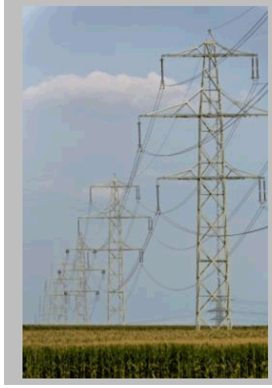

Power on Demand (PoD) Research Challenge: An Informal Overview

J. Charles Barbour, Director

Radiation & Electrical Sciences Center

Sandia National Laboratories, New Mexico, USA

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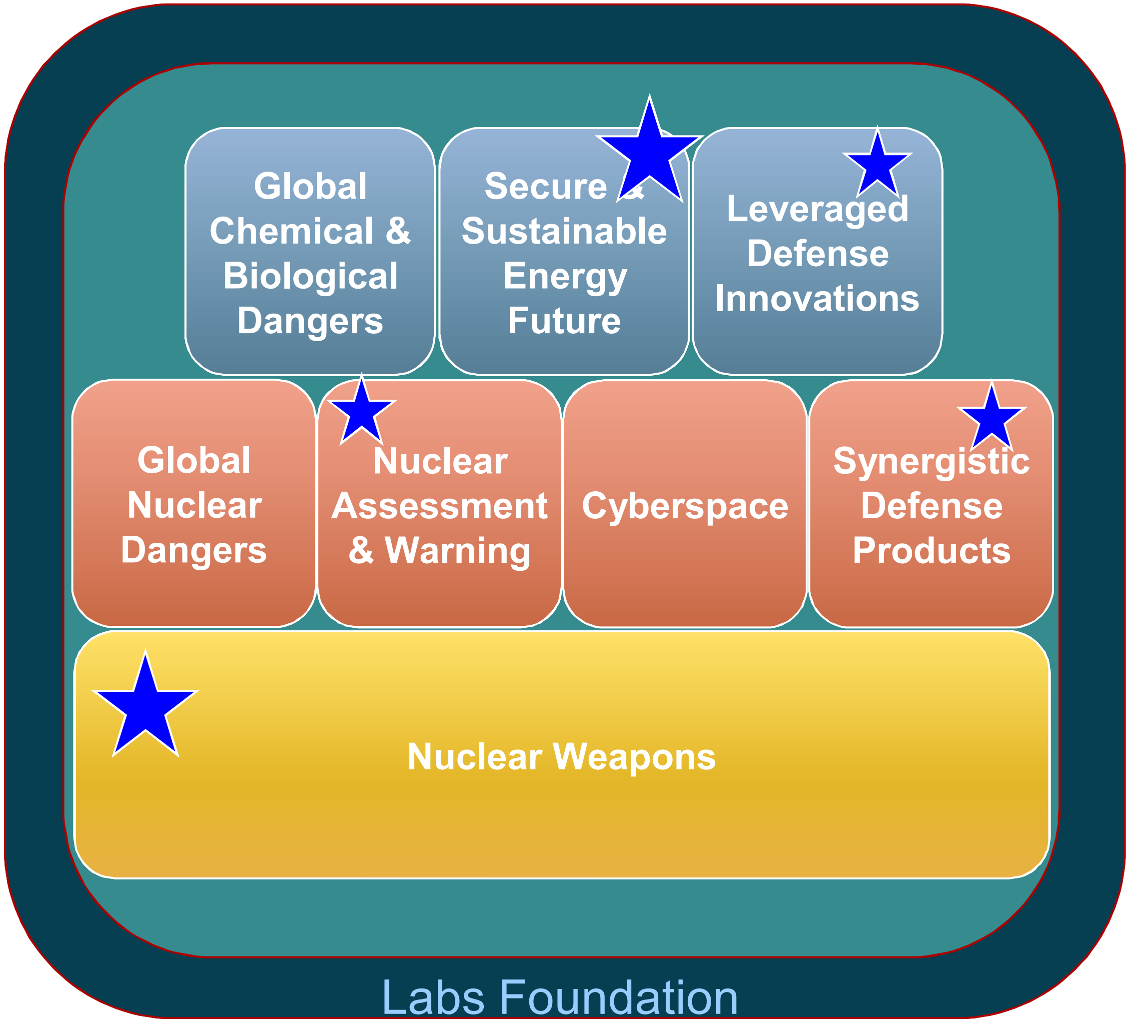
Compact, lightweight, reliable Electrical Power is a crosscutting need of several Mission Areas



Power on Demand: Vision and Goal

- **The need for power is ubiquitous.**

  We will develop power systems with the smallest size, lightest weight and highest conformability, for the harshest environments

- **Focus on Electrical Energy**
- **Seek Impact on Mission Areas**
- **Power on Demand** will coordinate a portfolio of work to develop **innovative new technology capabilities** that enable electrically powered systems with differentiating SWaP characteristics:
  - **National security applications** (low, medium & high power)
  - **Civilian energy sector** (grid-scale conversion, storage, and transmission; electric vehicles; and building and industrial efficiency).

PoD Bridge from RF to MA

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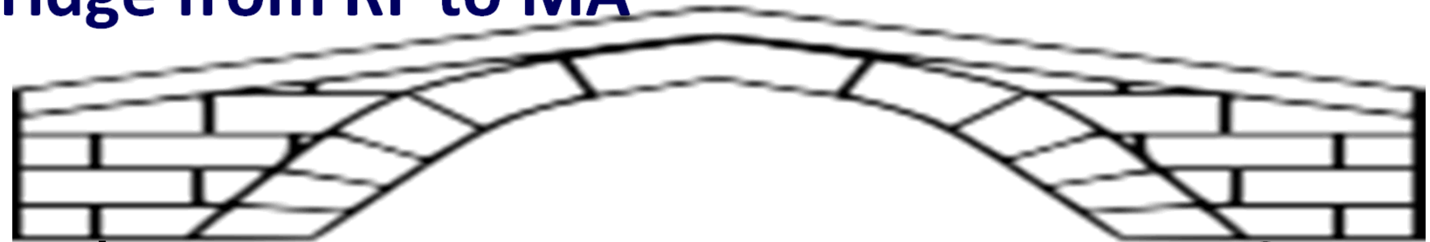
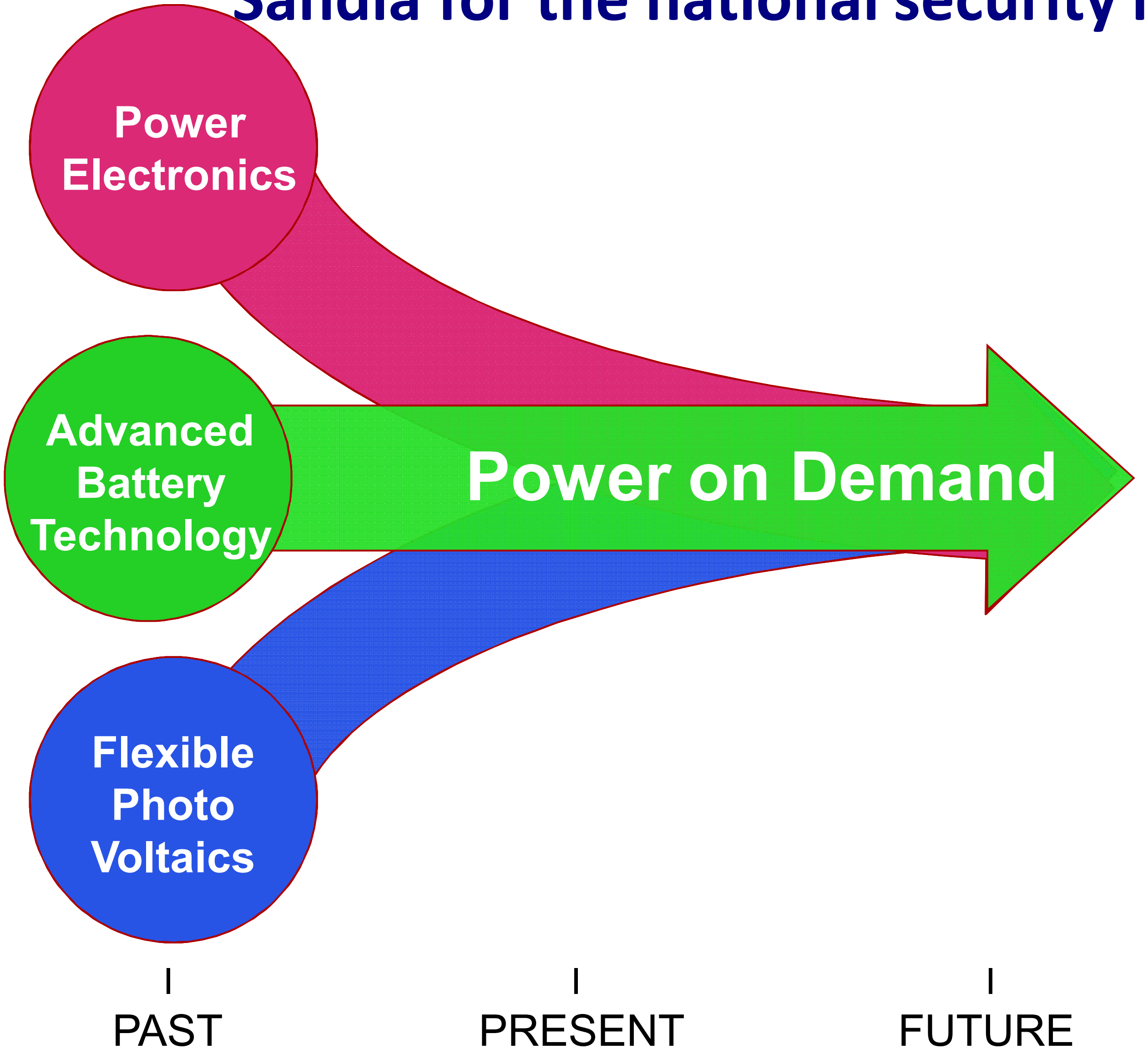


Research Foundations	Research Goals	Sandia Mission Area
Material Science	• High efficiency, ultra-light weight and compact electrical power systems • *Requires innovation across generation, storage, conversion technologies*	**Nuclear Weapons**
Nanodevices & Microsystems	• New devices and systems with enhanced lifetimes, reliability, and resilience, for both civilian and military applications • *Fundamental understanding for predictive reliability of power system components*	**Leveraged Defense Innovations**
Radiation Effects and High Energy Density Science	• Novel approaches for generating and harvesting power for long times in harsh environments (incl. radiation)	**Nuclear Assessments and Warning**
Engineering Science		**Synergistic Defense Products**
		Secure and Sustainable Energy Future

Integrated capabilities will differentiate Sandia for the national security missions



Sandia will be the Lab that best understands how to deliver electrical power systems with differentiating SWaP characteristics and reliable performance in harsh environments

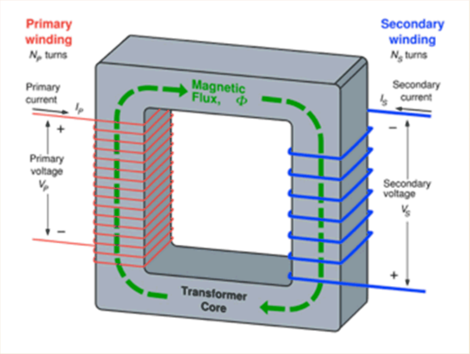
Three technical focus areas were chosen (in order)

1. ***Power electronics: wide bandgap semiconductor materials, devices, and power systems.***
   - Large gains in size, weight, and power efficiencies (SWaP) possible.
   - Materials are inherently rad-hard
   - Leverages SNL strengths in semiconductors and rad-hard components
2. ***Battery-based electrical energy storage – especially reliability.***
   - SWaP needed by both civilian and non-civilian applications.
   - Leverages SNL's lead NNSA role in batteries; SNL's lead partner role in JCESR
3. ***Microsystem-enabled photovoltaics (MEPV).***
   - Leverages results of MEPV Grand Challenge LDRD
   - MEPV cells superior in light weight and flexibility

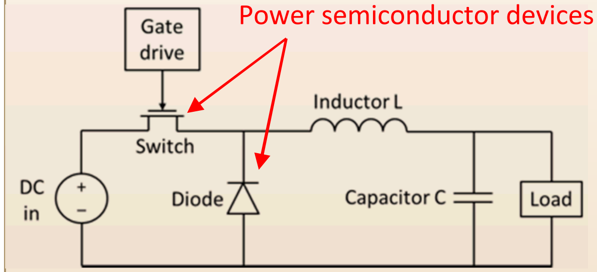
What are *Power Electronics*, and Why Do We Care?

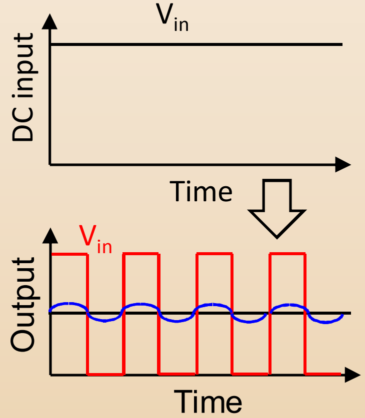
- ***Power electronics***: Application of solid-state electronics for routing, control, and conversion of electrical power

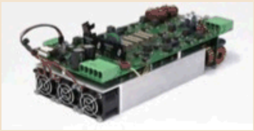
Passive transformers (dumb)



Power Electronics – Active switching (smart)





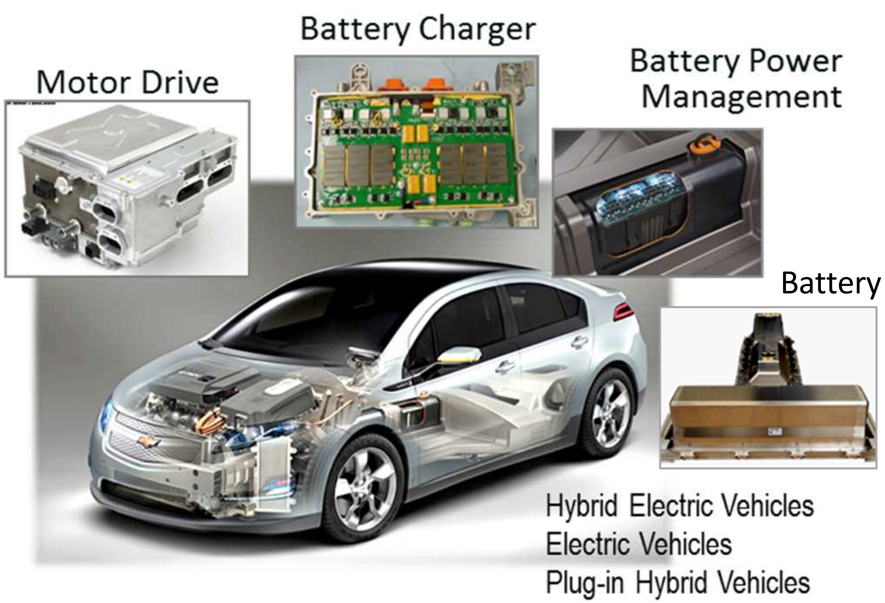


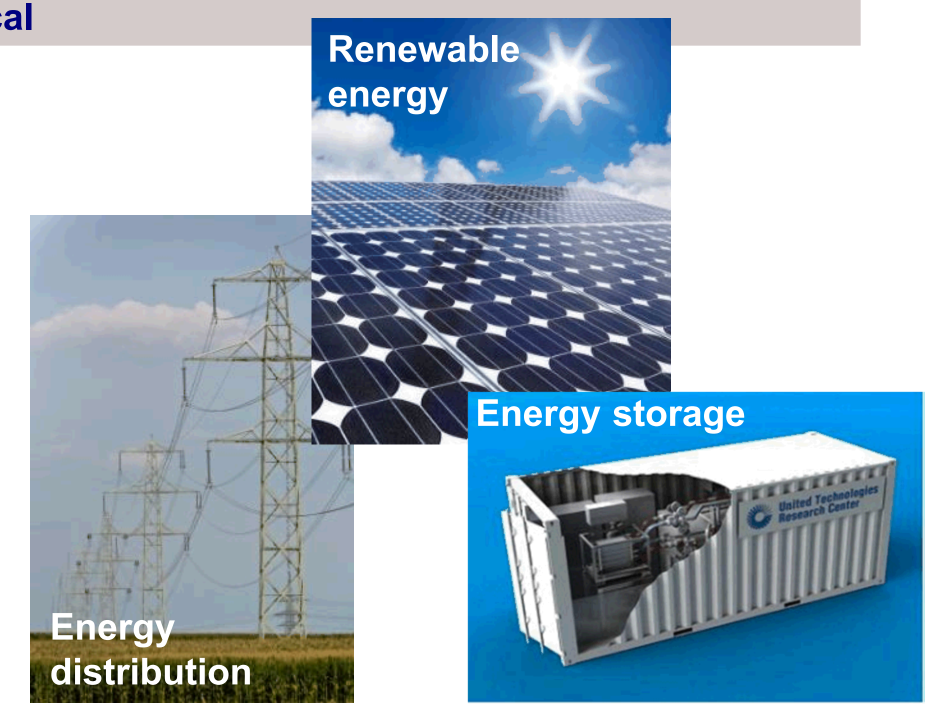
- Current power electronics are limited by the properties of Silicon semiconductor devices
- New system capabilities are enabled by:
  - Higher switching frequency (enables better SWaP)
  - Lower power loss
  - Higher temperature operation
  - Radiation resistance

➢ ***Motivation for (U)WBG semiconductors***

Mission Needs: Civilian Energy

Mission Area	Examples of Specific Areas of Interest and Impact
Secure and Sustainable Energy Future (Energy and Climate)	• **Next-generation grid** (efficiency & intelligence; long & short term storage) • **Transportation sector** (vehicle electrification) • **Solar PV, PV Inverters and Wind Inverters** (clean electricity; key enabling technology for increasing grid renewable generation) • **Building and Industrial efficiency** (variable speed electrical motors for HVAC, elevators, industry) • **Small power supplies and appliances** – computers, solid-state lighting power drivers, appliances • **Electric rail, aeronautical**





Scope: Sample Research Questions

- **Power Electronics (Materials)**
  - What influences conductivity and defect structure of UWBG AlGaN and how can this understanding be used to generate device quality materials? What 2D charge densities can be achieved?
  - What are the dominant atomic-scale failure mechanisms of power devices? Why does GaN break down before its calculated avalanche breakdown field?
  - What are the defects introduced in relevant radiation environments (x-ray, γ, protons, electrons, neutrons, heavy ions) and how do they affect the material (displacement vs. ionization); what is important for different device types?

Energy Storage Safety/Reliability Issues Have Impact Across Multiple Application Sectors

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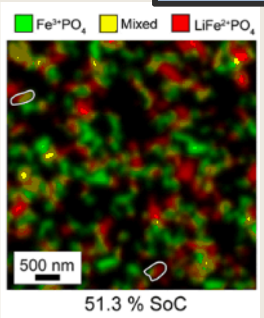
Current and Desired Future States: Assure Safe and Reliable Energy Storage Systems

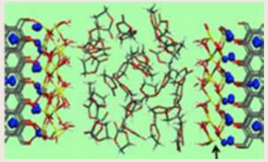
Sandia National Laboratories

Basic Research: Mechanisms & Models | Component: Testing | Demonstration: Design & Validation | Extension To Large Format: Prediction | Inform Policy and Regulation | Industry Deployments

Current Position for Battery Safety: Lacking the predictive capability to address today's government and industry needs; capabilities lack connection

Desired End State for Battery Safety: Increased depth of the scientific capability establishes an integrated science-based safety and reliability predictive design capability, meaningful codes and standards





DETL ESTP – as an experimental facility, more than just testing

LNG tests as prototype

Codes and Standards for Battery Safety and Reliability

2013 Boeing Dreamliner Battery Fires, FAA Grounds Fleet

Scope: Sample Research Questions cont.

- **Battery Safety and Reliability**
  - How can we translate a foundational understanding of degradation and failure mechanisms into a means to prevent them or minimize their impacts?
  - Can the scientific insights we gain be used to design inherently safe and reliable energy storage systems?
  - What scaling methods can be developed to extend understanding of failure modes and mechanisms at testable scales to very large format energy storage systems?
  - What ingenious new form factors and mechanisms for micro-power can be achieved?

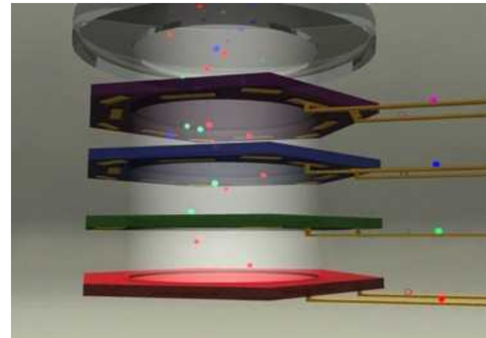
Microsystems Enabled Photovoltaics (MEPV) Vision

Sandia National Laboratories

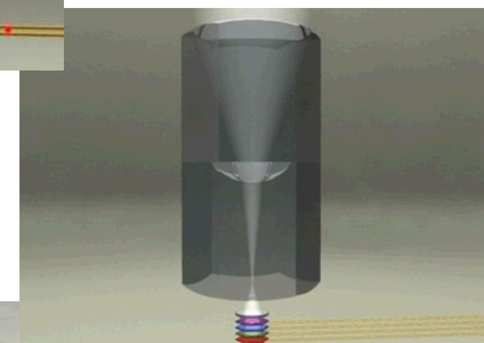
Explore fundamental scale effects within photovoltaic cells, modules, and systems for enhanced performance, reduced costs, and new functionality

Goals:

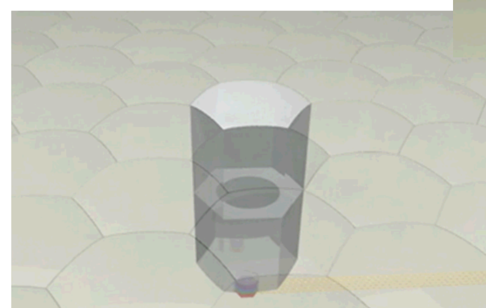
- 40% efficient PV system with the potential for $0.10/kWh levelized cost of energy (LCOE)
- Highly functional, highly flexible PV modules
- Establish Sandia leadership in this R&D area



Micro-PV Cells



Micro-optics



High Performance Modules

Low-cost, uniquely functional Solar PV Systems

EPRI Technology Brief and Presentation

Sandia National Laboratories

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

MICROSYSTEMS-ENABLED PHOTOVOLTAICS (MEPV)

Solar Glitter

THE TECHNOLOGY

Micro-scale solar photovoltaic cells on flexible and rigid substrates with conversion efficiency comparable to, and materials efficiency greater than, today's conventional technologies.

THE VALUE

MEPV could deliver breakthrough cost reductions in solar concentrating systems, as well as increased application diversity.

EPRI'S FOCUS

Innovation scouting continues, and validation studies of near-commercial technologies are pursued at the SolarTAC test facility.

TECHNOLOGY OVERVIEW

Leveraging microdesign and microfabrication techniques common to the semiconductor and microelectronics industries, researchers with national laboratories, universities, and private industry are developing microsystems-enabled photovoltaics (MEPV) technologies with disruptive potential. About the thickness of a human hair and comparable in size to an ordinary grain of salt, the miniaturized PV cells—which range between 3–20 microns (μm) thick and 100–500 μm wide—take on the appearance of glitter. They can be printed onto low-cost flexible or rigid substrates incorporating embedded electrical contacts and microlenses that allow the focusing of sunlight for concentrating PV applications (Figure 1).

Mass-produced microscale PV technology holds promise for efficiently generating solar electricity at significantly reduced costs, with some designs showing a possible pathway to $1/Watt (W) for utility-scale power applications. For one, the amount of expensive, high-quality crystalline silicon (c-Si) or gallium arsenide (GaAs) semiconductor material utilized in MEPV cells is many times less than that used in conventional one-sun PV cells. Meanwhile, demonstrated efficiencies for c-Si MEPV cells have reached 15%, with an expectation that they will exceed 20%, and GaAs MEPV cells have demonstrated greater than 20% conversion efficiency.[1] Achieving 40%+ efficiency is anticipated for more advanced multijunction MEPV cell architectures.

Figure 1 – Sample of Microscale Solar PV Cells Embedded in Silicone (Courtesy: Sandia National Laboratories)

Given the versatility of MEPV, the possible commercial applications for its use are wide ranging. The technology has potential to be utilized for grid-connected and space-based power; embedded in clothing, the shells of smart phones, and other consumer electronics; or used for defense and medical purposes. This brief focuses on MEPV innovations emerging from Sandia National Laboratories. Other organizations pursuing MEPV technology include Panasonic, University of Illinois, Stanford University, and Australia National University.

1 *Typical commercial c-Si cell efficiencies range between 14% and 20%+.*

Electric Power Research Institute
International Technology Innovation Summit

October 30-31, 2013 New York, New York, USA
November 1, 2013 (optional day) Niagara Falls, New York, USA
Venue: Millennium Broadway Hotel, 145 West 44th Street, New York, NY
Hosted by New York Power Authority (NYPA)
Co-Hosted by Consolidated Edison Company of New York, Electricite de France & Hydro One

Purpose

The electricity industry will likely see more changes in the next 10 years than it has in the last 100. Recognizing that innovation will undoubtedly be one of the best ways to meet the challenges of the next 10 years, many leading electric utilities have launched and reinforced innovation efforts often consisting of research and development (R&D) activities. Just as the electric industry is increasingly global, so are the challenges. As a result, opportunities for members of the electricity sector around the globe to collaborate and leverage developments in electricity R&D are essential. This summit follows the first such successful summit held I June 2012 in Pisa, Italy. This is a forum where the world's electric utility Chief Technology Officers (CTOs) or equivalent can exchange information on the opportunities for influencing and scouting innovation. The theme of the 2013 International Technology Innovation Summit will be flexibility, resiliency and connectivity. This will be combined with a visit to the largest hydroelectric generating power plant in the U.S.

15:20 – 17:30	**Session III – Technologies Which Facilitate the Need for Resiliency** This session is intended to focus on innovations that are needed in order to provide the resiliency needed to assure the power system is able to harden, recover or survive from extreme events of all types. **Participants will be asked to identify what the priority innovations are which will facilitate the need for resiliency.**	Moderator: Urban Keussen, Senior V.P. Technology & Innovation, E.ON AG Michael Edmonds, VP S&C Electric (Confirmed) Le Tang, VP Corporate Research, ABB (Confirmed) Greg Nielson, Project Lead – Glitter, Sandia National Labs (Confirmed) Takahiro Kase, Head N. American Solution Center, Toshiba International (Confirmed)
17:30 – 18:00	**Featured Summit Speaker – "Innovation needed to Provide Consumers with Safe, Reliable, Affordable and Environmentally Responsible Electricity"**	Congressman Paul D. Tonko (NY-20), Member U.S. House Energy & Commerce Committee, former CEO NYSERDA (Confirmed)

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Scope: Sample Research Questions cont.

- **Flexible Photovoltaics**
  - What new semiconductor material families can enable a wider spectral range of peak efficiency wavelengths while maintaining crystal lattice matching?
  - How can plasmonic and photonic crystal effects be leveraged to enable ultra-wide spectrum PV?
  - What innovations in concentration optics and device design or fabrication will decrease the balance of system cost in weight and size?
  - Can power electronics and storage be integrated with flexible PV for lighter weight, higher configurability, and agility? What limits the power efficiency and reliability in the design of this integrated power system?

Why Sandia?

- Sandia is branded as a leader in **compound semiconductor materials and device research** for national security needs - **DOE/NNSA mission lead in electronics**
- Sandia is a recognized leader in **battery materials and device research** with a focus on understanding battery performance and reliability in multiple environments - Lead lab in battery safety, reliability, and abuse testing
- Expertise in power systems (circuits, modules, networks)
- We have unique facilities in that are aligned with national security mission needs - **MESA, BATLAB, DETL, SSLS EFRC, CINT**, etc
- World class, multi-disciplinary research teams with a deep understanding of how our **materials and device research** can advance the missions
- Partnerships: Strong relationships with select labs, academia and industry
- ***Highly relevant historical expertise and ongoing research programs***