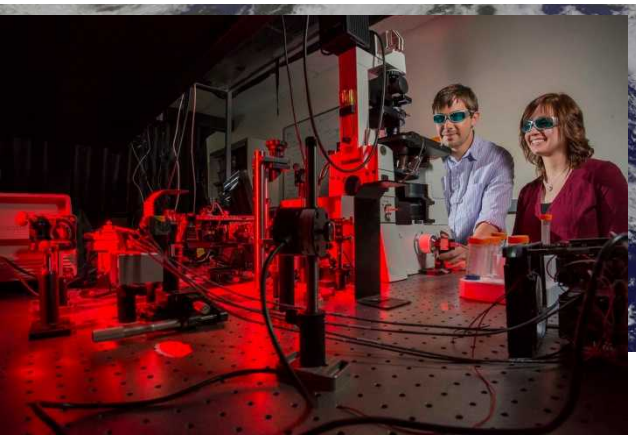
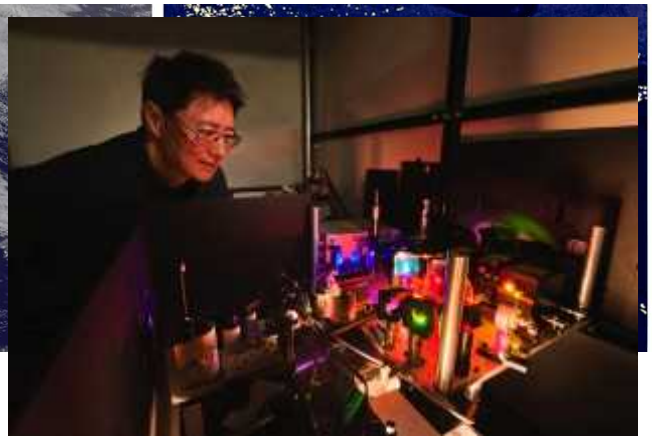
SAND2016-6810C

Exceptional service in the national interest

Sandia National Laboratories

energy.sandia.gov


Energy Research at Sandia

Babu Chalamala

May 6, 2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE SAND2015-9385 C

Sandia National Laboratories

Sandia National Laboratories

Albuquerque, New Mexico

Livermore, California

Kauai, Hawaii

Waste Isolation Pilot Plant, Carlsbad, New Mexico

Pantex Plant, Amarillo, Texas

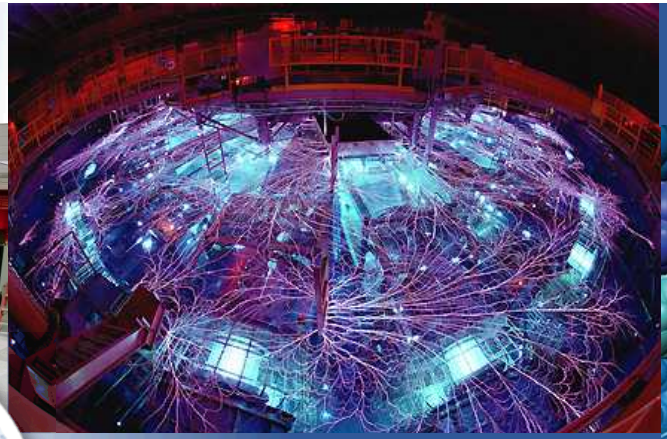
Tonopah, Nevada

Our Research Framework

Strong research foundations play a differentiating role in our mission delivery

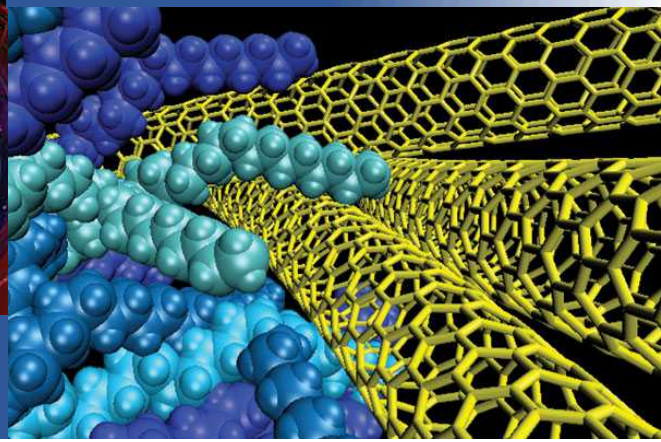
Sandia National Laboratories

Computing & Information Sciences

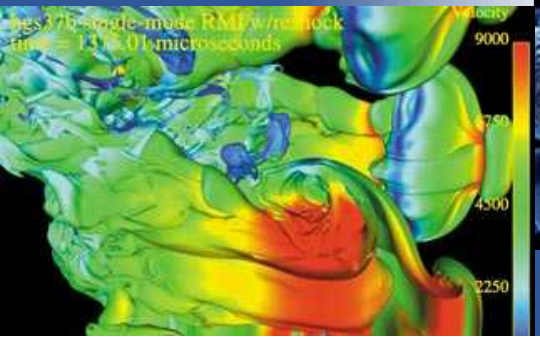


Radiation Effects & High Energy Density Science

Materials Sciences

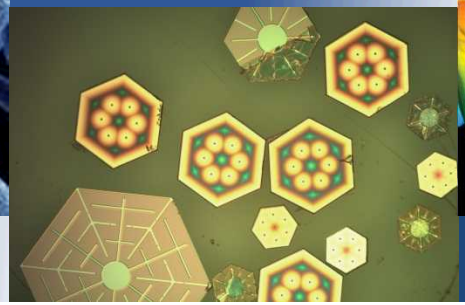


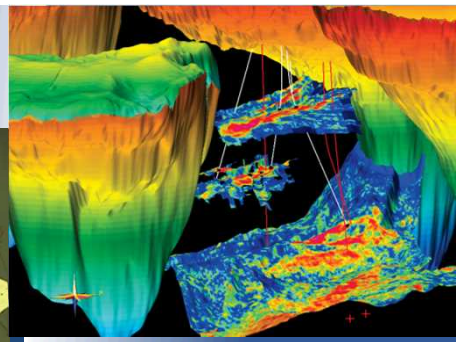
Engineering Sciences



Bioscience

Nanodevices & Microsystems



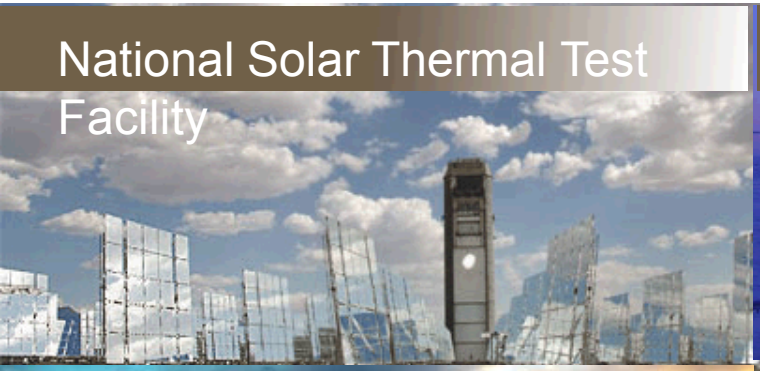


Geoscience

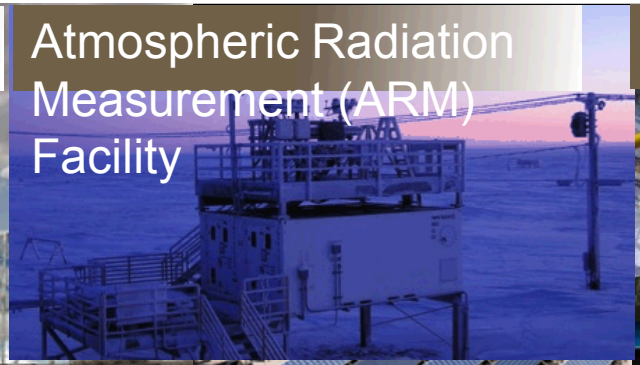
Sandia Differentiating Facilities

Sandia National Laboratories

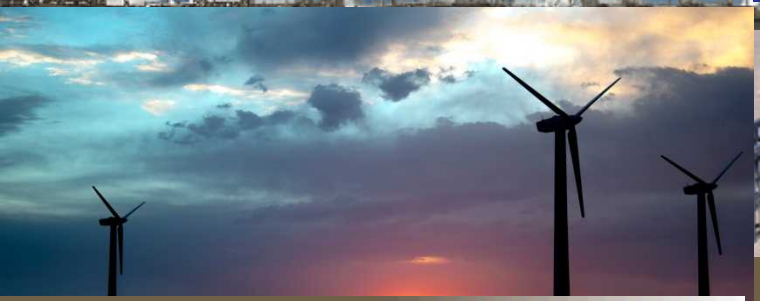
National Solar Thermal Test Facility



Atmospheric Radiation Measurement (ARM) Facility



Geomechanics Laboratory



Scaled Wind Farm Technology (SWIFT)

Distributed Energy Technologies Laboratory (DETL)

Nuclear Energy Systems Laboratory (NESL) Brayton Laboratory

Center for Integrated Nanotechnologies (CINT)

MESA and Epitaxy

2020: CHIP^2 (new multi-$B fab)

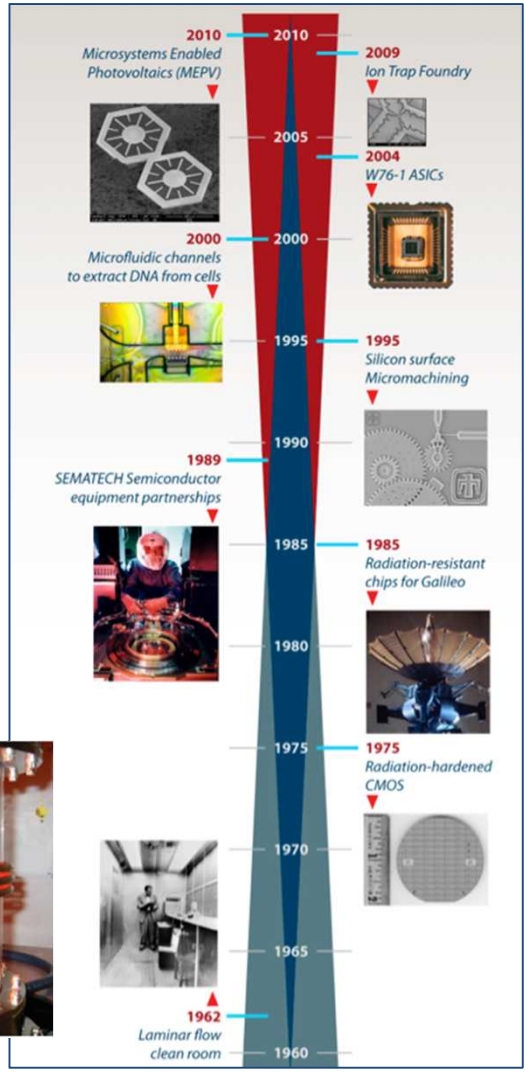
Sandia National Laboratories

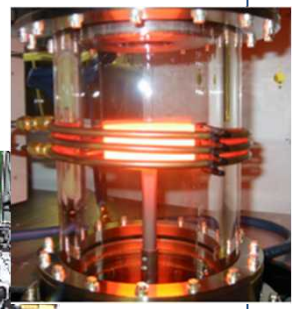
MicroFab for compound semiconductors

- Enables discovery science in materials and device sciences: very broad suite of tools, flexibility in materials sets
- 17,000 sq ft class 10 cleanroom space
- Complete fabrication capability incl. e-beam direct write and projection stepper, 2 to 6 inch wafer handling

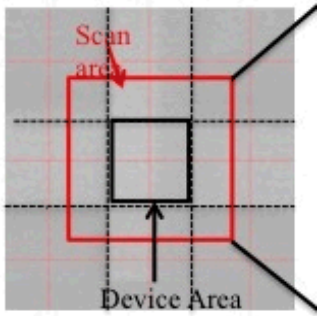
Complemented by an exceptionally deep world-class capability in III-V epitaxy

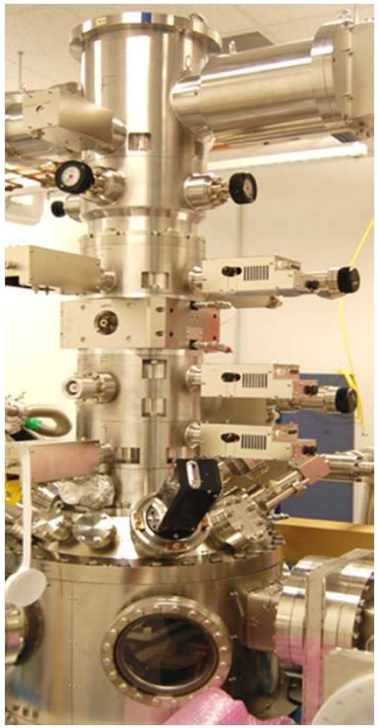
- 2 MBE systems (As-P-Sb)
- 5 MOCVD systems (As-P, III-N)
- New $2.5M investment enables ultra-high Tg, high Pg for high-Al and B alloys





Ion Beam Lab





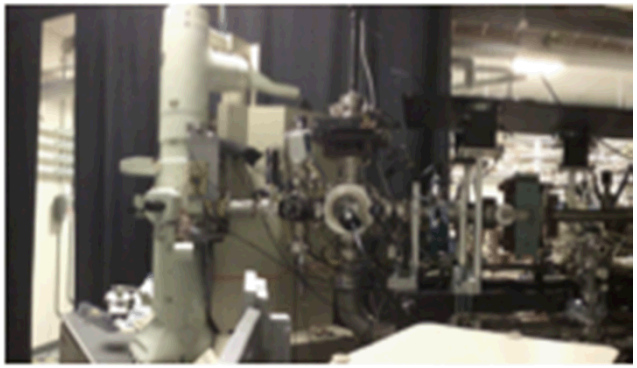
Nanoimplanter – *single ion* implant capability

- Focused Ion Beam with liquid metal source

  Ga, Au, Si, Sb, Cu, Pt, P, Li, Bi have all been run
- 20keV to 200keV ion energy
- 20nm spot size on target
- Have deterministically implanted a single ion for quantum devices

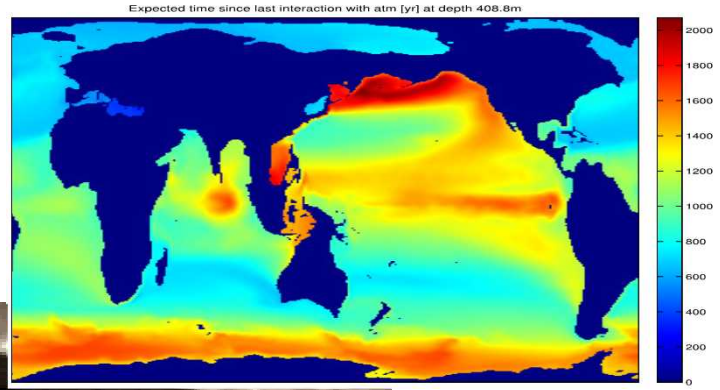
I3 TEM – In-situ Ion Irradiation

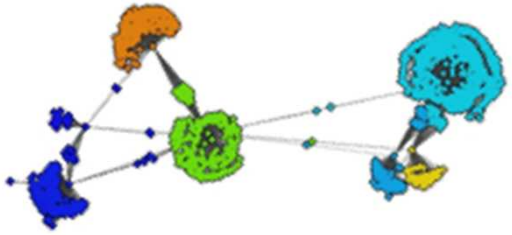
- In situ mechanical, chemical, optical, and irradiation (keV – MeV) capabilities
- Precession electron diffraction
- Moving towards Dynamic TEM (DTEM) capability resulting in multiple, nanosecond-resolved snapshots

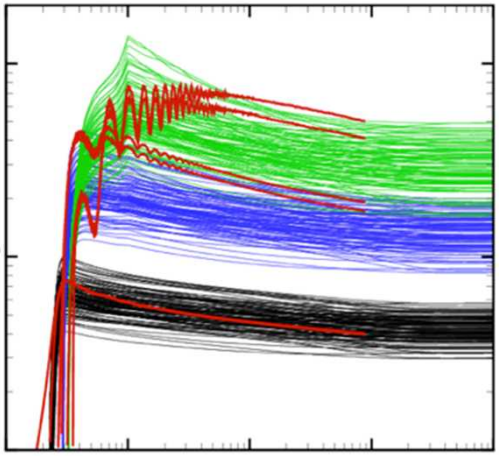


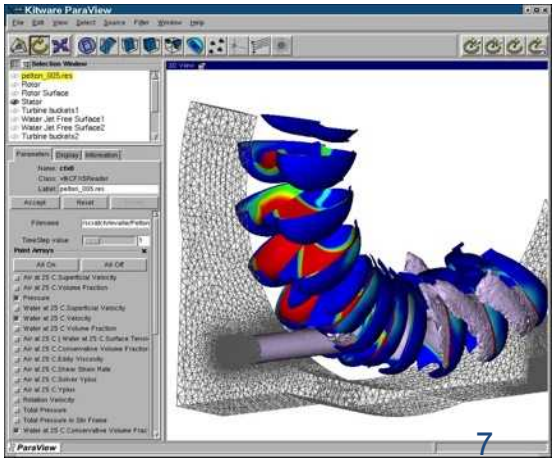
Computing Capabilities

- Math & Algorithms
- Capability Computing
- Visualization
- Uncertainty Quantification
- Informatics & Data Analytics
- Architectures Testbeds & Miniapps
- Advanced Modeling



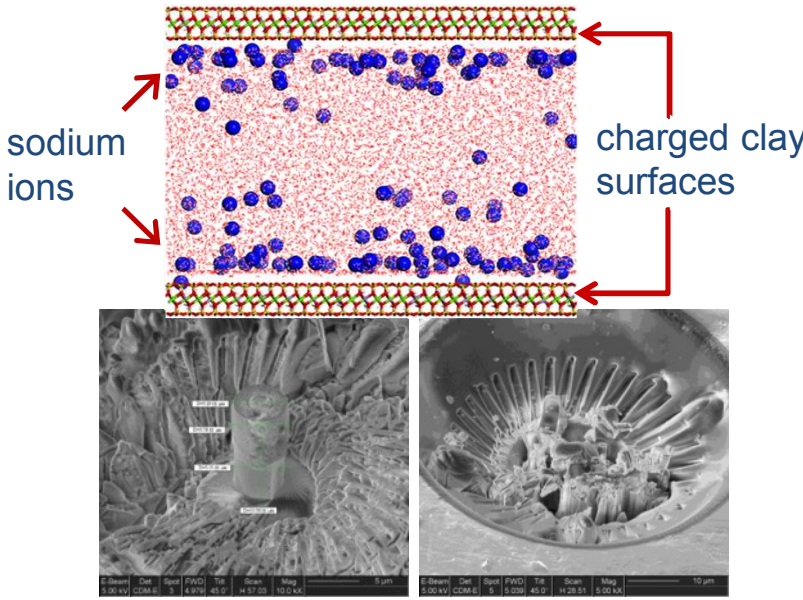






Integrating Modeling/Simulation & Multiscale Experimental Efforts

- World-class geomaterials testing in all scales (nano to in situ), modeling, simulation, and imaging capabilities in partnership with 1400 and 1500
- Computational chemistry of environmental phases and materials and experimental and analytical capabilities for evaluating molecular mechanisms of geochemical and environmental processes
- JASON reports singled out Sandia Geomechanics experimental capabilities as differentiating capabilities that should be available as the future DOE user facility



Center for Integrated Nanotechnologies (CINT)

Sandia National Laboratories

"A DOE/SC user facility has unique world-class research capabilities and technologies which are available broadly to science community worldwide from universities, industry, private laboratories, and other Federal laboratories for work that will be published in the open literature."

- A DOE/SC national nanoscience user facility
- Jointly operated by SNL/LANL
- Capabilities include synthesis, fabrication, characterization and theory of nanostructured materials
- Number of publications (>200)
- Users (>450) annually

Energy & Climate

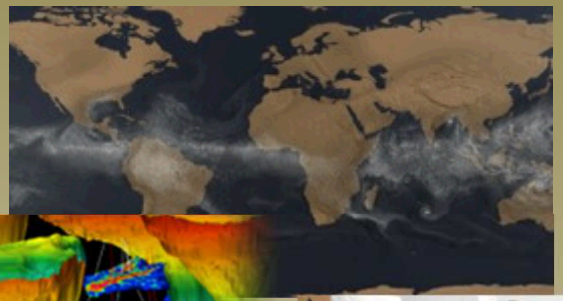
Sandia National Laboratories

Energy Research

ARPAe, BES Chem Sciences, ASCR, CINT, Geo Bio Science, BES Material Science

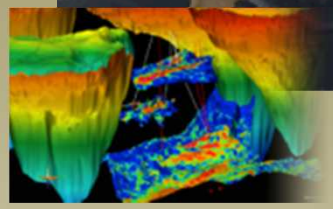
Climate & Environment

Measurement & Modeling, Carbon Management, Water & Environment, and Biofuels



Nuclear Energy & Fuel Cycle

Commercial Nuclear Power & Fuel, Nuclear Energy Safety & Security, DOE Managed Nuclear Waste Disposal



Renewable Systems & Energy Infrastructure

Renewable Energy, Energy Efficiency,
Grid and Storage Systems

Transportation Energy & Systems

Vehicle Technologies, Biomass, Fuel Cells & Hydrogen Technology

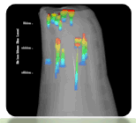
History of Sandia Energy Programs

Sandia National Laboratories

Sandia was born as a nuclear weapons engineering laboratory with deep science and engineering competencies

Energy crisis of the 1970s spawned the beginning of significant energy work

Strategic Petroleum Reserve – geological characterization of salt domes to host oil storage caverns



DOE's Tech Transfer Initiative was established by Congress in 1991

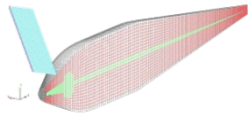
METAL HYDRIDE CENTER OF EXCELLENCE

Advent Solar

Energy Policy Act of 2005

Combustion Research Facility (CRF) & Cummins partner on their newest diesel engine

Joint BioEnergy Institute



Water Power Program

1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2007 | 2009 | 2010

Our core NW competencies enabled us to take on additional large national security challenges

Vertical axis wind turbine

NRC cask certification studies & core melt studies

Solar Tower opens

CRF opens to researchers

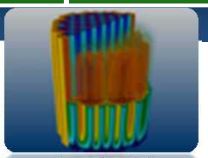
Distributed Energy Technology Laboratory (DETL) to integrate emerging energy technologies into new and existing electricity infrastructures

Power grid reliability study

SunCatcher™ partnership with Stirling Energy Systems

Sunshine to Petrol Pilot Test

Large-scale pool fire tests of liquefied natural gas (LNG) on water



Consortium for Advanced Simulation of Light Water Reactors (CASL)

Climate study uncertainties to economies

Combustion Research Computation and Visualization (CRCV) opens

Impact of Sandia Energy Programs

Sandia National Laboratories

MELCOR computer code

WIPP & Yucca Mtn. Technical

Fukushima Daiichi

Strategic Petroleum Reserve

CRF Collaboration

Deepwater Horizon Response

Solid State Lighting

Wind Blade Design

Polycrystalline Diamond Compact

Hydraulic Fracture Mapping

Stationary Power R&D

Safety, security, and resilience of energy infrastructure and assets

- Next generation severe-accident modeling and analysis
- Understanding the vulnerability of grid infrastructure and nuclear plant safety and operational systems to sophisticated cyber threats

High-efficiency conversion of low/zero-carbon energy sources to electricity

- Brayton-cycle (e.g. materials behavior under high temperatures and pressures)
- Solar-thermal efficient electricity generation (e.g. receivers- next gen coatings, high-temperature storage materials, wafer-scale fab processes for III-V)

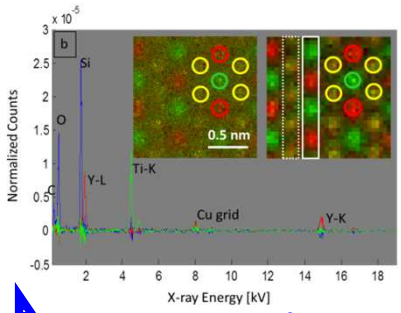
Back end of the nuclear fuel cycle

- Operational and long-term performance of salt as a disposal medium, especially for heat-generating waste
- Drilling technologies for deep borehole disposal

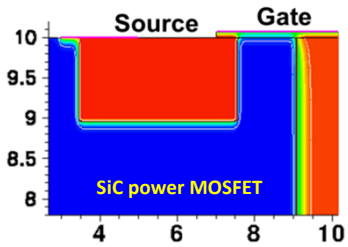
SNL has extensive R&D capabilities in WBGs – materials, devices, and systems

- **60+ years as DOE/NNSA mission lead in electronics**
- **35+ years of compound semiconductor research**
- **20+ years of wide band gap materials & device R&D**
- **Facilities:** ~30,000 ft^2 clean room (MESA facility); Solid-State Lighting EFRC; microgrid testbed (DETL facility); ASIC design & fab; extensive reliability testing and failure analysis

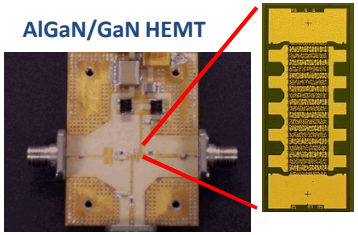
Atomic scale



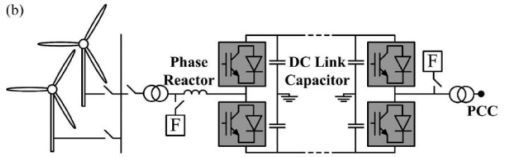
Atomic-resolution characterization



Material and device simulation



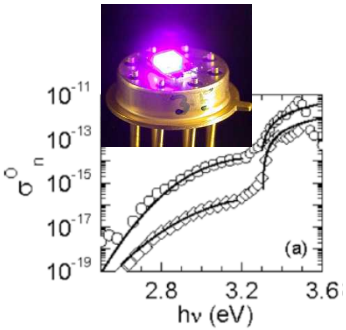
Device fabrication (MESA fab)



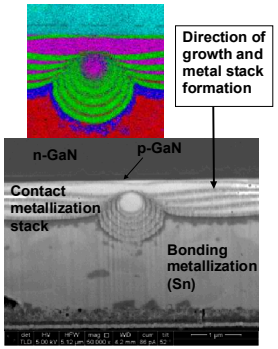
Power circuits and systems

Grid scale

Epitaxial growth



Defect spectroscopy



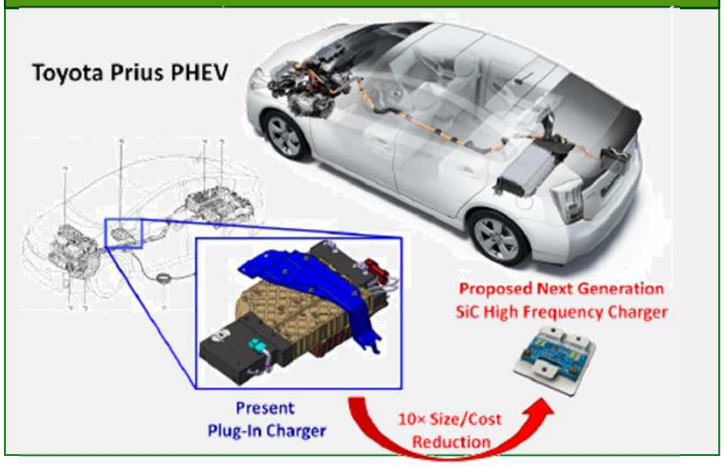
Reliability physics

Grid-level power networks (DETL)

WBG Power Electronics: SWaP reductions for electrical energy applications

Sandia National Laboratories

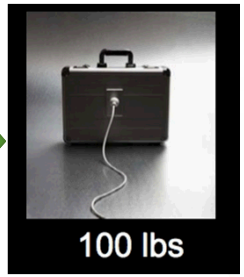
Automotive



SiC is 10% the volume and weight of Si for equivalent capability (10 kV, 100 A)

Power Grid

8000 lbs, 60 Hz Distribution Transformer



Silicon Carbide IGBT;
15 kV, 100 A;
50 kHz from Cree Inc.

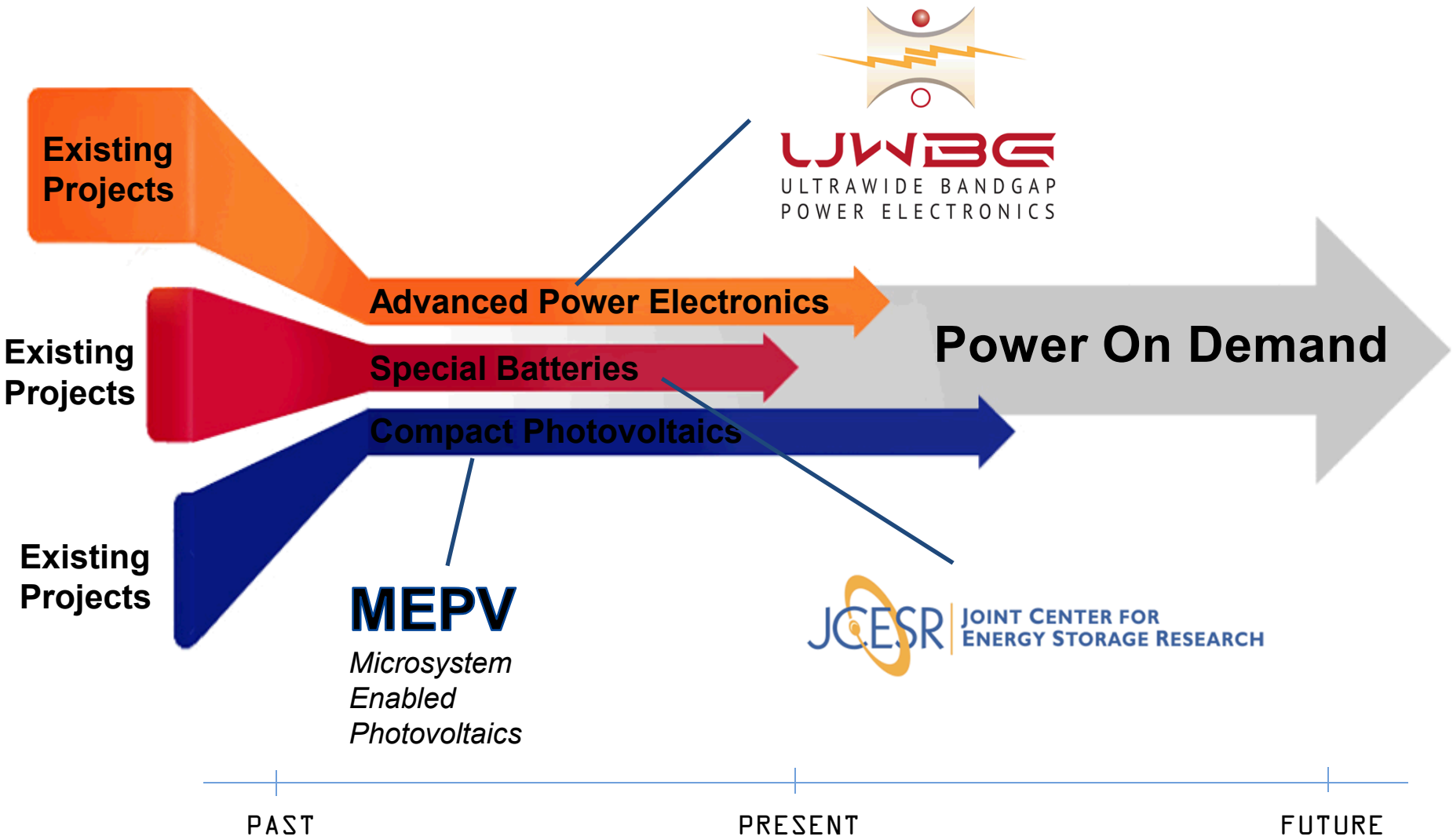
Potentially 100 lbs Transformer

80% of grid power expected to flow through PE by 2030

Ultra-WBGs will offer an *additional* 10× SWaP improvement compared to SiC and GaN, as well as Ultra-High-Voltage (potentially 100's of kV)

Power on Demand – Research Challenge

Sandia National Laboratories



EFRC for Solid-State Lighting Science

Exploring energy conversion in tailored photonic structures

Sandia National Laboratories

THE UNIVERSITY of NEW MEXICO

Los Alamos NATIONAL LABORATORY

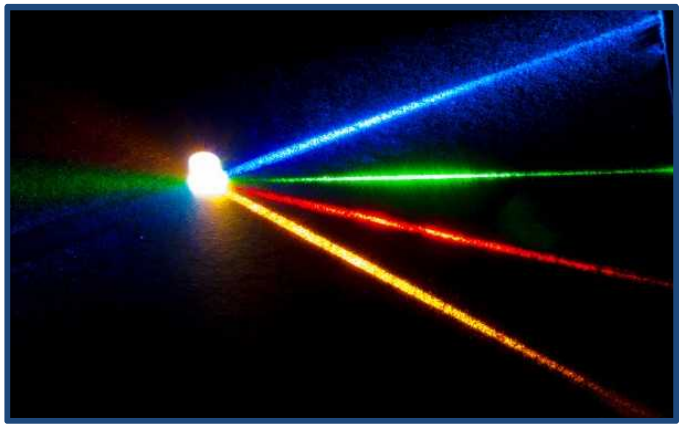
UCMERCED

UCSB

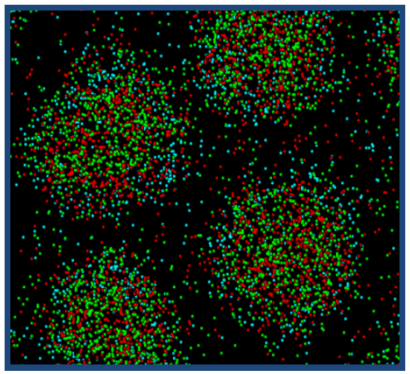
PHILIPS

UCI University of California, Irvine

New emission approaches

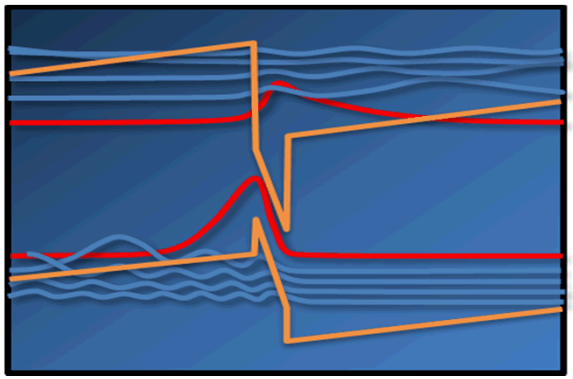


Lasers for white lighting



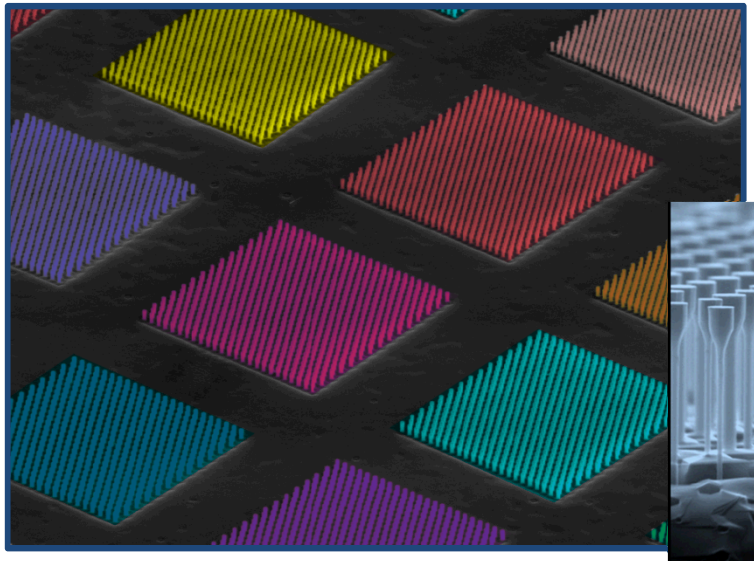
Core-shell quantum dot emitters

Light emission physics



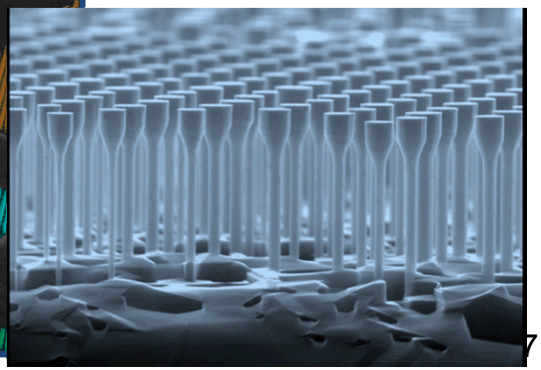
Radiative recombination processes

Novel nanostructures



Nanowire photonic crystal laser arrays

Nanowire LEDs



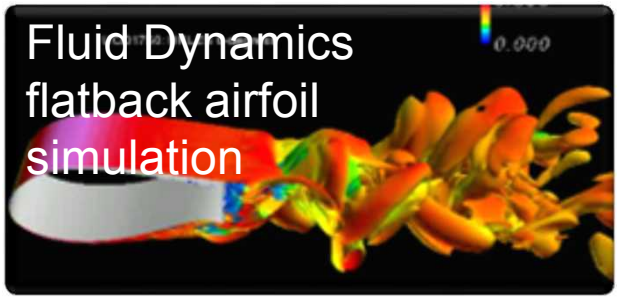
SSLS EFRC

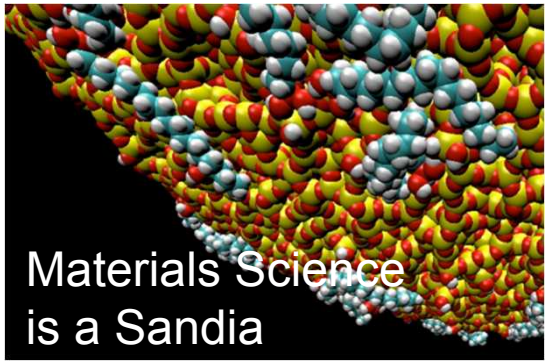
Renewable Energy: Differentiating Capabilities

Sandia National Laboratories

- **Unique R&D and test facilities:** Scaled Wind Farm Technology Facility (SWiFT), Photovoltaic Systems Evaluation Laboratory (PSEL), National Solar Thermal Test Facility (NSTTF), Microsystems and Engineering Sciences Applications (MESA), and the Center for Control System Security.

- **Differentiating expertise:** materials science, reliability analysis, modeling and simulation, cybersecurity, intelligence based threat analysis, microsystems, deep experience with the DOD.



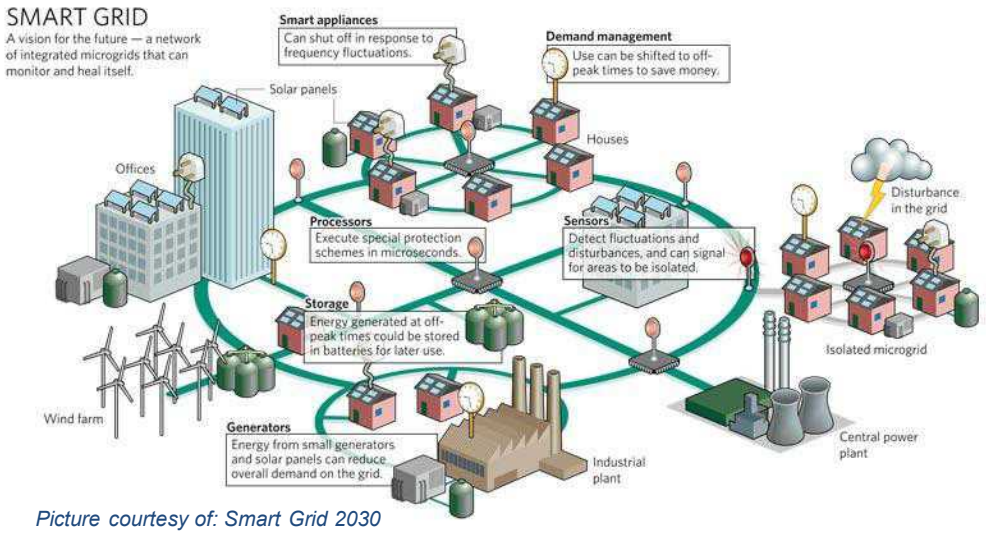


Sandia Grid Modernization R&D

- Leveraging foundational expertise
  - Power electronics
  - Testing and Reliability
  - High Performance Computing
  - Cyber Security
  - Modeling & Simulation
  - Optimization
  - Uncertainty Quantification
  - Systems engineering for integrated infrastructures
- Internal Investment
  - LDRD investment (Microgrid GC, Resiliency, Optimization)
  - Targeted recruiting
- Stakeholder Outreach
  - Engage utilities, industry and consortia
    – standards development
  - Increasingly engage states (eg. NM, CA, AZ, VT, NJ, NY)

Sandia's Grid Modernization Vision

A world of interdependent and variable distributed systems that are optimized at multiple scales to maximize local resources in providing secure, resilient, and clean energy to all users at all times.



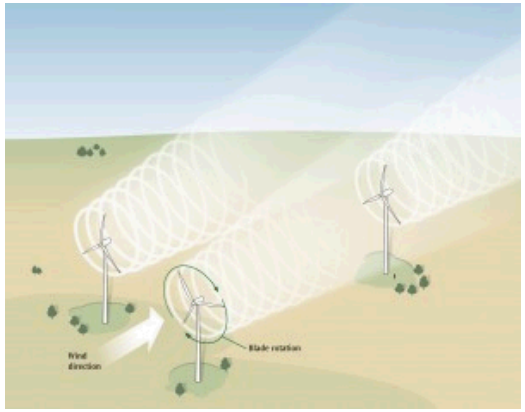
Picture courtesy of: Smart Grid 2030

Sandia capabilities support this vision:

- DER and renewable energy integration
- Power electronics and controls
- Secure and scalable microgrids
- Advanced grid analytics
- Infrastructure interdependencies
- Cyber and physical security
- Embedded sensors, information processing, and secure manufacturing
- Energy storage systems

Renewable Energy Grid Integration

Sandia National Laboratories



Key Concept

- Large-scale impact studies based on field data
- New technologies for advanced integration
- New rules and guidelines for high penetration integration

Capabilities/Investment

- Several large-scale facilities: Scaled Wind Farm Technology Facility, National Solar Thermal Test Facility, Distributed Energy Technologies Laboratory, PV Regional Test Centers
- Represents DOE infrastructure investment of more than $500M

Relevant Sectors and Agencies

- Utilities, regulators, decision makers
- Manufacturers, developers, and system integrators

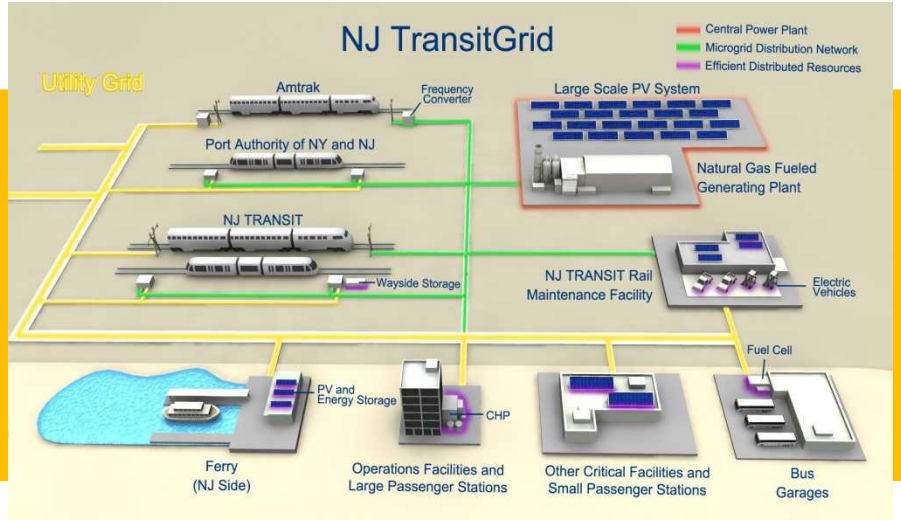
Anticipated Impact/Importance

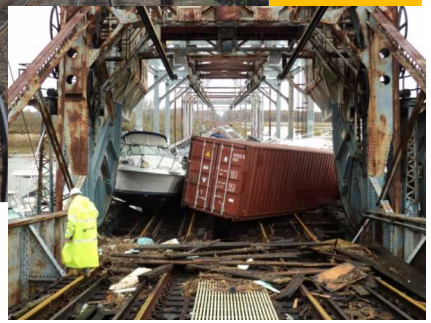
- High penetration RE can enhance grid operations:
  - Adaptable to environmental transitions
  - Distributed – less need for high investment on transmission

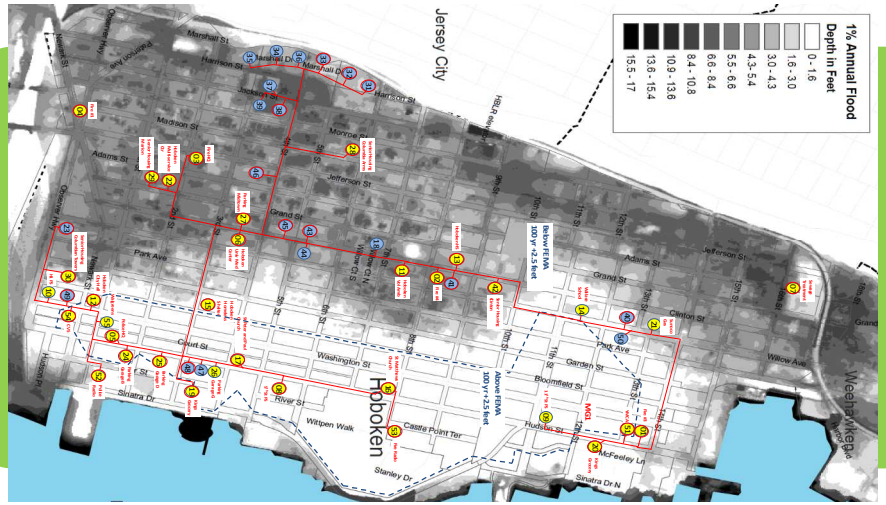
Microgrids and Grid Resiliency

Sandia National Laboratories

NJ TransitGrid Transportation Microgrid







City of Hoboken, NJ Energy Resilience Microgrid

Concentrating Solar Program

UNIQUE CAPABILITIES

Broad portfolio of CSP testing capabilities including:

- Only major power tower test facility (heliostat field and solar tower - 6 MWt) available for customer testing in western hemisphere
- Solar furnace, high-flow-rate molten salt test loop, rotating platform (trough)

COLABORATIVE PROJECTS

- Molten salt power towers with Gemasolar in Spain, Solar Reserve in Nevada
- Dish engine technology with Infinia
- Perform testing for Abengoa, Solar Reserve, NASA, Nooter/Eriksen, 3M, BP, eSolar

IMPACT EXAMPLES

- Extending temperature range of CSP (>600C) to meet SunShot Goals of 6¢/kWh
- Developing key systems to reduce cost of CSP including heliostats, power block (advanced thermodynamic cycles), heat transfer fluid, storage materials, receiver
- World record solar to electricity conversion efficiency

csp.sandia.gov

National Solar Thermal Test Facility (NSTTF)

Sandia National Laboratories

UNIQUE CAPABILITIES

This facility, unique in the United States, and the expansive co-location of highly experienced and world-renowned CSP researchers and technologists, has made the NSTTF instrumental in many significant developments:

- World record for solar-to-grid energy efficiency achieved on parabolic dish-Stirling systems
- First full-scale steam and molten salt receiver tests enabling Solar One and Solar Two and the current industry-standard technology
- Long shafted pump development eliminating the risk of high-head pumps
- Valve packing, flange gasket, and alloy compatibility salt testing that is the basis of current storage technology for the whole industry
- Enabling SunShot goals in concentrating photovoltaics (CPV), optics lab and associated tools
- World-class, forward-reaching, large-scale research
- Sunshine-to-Petrol first prototype demonstration
- Full-scale solid particle receiver test

Scaled Wind Farm Technology (SWiFT)

Increasing the performance of current wind farms to reduce wind power's costs

Sandia National Laboratories

Vestas Wind. It means the world to us.™

U.S. DEPARTMENT OF ENERGY

TEXAS TECH UNIVERSITY

The Scaled Wind Farm Technology (SWiFT) facility is the first public facility to use multiple wind turbines to measure how wind turbine wakes interact with one another in a wind farm.

SWiFT exists to:

- Reduce turbine-turbine interaction and wind plant underperformance
- Develop advanced wind turbine rotors
- Public open-source to advance turbine technology and simulation via collaboration with commercial and academic entities

Facilities:

- Three variable-speed variable-pitch modified wind turbines with full power conversion and extensive sensor suite
- Two heavily instrumented inflow anemometer towers
- Site-wide time-synchronized data collection

Transportation Energy R&D

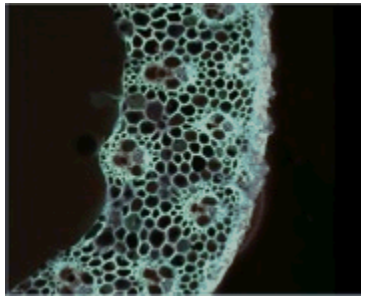
Sandia National Laboratories

Predictive simulation of engines

- Underlying chemistry and physics knowledge needed to inform predictive models of combustion
- High-fidelity, physically correct models for multiple-phase flow and chemistry relevant to engine sprays and multiple-fuel combustion

Co-evolution of biofuels and engines

- Biofuels performance in combustion environments
- Development and production of biofuels at commercial scale



Enabling a hydrogen fueling infrastructure

- Fundamental understanding of materials properties and reliability in the presence of high-pressure (70 MPa) hydrogen
- Predictive models for aging and reliability for systems design

Safe & reliable energy storage components and systems

- New in situ analysis of materials and components
- WBG and UWBG semiconductor materials synthesis

Combustion Research Facility (CRF)

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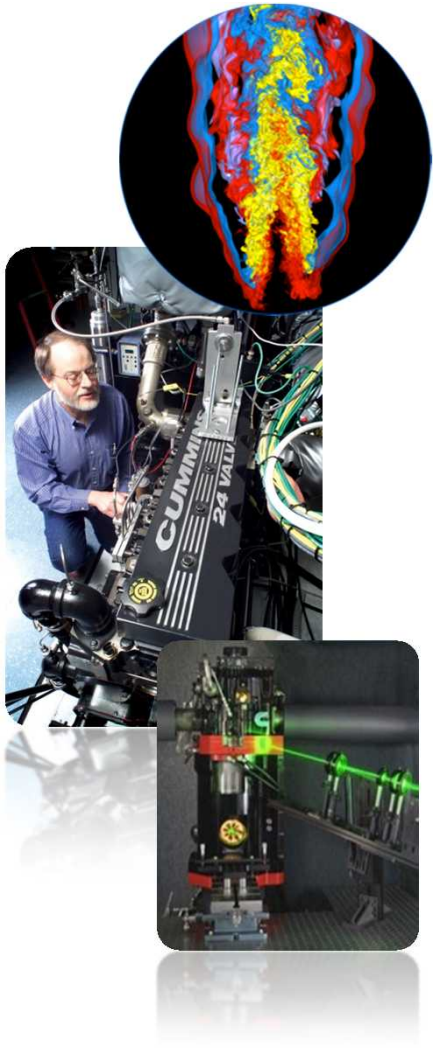
- Basic and applied research to improve and control combustion processes
- 8 highly specialized optical engine research labs and high performance computing center
- Advanced optical and laser based diagnostics and high fidelity computational simulation tools
- Extensive academic and private sector collaboration
- Every modern vehicle is cleaner and more efficient due to CRF research
- Allows engine companies to meet increasingly stringent CAFÉ standards



Power Sources Technology Group (PSTG)
Unique Capabilities

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Batteries:

- *Test/Analysis*
  - *Battery Abuse Testing Laboratory (BATLab)*
  - *Thermal Test Complex (TTC)*
  - *Burn Site (Laurence Canyon)*
- *Cell Prototype Facility*
- *Battery Calorimetry*
- *Mod/Sim*
- *Materials Development R&D (NM & CA)*

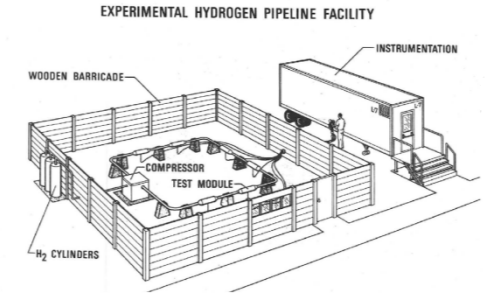
Electric Drive:

- ***MESA***
- *CINT*
- ***AML***
- *Mod/Sim*
- ***SNL/CA***

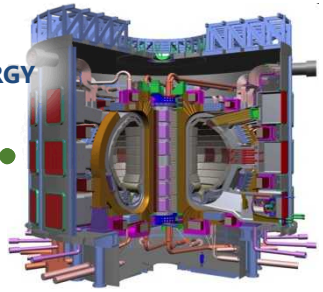
Thermal Test Complex (TTC)

Hydrogen Science and Engineering

- decades of complementary missions
- 70+ staff involved in H_2 Science and Engineering



FUSION ENERGY



METAL HYDRIDE CENTER OF EXCELLENCE

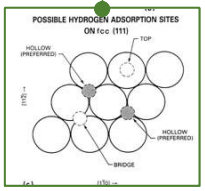
Lift-Truck Lifecycle Requirements

H2 Infrastructure Partnerships

H2FIRST

1960 1970 1980 1990 2000 2010 2000 2010 2014

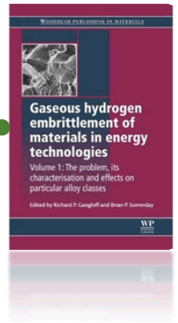
METALLURGY



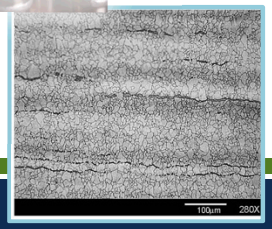
Embedded Atom Method

RATLER

AUTOMOTIVE STORAGE



TRITIUM RESEARCH



MINING LOCOMOTIVE

Partnerships are Key to Our Strategy

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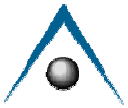
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BERKELEY LAB Laboratory
BROOKHAVEN NATIONAL LABORATORY
INL Idaho National Laboratory
JLAB

Los Alamos NATIONAL LABORATORY EST 1943
Pacific Northwest NATIONAL LABORATORY
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY
NREL NATIONAL RENEWABLE ENERGY LABORATORY
OAK RIDGE National Laboratory
SRNL SAVANNAH RIVER NATIONAL LABORATORY
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OPAL-RT
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THANK YOU