2019

DOE Missions

Energy

Catalyze the timely, material, and efficient transformation of the nation's energy system and secure U.S. leadership in energy technologies.

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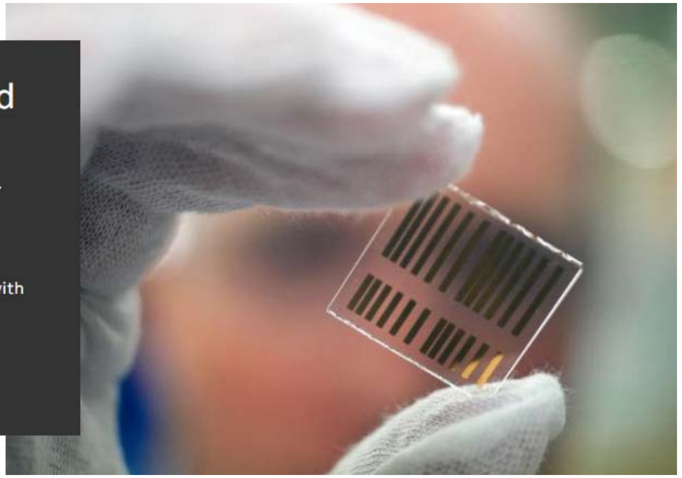

Science and Innovation

Maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.

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Nuclear Safety and Security

Enhance nuclear security through defense, nonproliferation, and environmental efforts.

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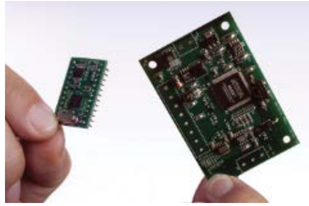
Future computing technologies underpin the DOE mission

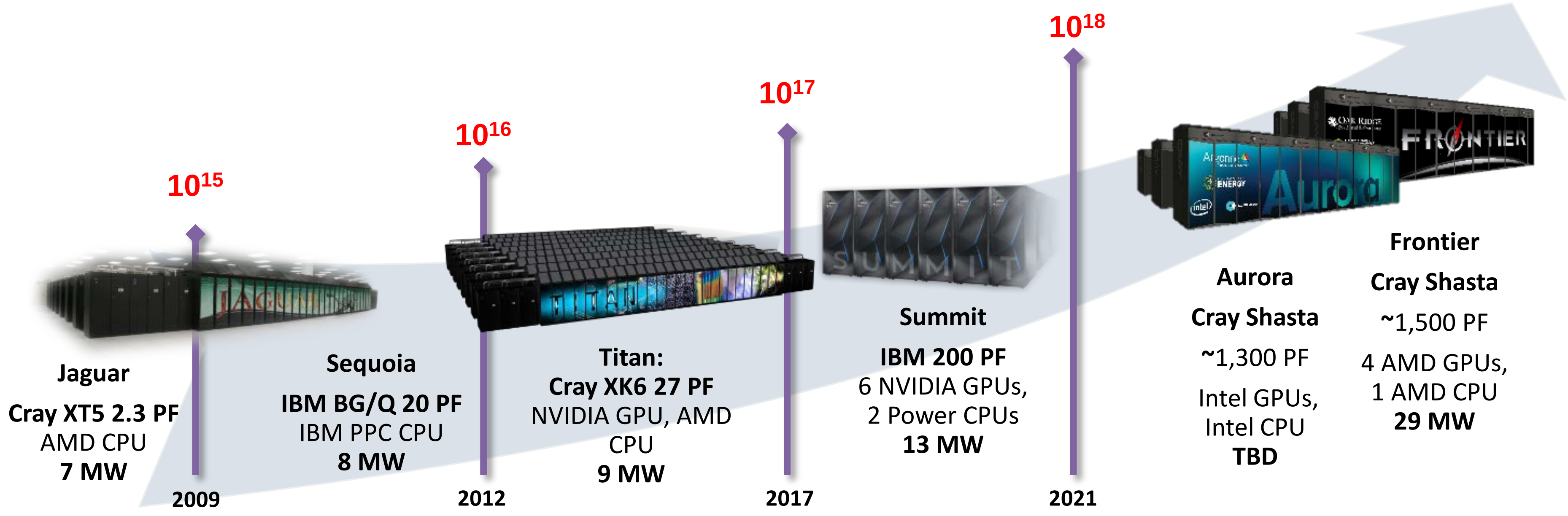
- High-performance computing & simulation underpin DOE missions in energy, environment, and national security
- Future computing technologies (e.g., quantum, neuromorphic, probabilistic, etc.) hold promise for next-generation DOE mission applications
- New directions for applied mathematics and computer science are likely to emerge that could enable new science across DOE-SC
- Advanced microelectronics and power electronics will be necessary to enable exascale and larger computers… and a smart electricity grid



ASCR Supercomputers: Size and Power Draw

Supercomputers take up about the size of a basketball court and have 300,000 to half-million leading edge processor and memory chips in them. They have a lifetime of 4-5 years

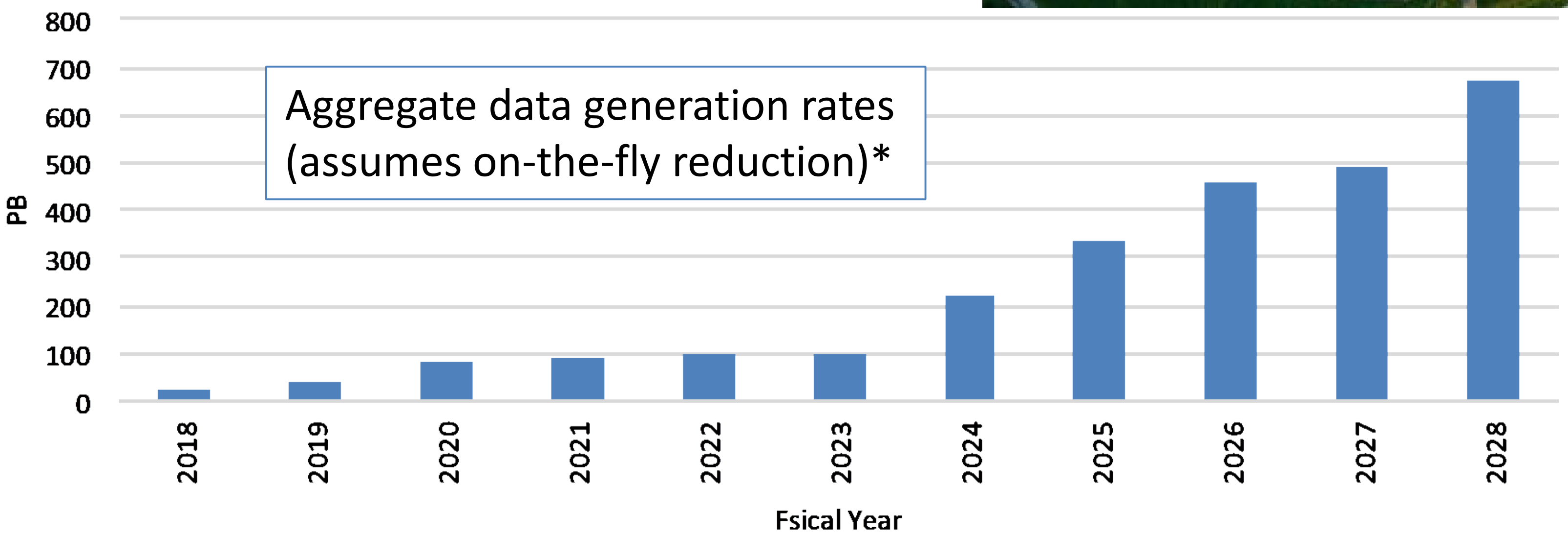


DOE Leadership Supercomputers
Power draw has steadily increased even as the power to performance ratio has greatly improved

DOE light sources will require data intensive edge computing

- **Future needs at DOE Light Sources**
  (ALS, APS, LCLS/LCLS-II, NSLS-II, SSRL)

- Facility computing needs will increase 10-15X over the next decade



- Similar data/compute challenges faced by other BES, HEP, NP, and FES facilities

** From: BES User Facilities Data Management and Analysis Resource Needs BES/ASCR Data Call*

The DOE Office of Science Labs Today

Berkeley Lab

$858M in FY 2018

- Founded 1931
- 202 acres, 96 buildings
- 3,302 FTEs, including: 486 post-docs, 411 students, and 232 joint faculty
- 2,241 visiting scientists
- 11,403 facility users

Pacific Northwest National Laboratory

$887M in FY 2018

- Founded 1965
- 781 acres, 71 buildings
- 4,238 FTEs, including: 256 post-docs, 745 students, and 64 joint faculty
- 302 visiting scientists
- 1,742 facility users

The Ames Laboratory

$56M in FY 2018

- Founded 1947 (1942)
- 10 acres, 13 buildings
- 307 FTEs, including: 46 post-docs, 174 students, and 43 joint faculty
- 321 visiting scientists

Fermilab

$414M in FY 2018

- Founded 1967
- 6,800 acres, 366 buildings
- 1,783 FTEs, including: 88 post-docs, 94 students, and 13 joint faculty
- 9 visiting scientists
- 3,472 facility users

Argonne National Laboratory

$782M in FY 2018

- Founded 1946 (1942)
- 1,517 acres, 154 buildings
- 3,225 FTEs, including: 273 post-docs, 569 students, and 274 joint faculty
- 1,107 visiting scientists
- 8,305 facility users

SLAC National Accelerator Laboratory

$593M in FY 2018

- Founded 1962
- 426 acres, 149 buildings
- 1,531 FTEs, including: 152 post-docs, 299 students, and 36 joint faculty
- 19 visiting scientists
- 2,692 facility users

Oak Ridge National Laboratory

$1,570M in FY 2018

- Founded 1943
- 4,421 acres, 271 buildings
- 4,957 FTEs, including: 320 post-docs, 633 students, and 214 joint faculty
- 1,888 visiting scientists
- 3,248 facility users

Jefferson Lab

$172M in FY 2018

- Founded 1962
- 169 acres, 69 buildings
- 1678 FTEs, including: 34 post-docs, 53 students, and 27 joint faculty
- 1,438 visiting scientists
- 1,597 facility users

PPPL Princeton Plasma Physics Laboratory

$100M in FY 2018

- Founded 1961 (1951)
- 91 acres, 30 buildings
- 495 FTEs, including: 21 post-docs, 48 students, and 6 joint faculty
- 50 visiting scientists
- 292 facility users

Brookhaven National Laboratory

$546M in FY 2018

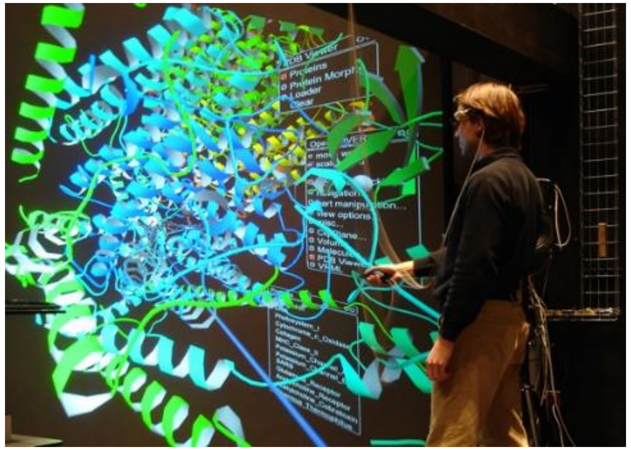
- Founded 1947
- 5,322 acres, 315 buildings
- 2,527 FTEs, including: 116 post-docs, 395 students, and 123 joint faculty
- 2,313 visiting scientists
- 2,923 facility users

Emerging applications will require new computing paradigms

Autonomous Vehicles

Smart Grid

Edge Computing



Artificial Intelligence

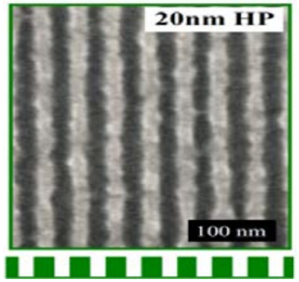
Machine Learning

Neuromorphic

DOE Provides User Facilities for Information and Semiconductor Technologies

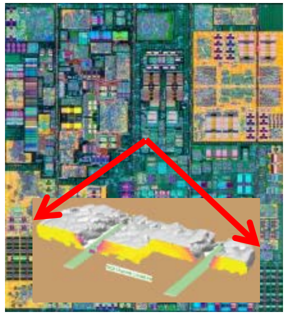
Next Generation Integrated Circuits

Novel Extreme Ultraviolet (EUV) photoresist was developed at NSRCs that has both high resolution and high sensitivity. This approach may be the key to achieving the industrial goals for sub14 nm nodes.



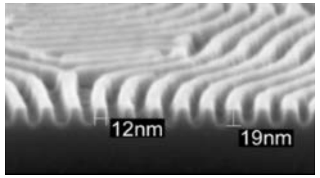
Advanced Microprocessors

Unique NSRC hard x-ray Nanoprobe enables nondestructive measure of in-situ stress distributions in silicon-on-insulator (SOI)-based CMOS for sub 75nm microprocessor technology.



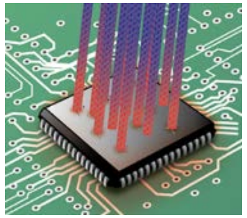
Ultradense Memories

Expertise in polymer nanostructure self-assembly and electron microscopy can be applied to Terabit/cm^2 scale magnetic memories for computing and imaging

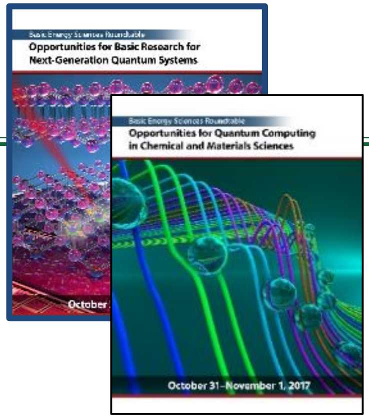


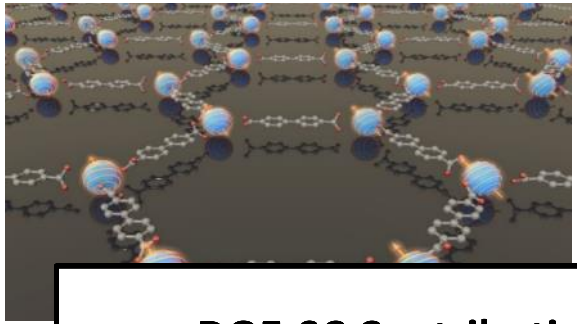
Cooling Computer Chips

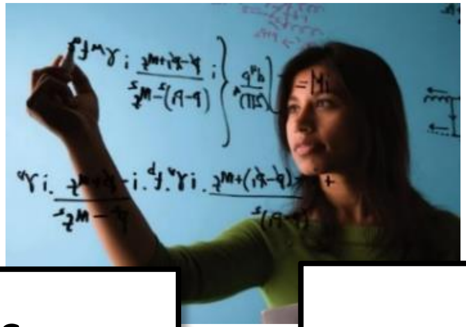
Cooling is critical to microprocessor speed. Carbon nanotubes (CNTs) conduct heat better than diamond so might be used as heat sinks. NSRC scientists showed that strong covalent binding of CNTs to devices can help remove heat six times better than with weaker ones.



DOE Office of Science QIS Strategy







DOE-SC Contributions to QIS

- Fundamental Science
- Tools, Equipment, Instrumentation
- DOE Community Resources

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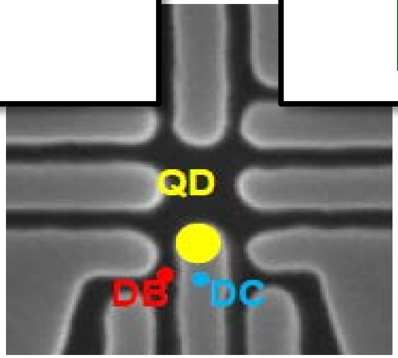
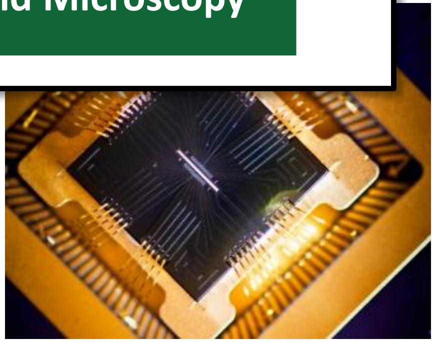
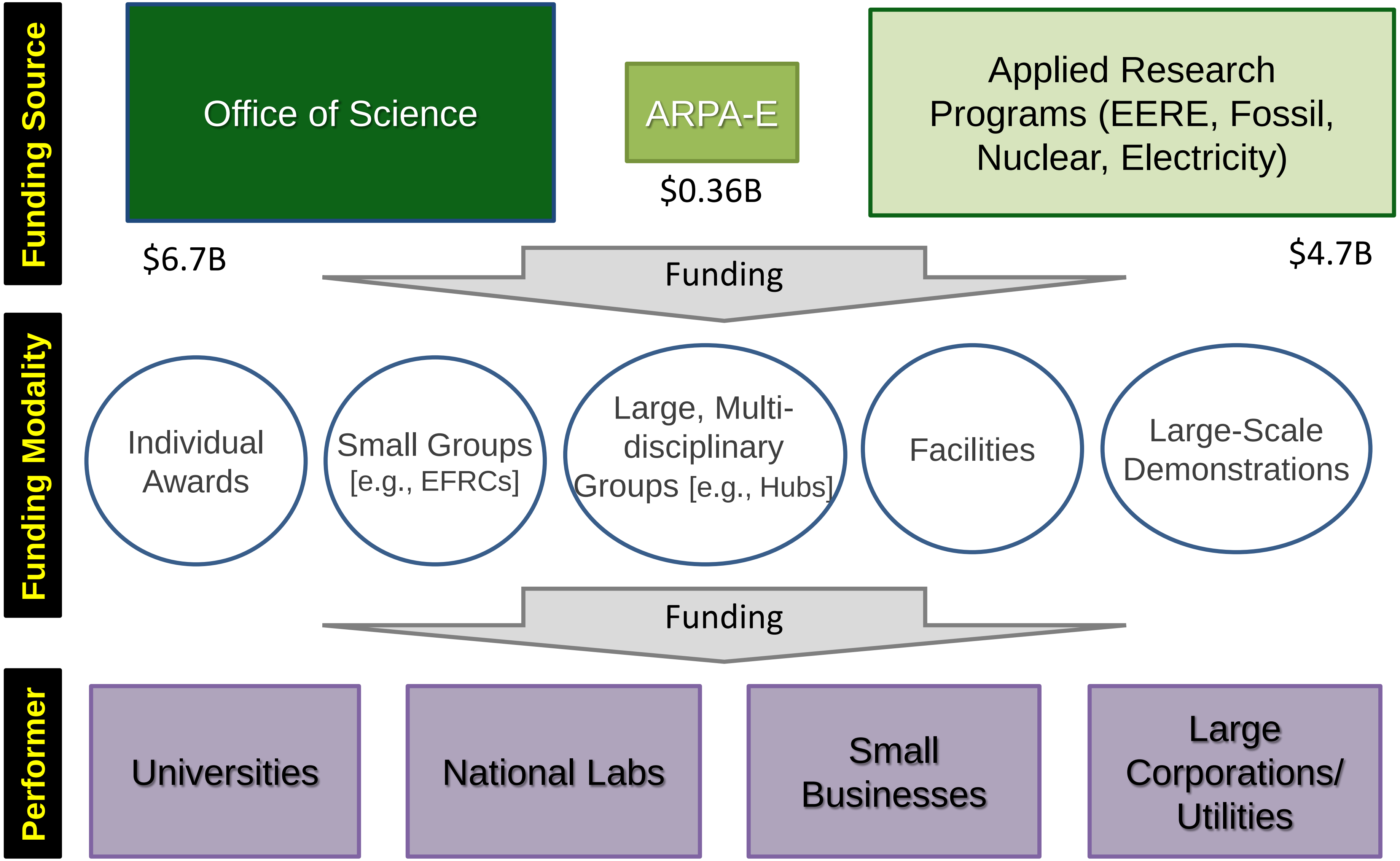
QIS Applications

- Quantum Computing
- Analog Quantum Simulation
- Sensing and Microscopy

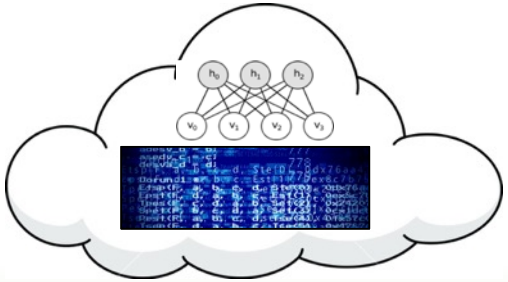




DOE as a Research Funding Agency

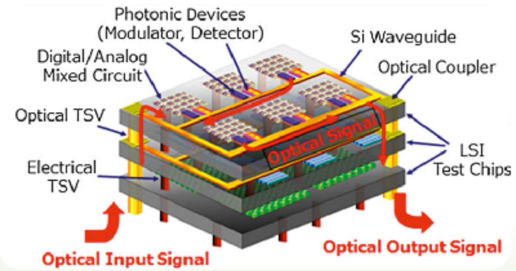


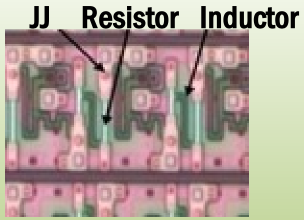
Enabling Technologies for Computing from SC



Algorithms & Programming

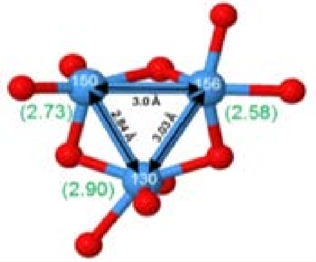
System architecture modeling

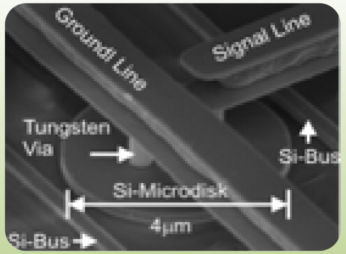




Component hetero-integration

Device demonstration





Fundamental materials science, chemistry, plasma physics

Advanced Scientific Computing Research

Basic Energy Sciences

High Energy Physics / Nuclear Physics

Fusion Energy Sciences

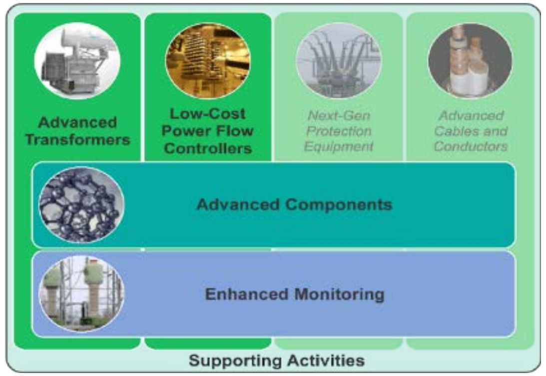
Images courtesy of Mike Witherell, LBNL

DOE microelectronics investments outside of SC

Advanced Research Projects Agency - Energy

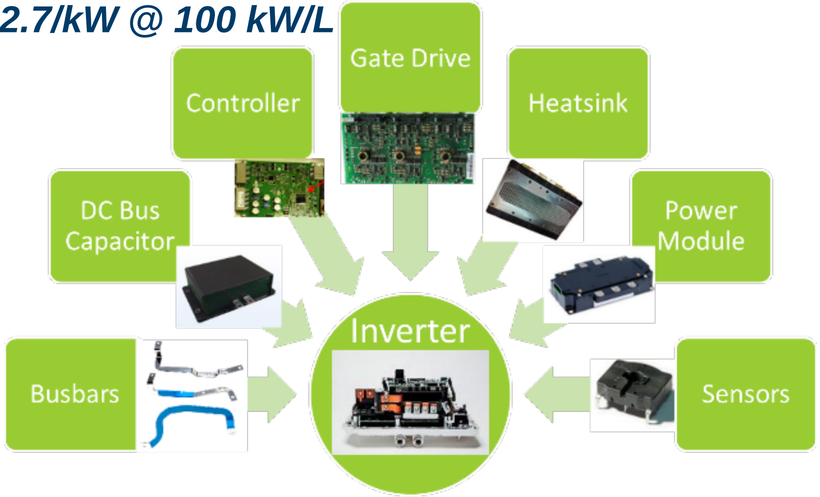
arpa·e
CHANGING WHAT'S POSSIBLE

Office of Electricity

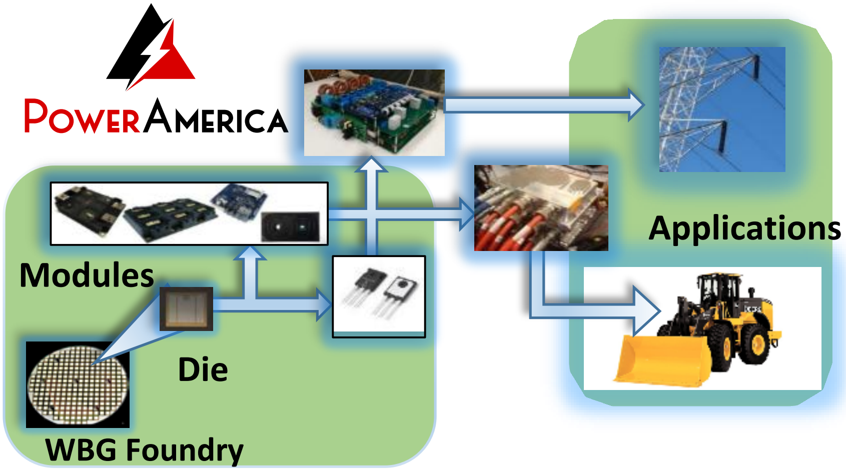


Vehicle Technologies Office

Inverter Target
$2.7/kW @ 100 kW/L

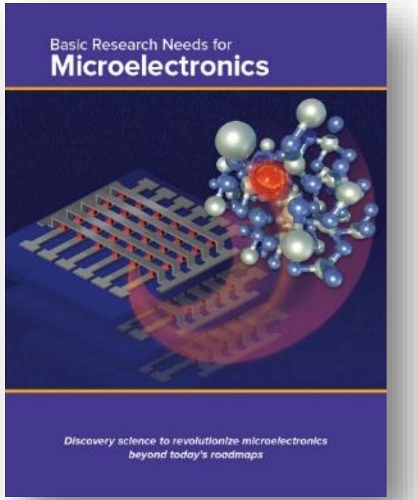


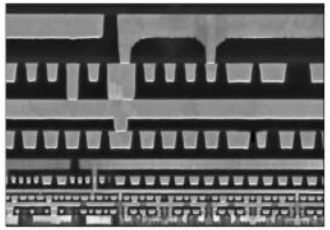
Advanced Manufacturing Office

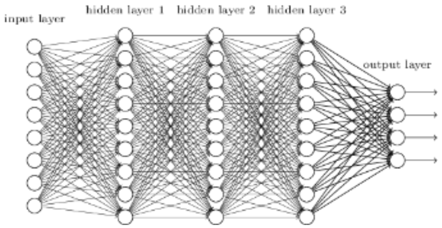


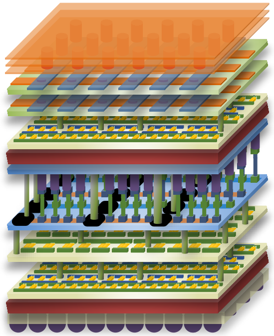
Workshop identified 5 Priority Research Directions

- Flip the current paradigm: Define innovative materials, device, and architecture requirements driven by applications, algorithms, and software
- Revolutionize memory and data storage
- Reimagine information flow unconstrained by interconnects
- Redefine computing by leveraging unexploited physical phenomena
- Reinvent the electricity grid through new materials, devices, and architectures

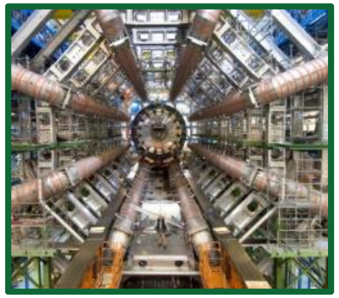


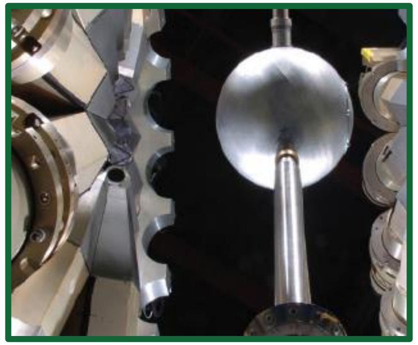






Office of Science User Facilities





27 world-leading facilities serving over 36,000 researchers annually

- Supercomputers,
- High intensity x-ray, neutron, and electron sources,
- Nanoscience facilities,
- Genomic sequencing facilities,
- Particle accelerators,
- Fusion/plasma physics facilities, and
- Atmospheric monitoring capabilities.

Open access

- Allocation determined through peer review of proposals
- Free for non-proprietary work published in the open literature
- Full cost recovery for proprietary work

DOE values stakeholder input

- Request for Information (RFI): Basic Research Initiative for Microelectronics
  - Published July 12, 2019; Closes on August 30, 2019
  - Input is requested in the following areas:
    - Topical Areas and Scope
    - Collaboration, Partnerships, and R&D Performers
    - National Impact and Unique DOE Role and Contribution
    - Program Planning and Evaluation
    - Other