



U.S. Army Research, Development and Engineering Command



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



Solar Photovoltaic for Tactical Applications **Cao Chung, US Army CERDEC Renewable Energy Team**

Presentation to Joint Service Power Expo 2011
04 May 2011, Myrtle Beach, SC



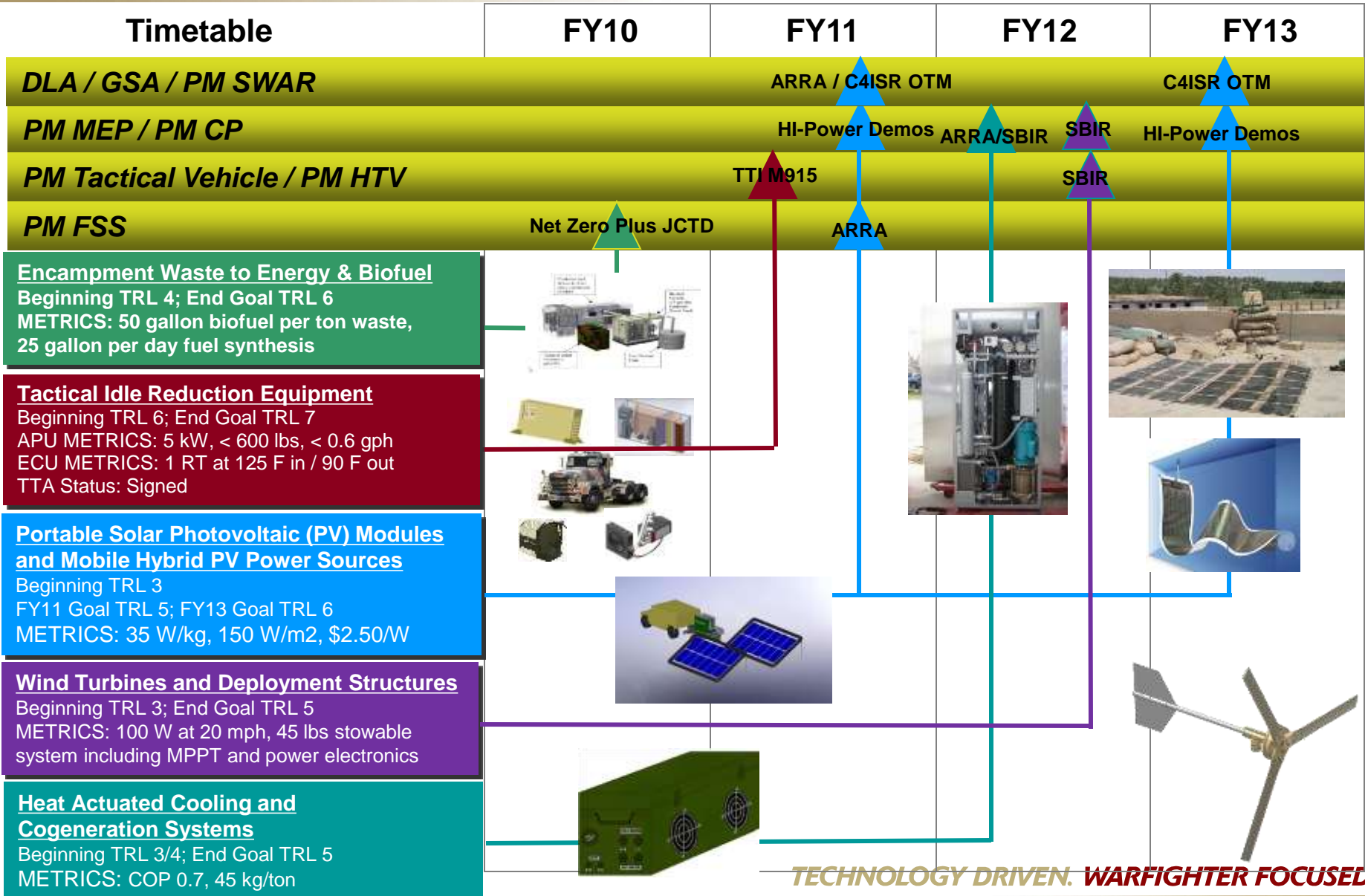
- Introduction
- Goals for the solar programs
- Summary of outdoor test results
- Programs within CERDEC



- 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: Logistic Savings and Mission extension



Renewable and Alternative Energy Products



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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 Rigid Ruggedized Thin Glint Free* Rollable*	Foldable Flexible Ruggedized Thin Glint Free Rollable Chemically Resistant	Foldable Flexible Ruggedized Thin Glint Free Rollable Chemically Resistant	Packaging Fabrication processes 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 Novel PV chemistry Encapsulation/coating
Conversion efficiencies	5 to 8 %	10%	15 %	Material selection Novel PV chemistry
Cost	\$15 per Watt	\$3.50 per Watt	\$2.50 per Watt	Material selection Fabrication processes



CERDEC's In House PV Test Results and programs

Sample ID: Unknown Model 11.375" x 6"

- CIGS based technology
- Monolithically integrated
- Roll-to-roll continuous production



Image courtesy of Ascentsolar.com

Ascent Solar Specs:

- P_{max} : 4.0 Watts
- V_{OC} : 23.8 V
- I_{sc} : 0.31 Amp
- V_{mp} : 16.5 V
- I_{mp} : 0.245 Amp

• CERDEC Test Results

- Irradiance: 875 W/m² @ MP
- Temp: 95° F, Partly cloudy
- P_{max} : 3.21 Watts; η : 8.35%
- V_{OC} : 17.0 V, I_{sc} : 0.271 Amp
- V_{mp} : 14.5 V, I_{mp} : 0.189 Amp

Sample ID: PowerFilm Rollable R15-300

- Amorphous Silicon base semiconductor
- Monolithically Integrated
- Roll-to-Roll production
- PowerFilm Specs:
 - P_{max} : 7.0 Watts
 - V_{OC} : ?
 - I_{sc} : ?
 - V_{mp} : 15.4 V
 - I_{mp} : 0.45 Amp

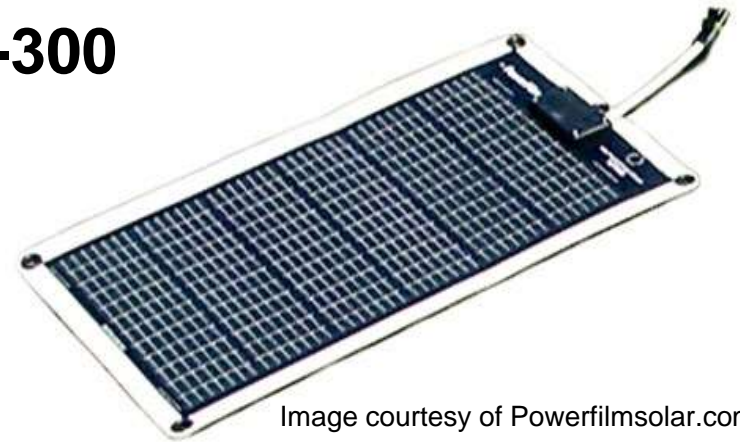


Image courtesy of Powerfilmsolar.com

- **CERDEC Test Results**

- Irradiance: 692 W/m² @ MP
- Temp: 80° F, Cloudy
- P_{max} : 6.59 Watts; η : 6.52%
- V_{OC} : 19.1 V, I_{sc} : 0.524 Amp
- V_{mp} : 13.0 V, I_{mp} : 0.507 Amp



Lite-PM 110 Watts

- Encapsulated crystalline silicon
- Mechanically assembled
- Batch production
- GreenPath Specs:
 - 36 Mono C-Si Cells
 - P_{max} : 110 Watts
 - V_{OC} : 23.76 V
 - I_{sc} : 5.45 Amps
 - V_{mp} : 20.16 V
 - I_{mp} : 5.35 Amp

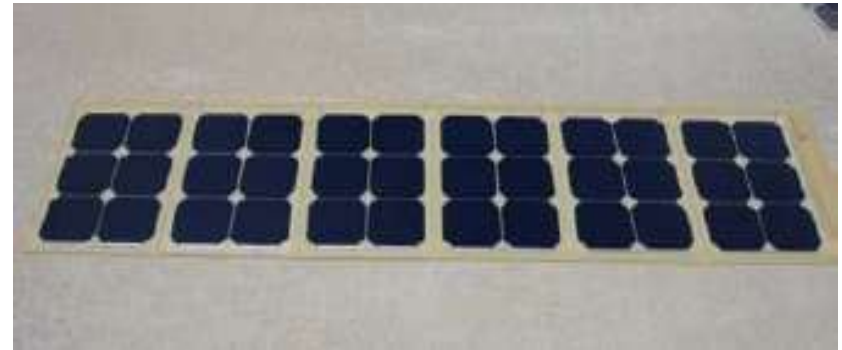


Image courtesy of GreenPath Technologies

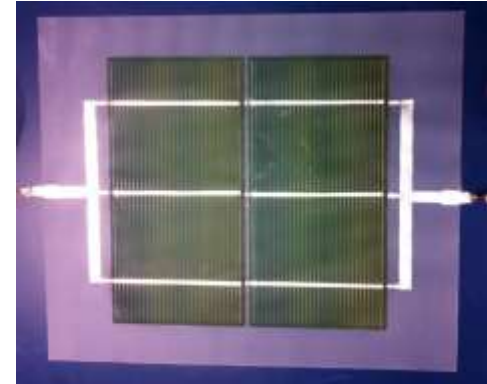
- **CERDEC Test Results**

- Irradiance: 514 W/m² @ MP
- Temp: 66° F and cloudy
- P_{max} : 49.6 Watts; η : 12.9%
- V_{OC} : 23.35 V, I_{sc} : 2.87 Amp
- V_{mp} : 18.9 V, I_{mp} : 2.13 Amp



Global Solar Energy SecGen Cell - 1

- CIGS based semiconductor
- Mechanically assembled
- CIGS material is roll-to-roll production
- GSE Specs:
 - P_{max} : 4.27 Watts
 - V_{OC} : 1.20 V
 - I_{sc} : 5.90 Amps
 - V_{mp} : 0.846 V
 - I_{mp} : 5.05 Amp



- **CERDEC Test Results**

- Irradiance: 514 W/m² @ MP
- Temp: 89.6° F, partly cloudy
- P_{max} : 2.01 Watts; η : 10.3%
- V_{OC} : 1.13 V, I_{sc} : 4.58 Amp
- V_{mp} : 0.665 V, I_{mp} : 3.03 Amp



Rucksack Enhanced Portable Power System (REPPS)

- Connects and recharges Li-ion BB-2590 batteries
- Recharge time: 4 to 6 hours
- Rated P_{max} : 62 Watts
- GSE manufactures CIGS solar PV modules and Brentronics is the systems integrator
- Available on the GSA
- 100 have been sent to the field





- Customer: US SOCOM
- Objective: Obtain Safety conf. report by 31 December 2010
- TRL 7, MRL 6
- Benefits: 1 gal/hour of fuel savings
- Specification (COTS Components):
 - 10 kW continuous power
 - 38.6 kW Solar PV arrays
 - 192 kWh lead acid energy storage
 - 7 kW diesel fueled power generator
 - Deployable in 24 man hours
- Follow-on support planned



Images courtesy of Sundial





- Customer: PM-MEP
- Five solar PV each rated at 90 Watts each
- Energy storage capable of storing 4 kWhrs using VRLA batteries
- 3 kW JP-8 fueled power generator
- 1.8 kW inverter
- Current TRL of 6
- Obtain a safety confirmation by end of September 2011
- Testing in progress @ APG, MD



Image courtesy of SolarStik



Image courtesy of SolarStik



- Current commercial CdTe from FirstSolar has 11.0% and costs \$0.76/Watt
- ARL's WMRD provide physical characterization services and conducting nitrogen doping experiments with CdTe using ion implantation.
- CERDEC & ARL are pursuing a two-year, two-phase program to advance polymer encapsulated CdTe solar PV.
 - Phase I: developing single-junction CdTe solar cells with threshold of 15% efficiency, 20% target and 75 W/kg
 - Phase II: modeling, simulation, and plant design to demonstrate \$2.50/W production cost at 15MW/year and less than \$1/W at productions of 1 GW/year

Current commercial CdTe PV

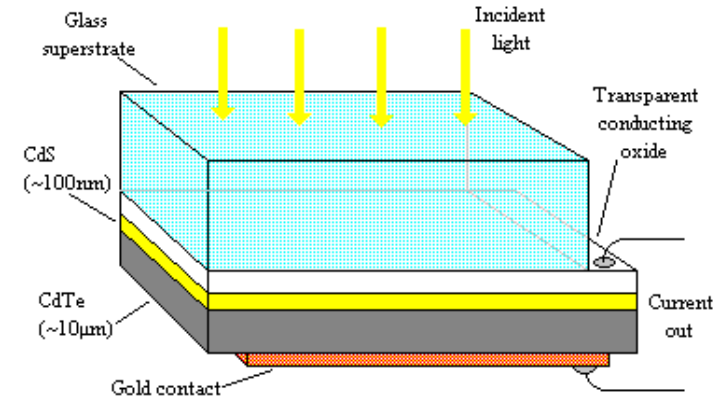
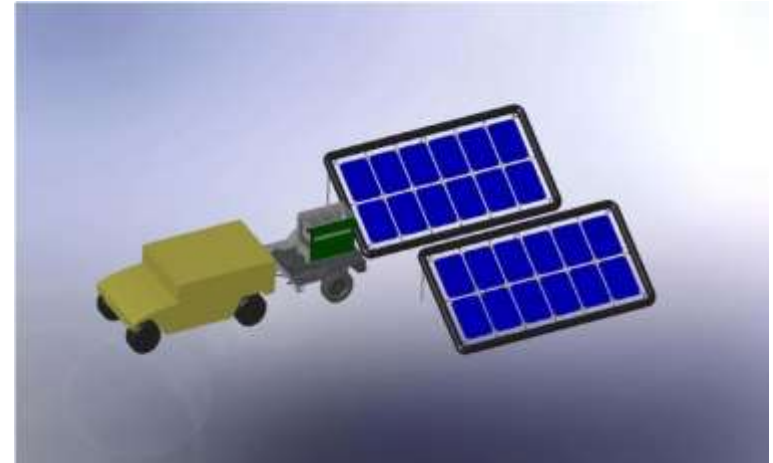


Image courtesy of Durham University, UK

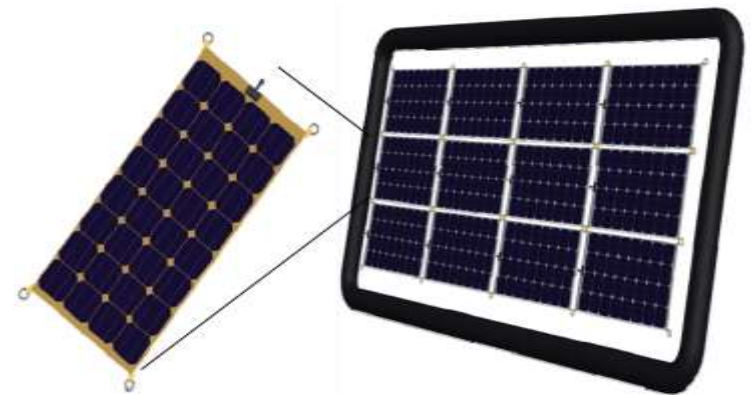


2.5-kW Advanced Solar Power Source

- Objective: 15% efficient solar PV array with 10% threshold
- Deliverables:
 - 5 kW bidirectional inverter
 - 2.5 kW encapsulated c-Si solar PV
 - 12 kWh Li-ion battery bank
 - Inflatable deployment structure
- Electricore Reports: 11.4% module efficiency and power dens. of 50 W/kg
- Demonstration: TBA @ APG, MD



Images courtesy of Electricore





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