**Power Technology and Alternative Energy Branch**

US Army RDECOM CERDEC C2D Army Power Division

Aberdeen Proving Ground, MD


**PTAE - TR – 10 – 01**

# Solar Photovoltaic Technology Assessment for Soldier-Portable and Mobile Power

Cao Chung, US Army CERDEC C2D

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RDER-CCA-PS

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# Solar Photovoltaic Technology

# Assessment for Soldier-Portable and Mobile Power

CERDEC
US ARMY – RDECOM

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

**Power Sources Conference 2010**
**Wednesday, June 16, 2010 , 3:30 - 5:10 PM**

*Cao Chung*
*US Army CERDEC – Command and Control Directorate – Army Power Division*

# Agenda

- Army needs and requirements
- Technologies that address the Army’s needs and requirements
- Current development efforts
- Future Opportunities

# Army Applications



- Soldier and Sensor
  - Soldier: Reconnaissance and Surveillance
  - Sensor: Perimeter or Border Security
  - Applicable to 8 hour, 1 day, 3 day, and 7 day missions
  - Need: Prime power and Battery recharging
- Hybrid
  - Remote Power and Silent Watch
  - Tactical Operations Centers (TOC)
  - Need: Fuel savings and Mission extension

# US Army CERDEC Solar PV Module Level Objectives

All performance metrics reported for AM1.5 insolation and standard, temperature, and pressure (STP) ambient conditions.

| | Current | Threshold | Objective | Pacing Technology |
|---|---|---|---|---|
| Architecture | Foldable<br>Rigid<br>Ruggedized<br>Thin<br>Glint Free*<br>Rollable* | Foldable<br>Flexible<br>Ruggedized<br>Thin<br>Glint Free<br>Rollable<br>Chemically Resistant | Foldable<br>Flexible<br>Ruggedized<br>Thin<br>Glint Free<br>Rollable<br>Chemically Resistant | Packaging<br>Fabrication processes<br>Encapsulation/coating |
| Power density | 35-40 W/kg or 50-80 W/m$^2$ | 40 W/kg or 100 W/m$^2$ | 75 W/kg or 150 W/m$^2$ | Material selection<br>Novel PV chemistry<br>Encapsulation/coating |
| Conversion efficiencies | 5 to 8 % | 10% | 15 % | Material selection<br>Novel PV chemistry |
| Cost | $15 per Watt | $3.50 per Watt | $2.50 per Watt | Material selection<br>Fabrication processes |

*Available for certain current technologies.

# Various Alternative Energy Technologies



**U.S Army CERDEC has interest in:**

- **Thermoelectrics**
- **Wind Turbines**
- **Waste to Energy**
- **Heat Actuated Cooling**
- **Solar Photovoltaics (PV)**
  - **Device construction**
  - **Energy storage**
  - **Systems**

# US Army CERDEC Solar PV Prior Developments



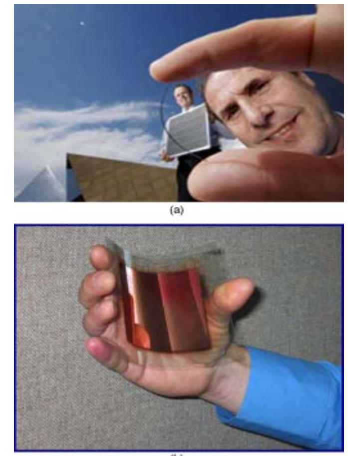
## Rucksack Enhanced Portable Power System (REPPS)

- Connects to BB-2590 lithium ion rechargeable battery to allow for continuous operation of unattended ground sensors and surveillance cameras
- Flexible panels use copper indium gallium (di)selenide (CIGS) photovoltaic chemistry
- Over 100 systems have been provided via the US Army's Rapid Equipping Force (REF) and US Marine Corps (USMC)
- Recharges BB-2590 in 4 to 6 hours, depending on sun
- Approximately 62-watt peak at AM1.5, 25degC

# Assessments of PV Technologies

- Legacy Silicon PV
  - Mono-crystalline
  - Poly-crystalline
  - Amorphous
- Near Term PV
  - Copper Indium Gallium di-Selenide
  - Cadmium Telluride
- Next Generation PV
  - Organic photovoltaic
  - Dye sensitized solar cells
  - Quantum dot solar cells
  - III-V

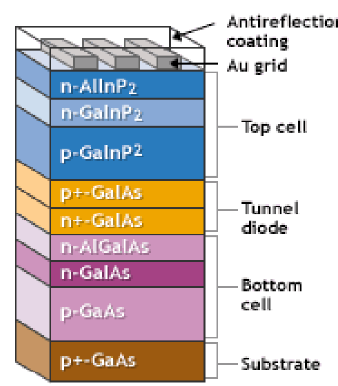
Device representation from Bell Laboratory. Image courtesy of Kazmerski.



(a)

(b)

Image courtesy of Kazmerski



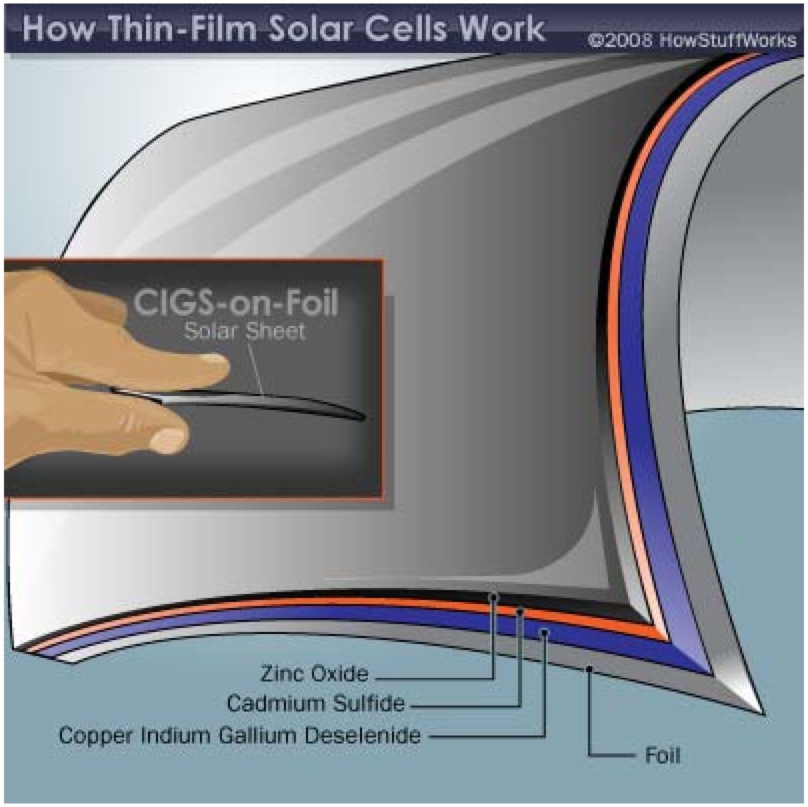

Multi-junction cell. Image courtesy of EERE.

# US Army CERDEC Solar PV Material Focus

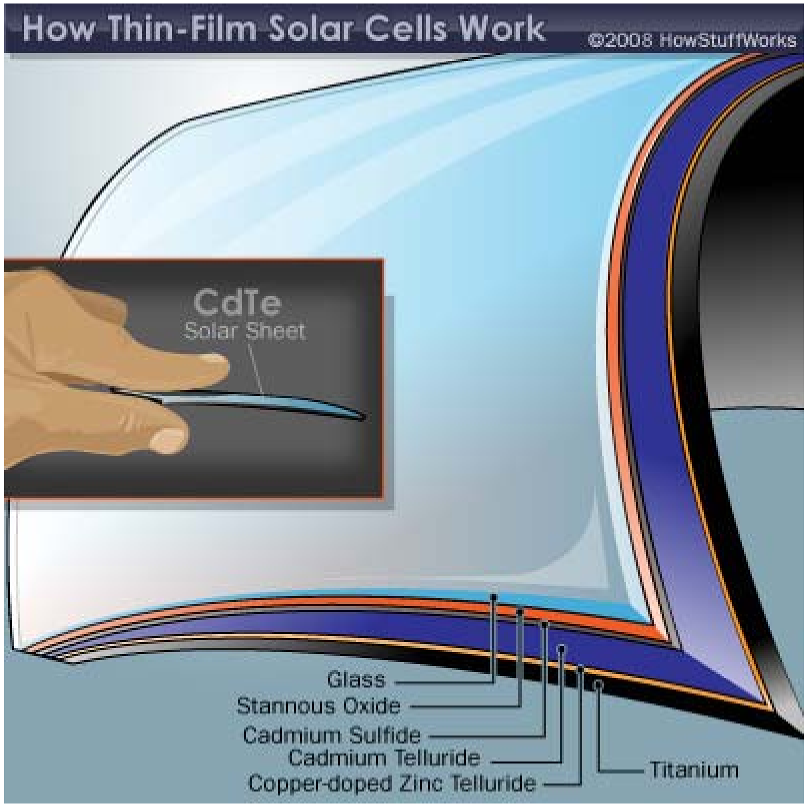
- Copper Indium Gallium Diselenide (CIGS)
  - Efficiency = 17%
  - PVD fabrication
  - Indium
- Cadmium Telluride (CdTe)
  - Cell Efficiency = 16.5%
  - PVD fabrication
  - Health and environmental concerns are alleviated

# CIGS and CdTe Device Construction

## CIGS




## CdTe



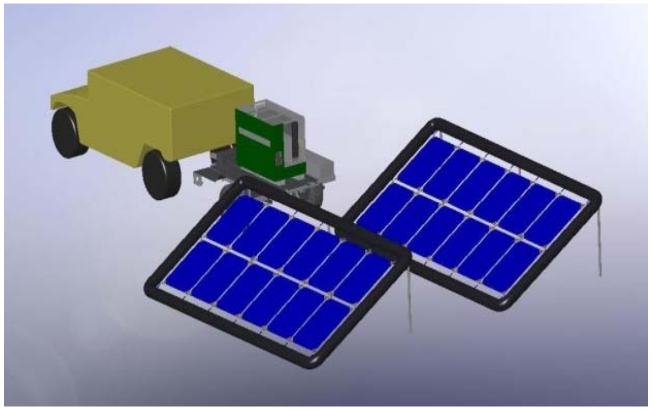

Images are courtesy of HowStuffWorks.com

## Portable Micro-Inverters

- 200-watt continuous inverter for rigid and flexible solar photovoltaic panels
- Provides 120-VAC, 60-Hz power that meets utility class 2C power quality per MIL-STD-1332B
- 94% target efficiency and interoperable with most commercial rigid PV panels in the 20 to 40-VDC range
- Capabilities include grid connectivity, islanding and micro-grid modes, and daisy-chaining panels together for additional power generation

## 2.5-kW Advanced Solar Power Source

- Target 15% efficient (threshold 10%) advanced solar PV panels that use cadmium telluride (CdTe) on virtual single crystal (VSC) substrate
- 5-kWe bidirectional inverter that provides 120-VAC single-phase or 208-VAC three phase power at ~90% eff.



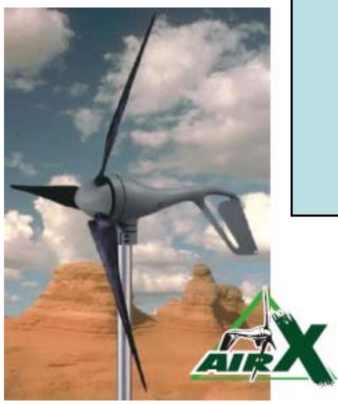
- 12-kWh lithium ion battery bank to allow for storage of additional solar power generation
- Demonstration of hybrid system in Spring 2011

# American Recovery and Reinvestment Act (ARRA) of 2009 US Army Flexible Solar Photovoltaic

# US Army CERDEC
# Solar PV ARRA of 2009



## Reusing Existing Natural Energy Wind and Solar (RENEWS)



and

\+

Li-ion Energy Storage

\+

DC to AC Inverter

→

Single Box System

**Re-Transmission Sites**

**Command Posts**

**Battery Chargers**

**Space Heaters**

**Communications**

# Summary



- Technologies Interests
  - Crystalline
  - Thin-film
  - No glass encased devices
- CERDEC's Objective / Focus
  - Power density ≥ 40 Watts/kg
  - $\eta \geq 10\%$
  - Cost ≤ $3.50 per Watt
- Applications
  - Inverters
  - Portable Systems
  - Hybrid Systems

# Conclusions

- In general, solar technologies show promise to
  - Enhance soldiers mission
  - Decrease logistics

- Opportunities for collaboration
  - Small Business Innovative Research (SBIR): Topic #OSD-EP5 (closes 23 June 2010)
  - FY12-15 Army Technology Objectives (ATO's) (in planning)
  - Broad Agency Announcements (BAA) (in planning)

# Questions?

Thank you for your attention

# Backup: TRL Definitions

| Technology Readiness Level (TRL) | Description |
|---|---|
| 1. Basic principles observed and reported. | Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties. |
| 2. Technology concept and/or application formulated. | Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic (paper) studies. |
| 3. Analytical and experimental critical function and/or characteristic proof of concept. | Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. |
| 4. Component and/or breadboard validation in laboratory environment. | Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory. |
| 5. Component and/or breadboard validation in relevant environment. | Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components. |
| 6. System/subsystem model or prototype demonstration in a relevant environment. | Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment. |
| 7. System prototype demonstration in an operational environment. | Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in structured or actual field use. |
| 8. Actual system completed and qualified through test and demonstration. | Technology has been proven to work in its final form and under expected operational conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended or pre-production configuration to determine if it meets design specifications and operational suitability. |
| 9. Actual system proven through successful mission operations. | Actual application of the technology in its production configuration and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system by operational users under operational mission conditions. |