SAND Number: XXXX SAND2007-0284C

# Component Reliability Standards at 100ºC+ Will Benefit the Alternative Energy Market: Solar & Wind Inverters, Geothermal Drilling and Hybrid Vehicles

**Randy Normann and John Witham of Sandia National Labs**

**Dr. Michael Ropp Professor of Electrical Engineering, South Dakota State University**

Sandia National Laboratories

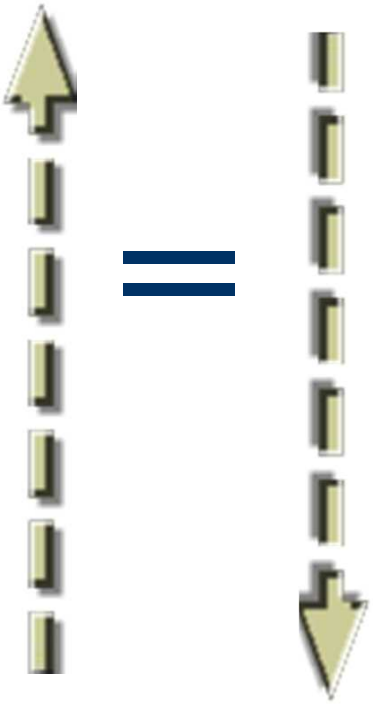
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000

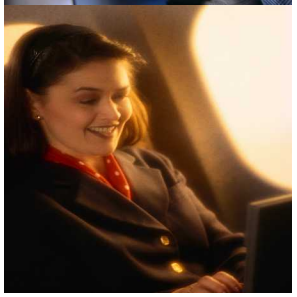
NNSA National Nuclear Security Administration

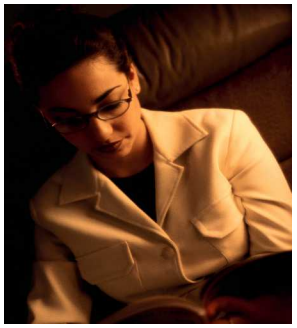
Sandia National Laboratories

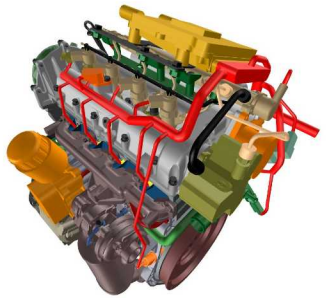
# Introduction

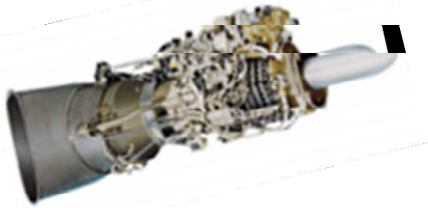
To demonstrate that new reliable HT electronics benefits both sides of the energy equation.

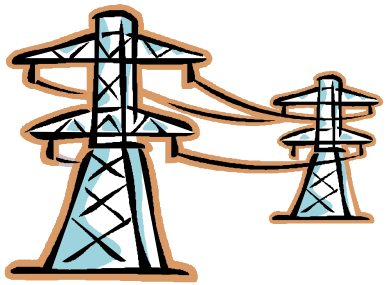








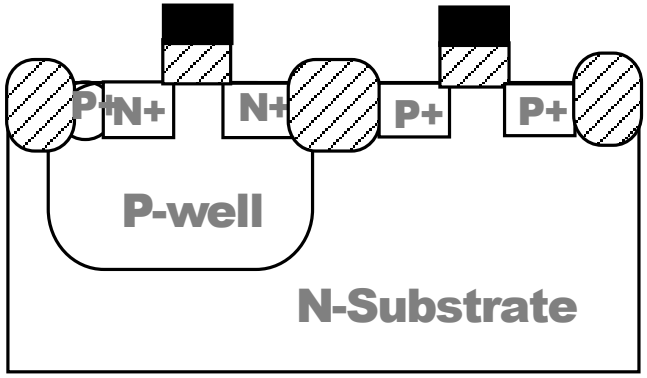




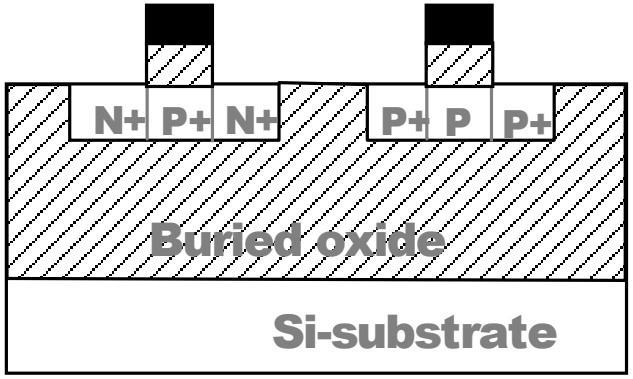
Sandia National Laboratories

# SOI Technology for Robust Electronics

- Silicon-On-Insulator (SOI) isolates transistors on an insulating material providing:
  - Isolation reduces leakage currents by ~100 times!
  - Latchup immunity
  - 25% Faster Switching
  - Better isolation for analog and digital on the same die
- SOI can operate at much higher temperatures




A: Cross-section of bulk CMOS inverter



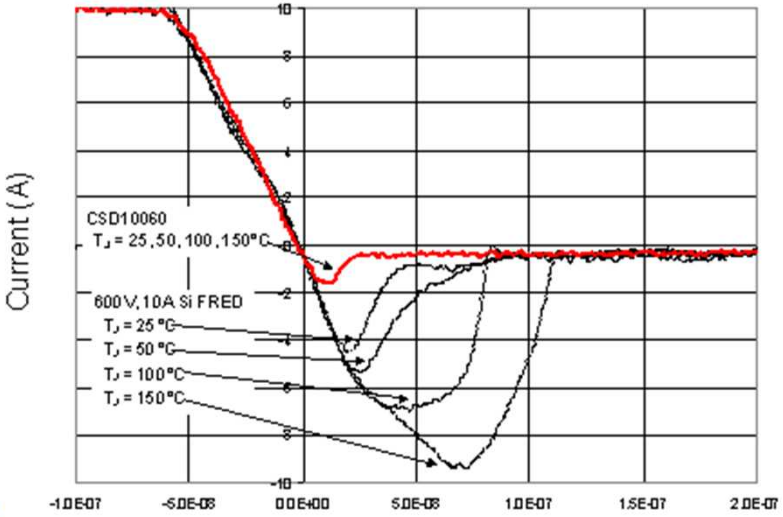

B: Cross-section of a SOI CMOS inverter

**In short, SOI is just a better way to build silicon electronic devices**

Sandia National Laboratories

# SiC Power Devices

- SiC has higher voltage breakdown than Si
- SiC has a better thermal conductivity than Si
- SiC power devices can be produced 5 to 10 times smaller than Si
- The smaller SiC power transistor can be operated much faster allowing for smaller passives devices




Courtesy Anant Agarwal, Cree HiTEC 2006

**Silicon** **SiC**

Courtesy Emil Hanna, Teledyne 2006

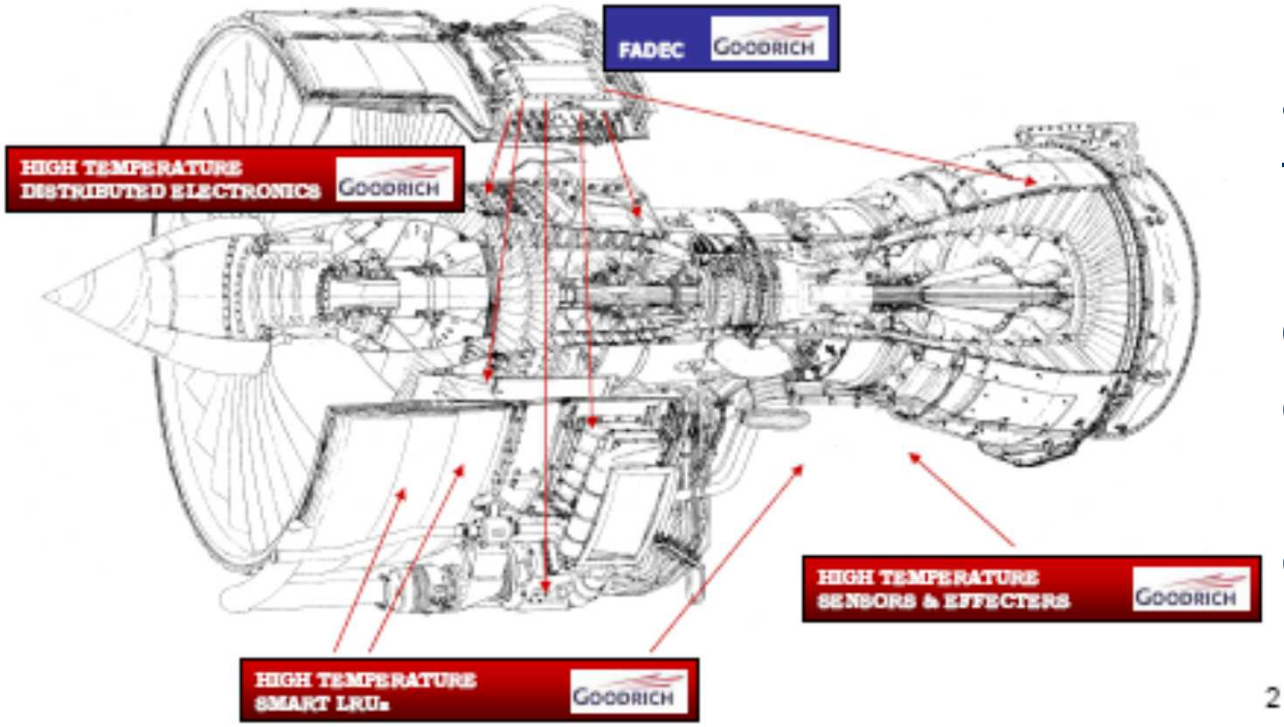
Sandia National Laboratories

# Results of this Technology

- Future electrical power systems will be:
  - Smaller
  - Lighter
  - More efficient ( 2-5%)
  - Require less heat dissipation
- A large number of industrial benefits
  - More Electric Aircraft (MEA)
  - Hybrid vehicles
  - More efficient power inverters/converters
  - Enabled new drilling tools for the Geothermal industry
  - New power grid controls

Sandia National Laboratories

# Distributed Engine Controls Save LBS



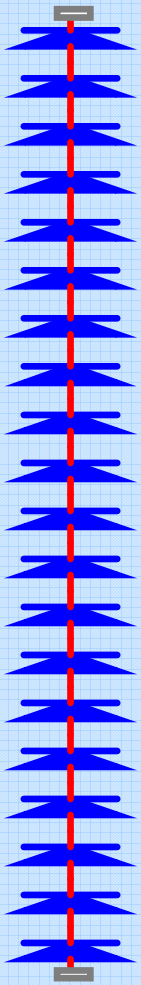

Engine controls are currently in the cockpit. Distributed engine controls can save >600 lbs/engine in copper cables.

Engine Requirements:
40,000 hrs at 220C and 80,000 hrs at 200C

Thanks to Peter Shrimpling, Goodrich, UK

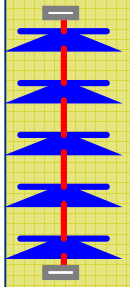
Sandia National Laboratories

# The Grid: 100KV Stack



Silicon 5 kV GTO

20 Devices



SiC 20 kV GTO

5 Devices

- Lower Part Count
- Reduced Cooling

→ Lower Cost

Courtesy Anant Agarwal, Cree HiTEC 2006

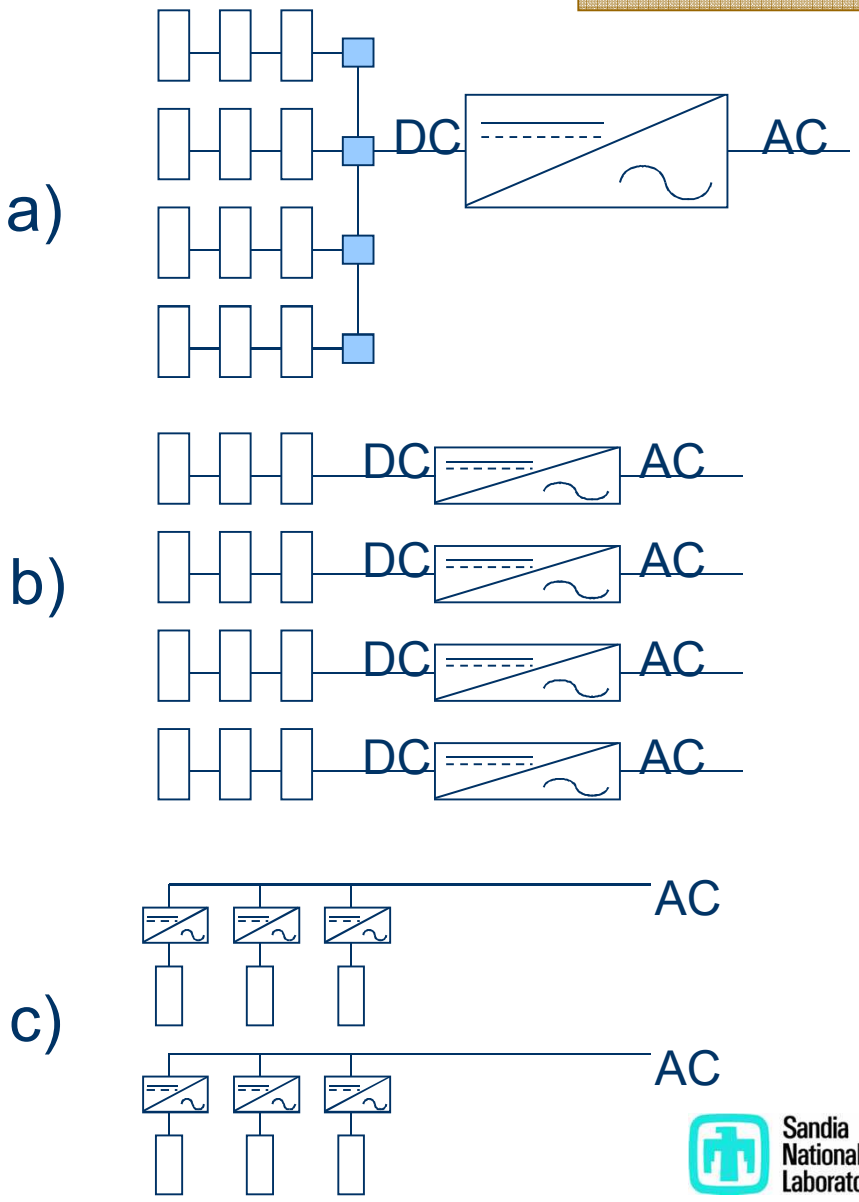
Sandia National Laboratories

# PV Inverters are Evolving

In the past, we used centralized inverters in which all the power went through one unit (a).

Some manufacturers now offer a "string inverter" in which each module string has its own inverter (b).

We wish to move to "AC modules" in which each module has an on-board inverter (c). This increases modularity, improves reliability through redundancy (!), increases system output through individual max power tracking, and *dramatically* simplifies system design and installation.




Sandia National Laboratories

# Desired AC Module Inverter Specifications and Design Constraints

## Lifetime

- MTFF = 20 yr (approx 100,000 hrs, assuming 50% “on” time)
- Lifetime limiters: high T kills large capacitors between inverter and PV array (absorbing 120 Hz power ripple); transient overvoltages wreck semiconductors (kV spikes possible due to voltages induced by lightning EMPs); high T causes eventual failure of semiconductors.

## Power rating

100-300 W range.

## Input voltage range

Probably 24 $V_{DC}$ < $V_{in}$ < 70 $V_{DC}$ for crystalline silicon. Could be >120 $V_{DC}$ for some thin-film technologies.

## Size and weight must be minimized

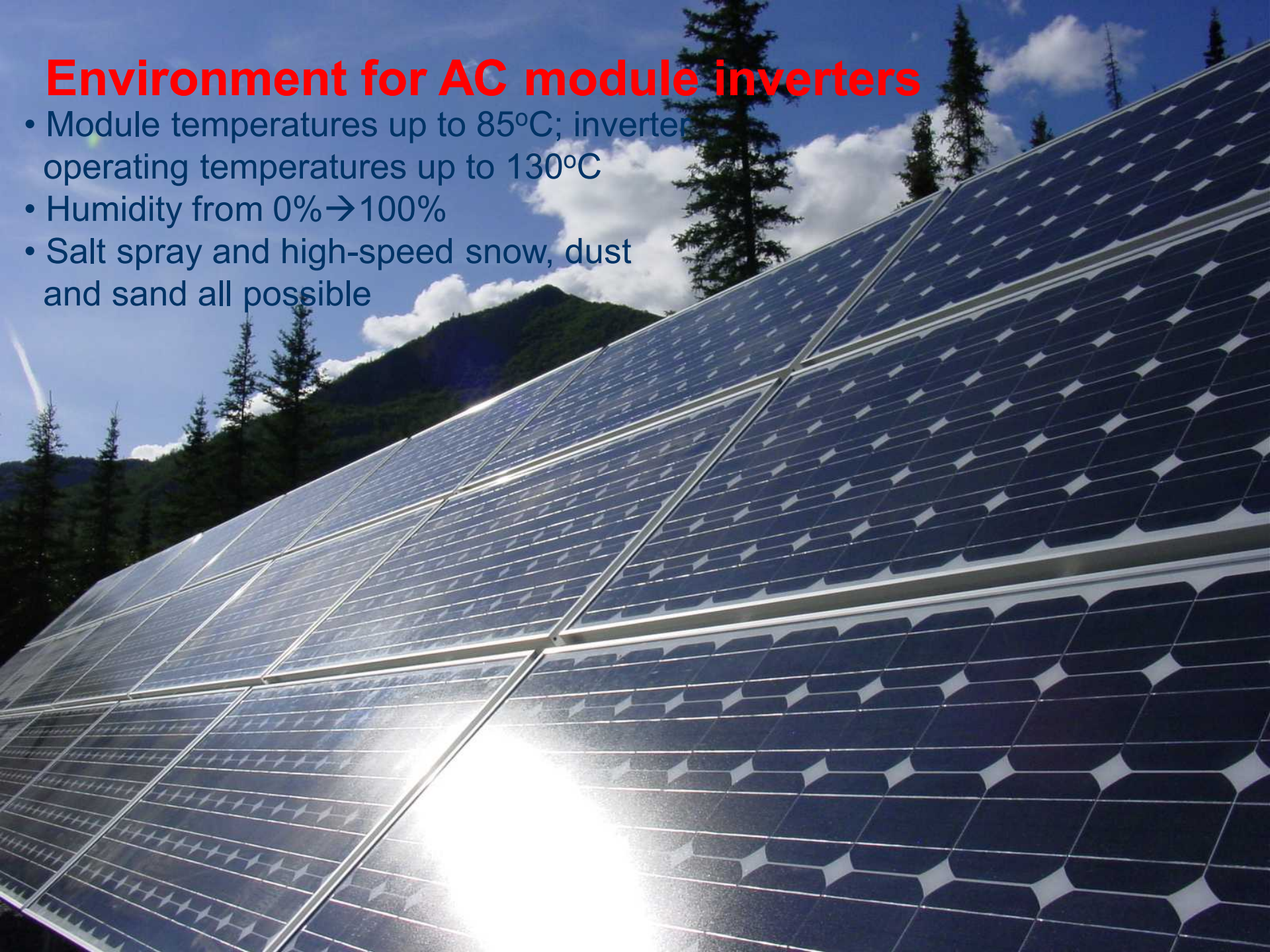
## Communications

At a minimum, some form of status indication is needed to facilitate maintenance.

## Cost

< $0.30/watt. **(This is the killer.)** Also should be designed for ease of replacement or repair.

Sandia National Laboratories



# Environment for AC module inverters

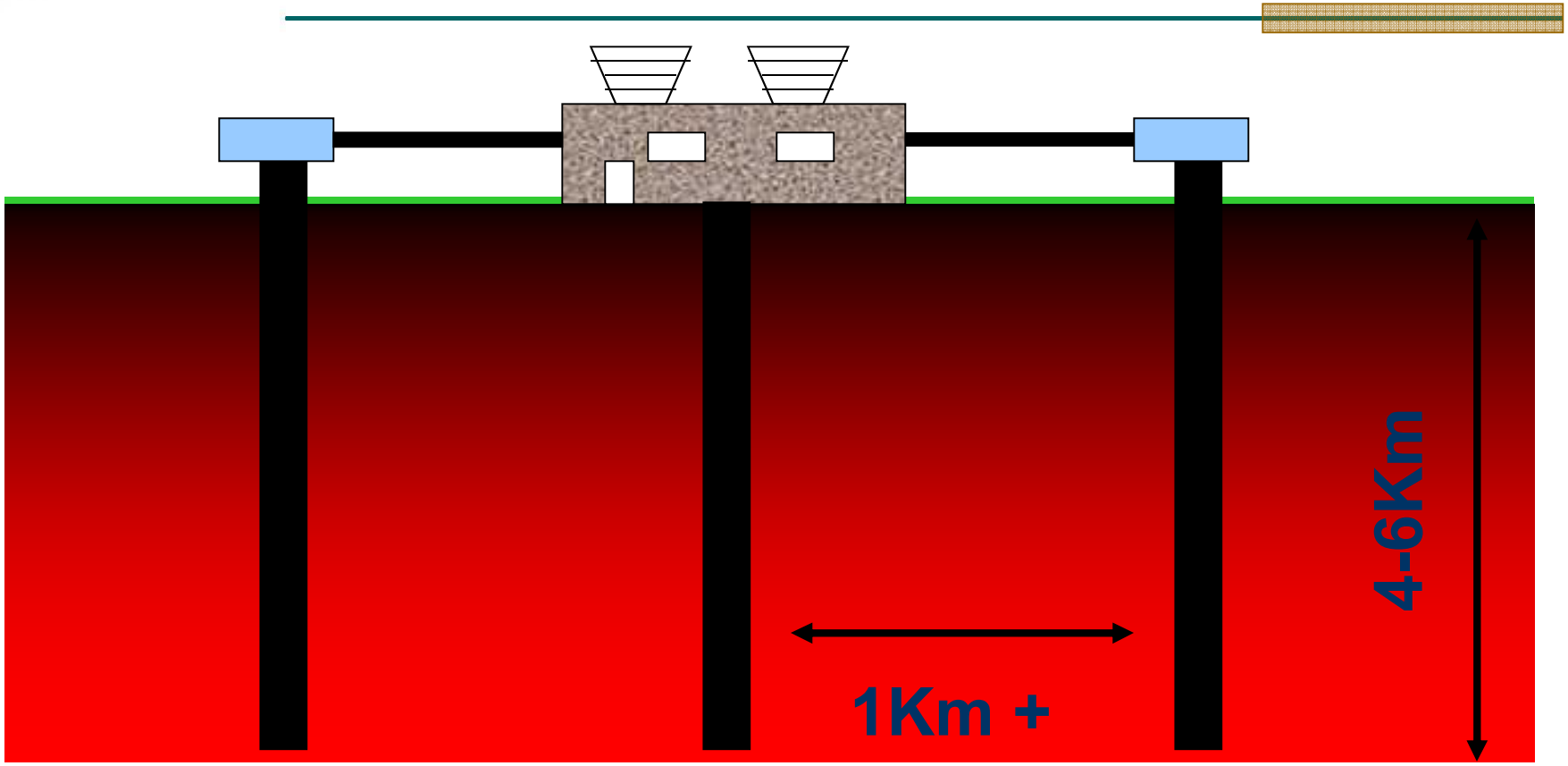
- Module temperatures up to 85°C; inverter operating temperatures up to 130°C
- Humidity from 0%→100%
- Salt spray and high-speed snow, dust and sand all possible

# SOI and SiC could be key enabling technologies

- SiC has better tolerance of voltage transients (such as lightning-induced ones on the AC or DC sides)
- PV inverters can use SiC JFETs (MOS not required); possible early market penetration point for SiC
- Previously-mentioned reduction in volume enabled by SiC would be highly advantageous
- SOI “brains” would permit higher levels of distributed intelligence and communications capability, with error-free functioning at elevated temperatures
- SOI, alternative metallization (W instead of Al), and larger trace sizes (against current trends!) would enable longer lifetimes at high T

Sandia National Laboratories

# Enhanced Geothermal System

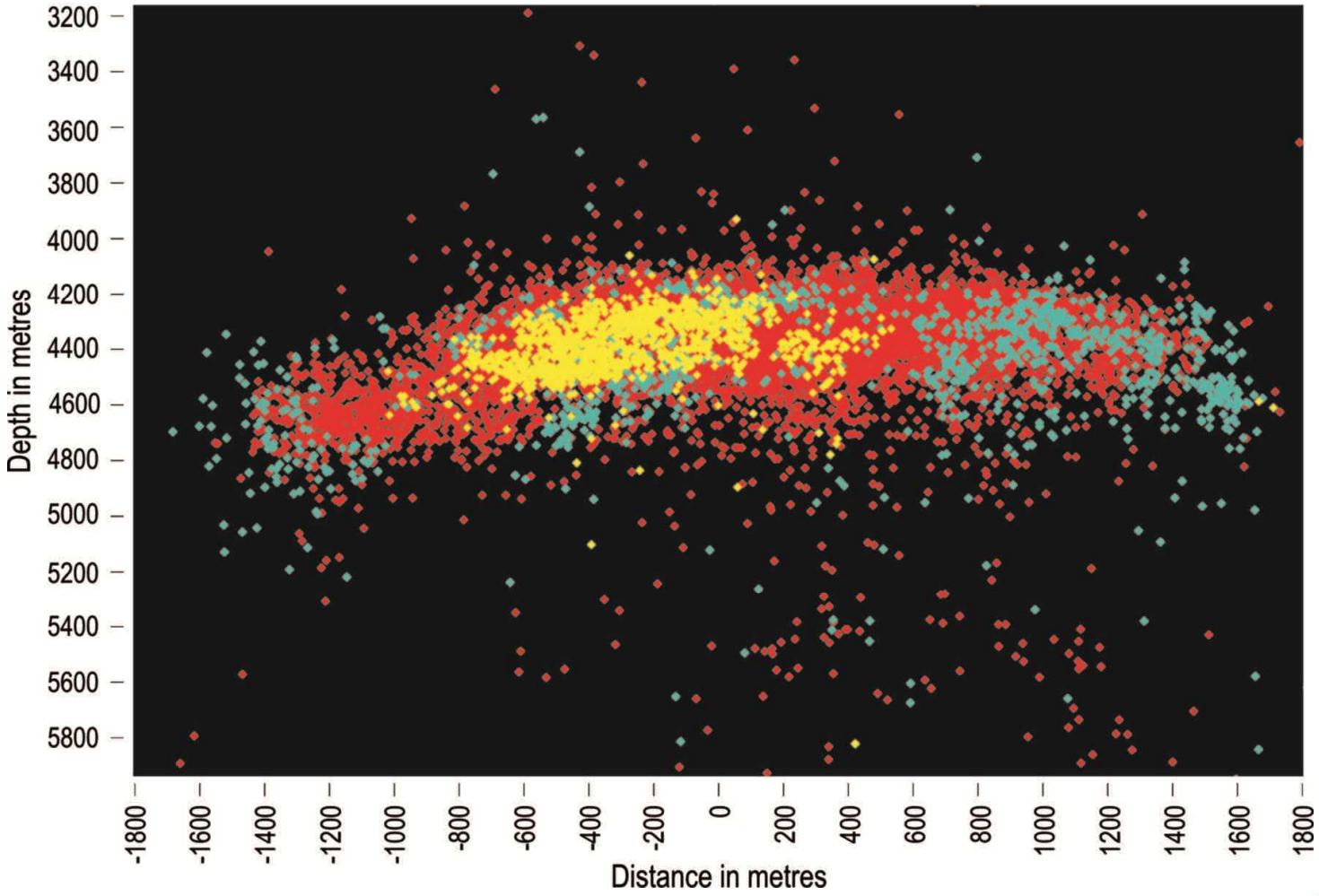



- The Earth is hot. At depths of 4 to 6Km temperatures exceed 200C
- Geothermal tools require electronics to operate from 250 – 325C
- The heat is mined by water flow from injectors to the producer via hydraulic enhanced fractures in the rock.

Sandia National Laboratories

# Fracturing Rock Away From the Well

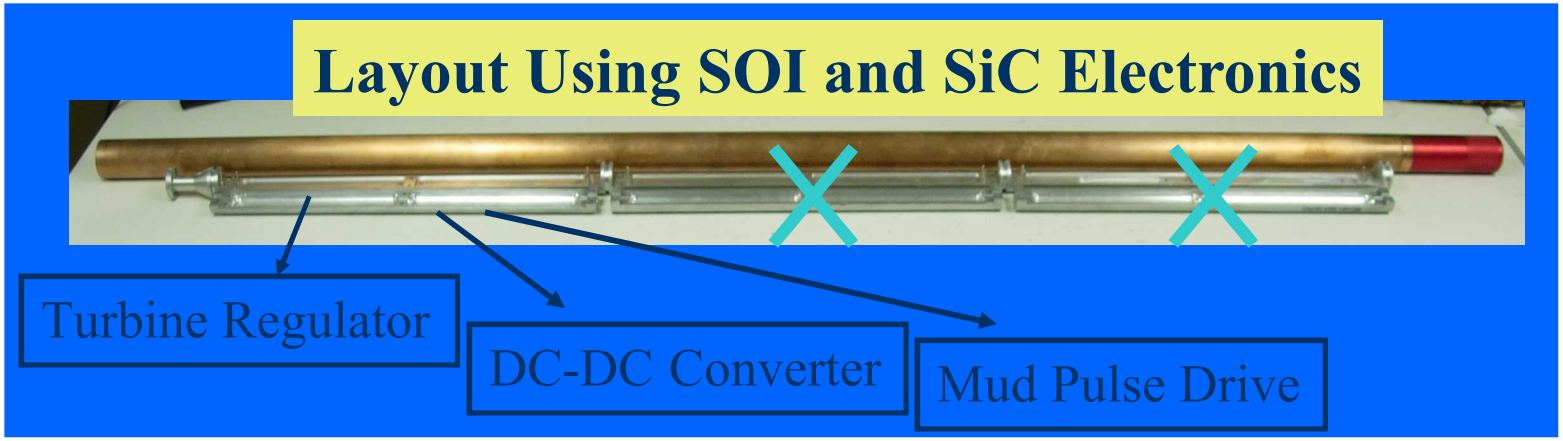
Seismic Sensors Track Rock Fractures as Hydraulic Pressure is Applied




Sandia National Laboratories

# MWD Benefits From SiC & SOI

- By using new SOI & SiC electronics
  - Old drilling tools can be converted for use in geothermal wells
  - Measurement-While-Drilling (MWD) tools to enhance drilling rates
  - In situ seismic sensors needed to map hydraulic fracture mapping
  - Below is a MWD mud turbine regulator needed for electric power
    - Its 1/3 the size of the conventional Si switcher
    - Operates up to 250C




- In 3-5 years SiC (Silicon Carbide) technology may dominate the drilling industry!!!

Sandia National Laboratories

# Reservoir Monitoring

**Conventional well monitoring tools operate from long cables for 4 to 5 years.**

**Sandia's SOI tool has 800+days in the well.**

**Future tools will be expected to operate for 5-15 years and in some cases operate wireless**

Sandia National Laboratories

# Conclusion

- Sandia is working with the SAE to develop standards for reliability testing of new high-temperature electronic components needed to.
  - Improve energy efficiency of power systems
  - Reduce weight of aircraft and hybrid vehicles
  - Improve long-term reliability
- The next SAE meeting on this topic is hosted by Airbus, April 24 - 26, 2007, Toulouse, France
  - http://www.sae.org/servlets/aerostd/committeeHome.do?comtID=TEAAE7

Sandia National Laboratories

- Time for Questions?

Sandia National Laboratories

# The Sandia Team: Electric Design

- Randy Normann and Joseph Henfling
- Sandia Drilling & Instrumentation Dept
- We have been working to develop HT tools for 8+ years.  We have a number of commercial success stories for a 350C PTS tool, 300C Fluid-Steam Sampler and now unheat-shielded 250-300C PT tool.
- http://www.sandia.gov/geothermal/

Sandia National Laboratories

# An outsider working with the Sandia team on utility power electronics

- Michael Ropp
- Associate Professor of Electrical Engineering, South Dakota State University
- Working with Sandia's Solar Energy Systems, Solar Technologies, and Energy Storage groups, and the Drilling and Instrumentation Department
- Areas of activity:
  - High-reliability modular power electronics for utility-scale applications
  - Improved means for controlling power systems using power electronics and communications
  - Integration of renewable energy resources into power systems

Sandia National Laboratories

# The Sandia Team: Electrical Interconnection

- Paul Vianco
- Metals Processing Department
- Part of the Materials and Process Science Center, performs research and development studies in the area of metals melting and casting at the Liquid Metal Processing Laboratory. http://www.sandia.gov/materials/sciences/1861.htm
- Paul has experience in designing reliable solder electrical interconnects.

Sandia National Laboratories

# The Sandia Team: MEMS

- Seethambal “Sita” Mani
- MEMS Technology Department
- Integrated Microsystems provides customer focused engineering services required for the development of micro sized products based on emerging micro technologies. While our focused developmental areas are dedicated to our mission of National Security we also partner with industry and government.
- Sita is working on this project along with others in a joint effort with the U of Texas at Austin.  This joint project is looking at what sensors are the most beneficial for the production life of a well.

Sandia National Laboratories