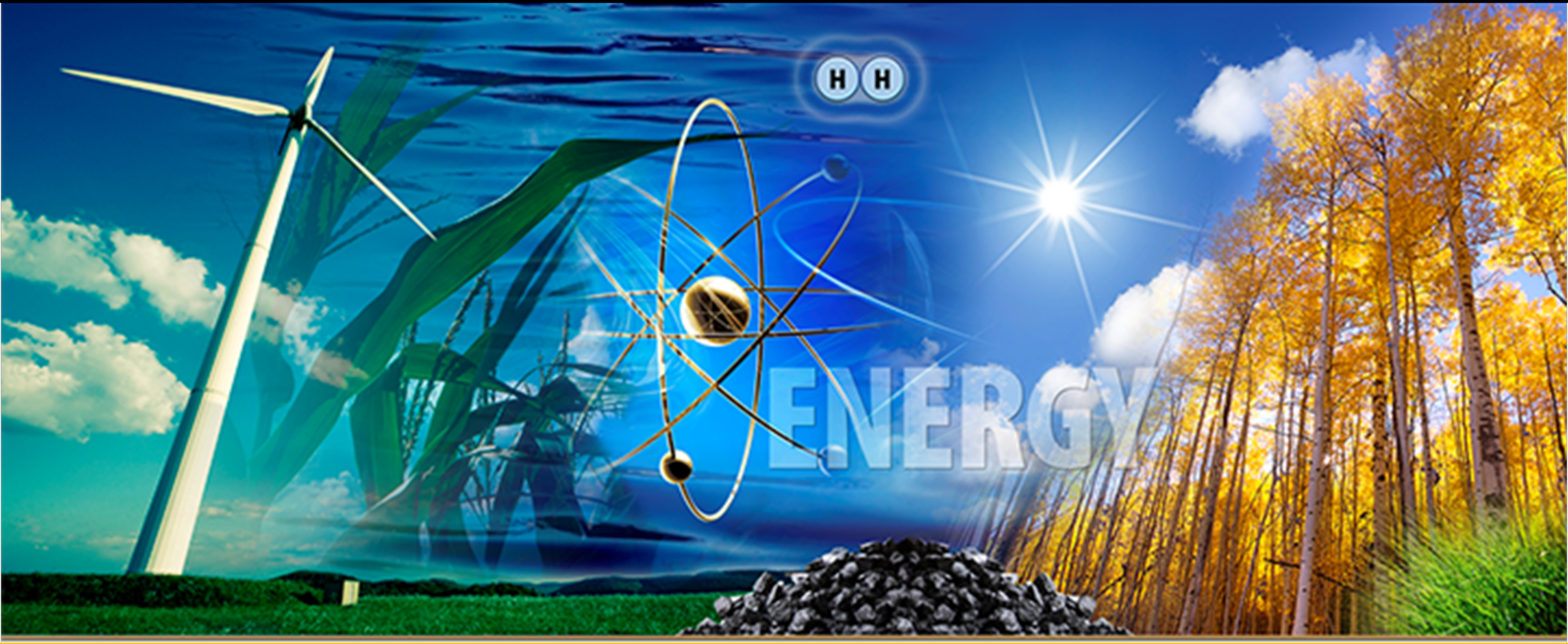
Solar Energy Research and Education at Purdue University



Pankaj Sharma

Energy Center, Discovery Park, Purdue University, West Lafayette, IN 47907

Windiana2011 and Indiana Renewable Energy Conference, Indianapolis, IN (July 20-21, 2011)

Outline

Energy Center

Challenges and Barriers

Programs/Facilities

Research - PV/Thermal

Education

Global Collaborations

Forthcoming Event

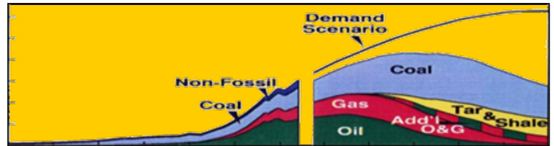
Discovery Park at Purdue University

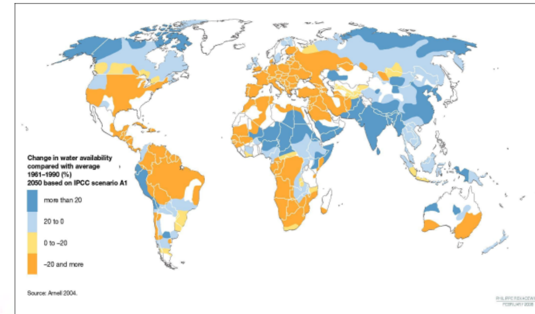
- ✓ Lilly Endowment support
- ✓ Institutional support
- ✓ Broad mission
- ✓ Synergism among centers

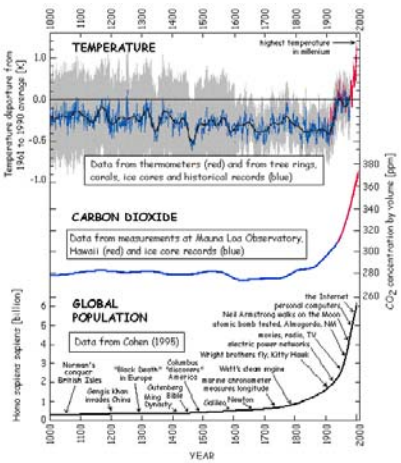
- Bindley Bioscience Center
- Birck Nanotechnology Center
- Burton D. Morgan Center for Entrepreneurship
- Discovery Learning Center
- **Global Sustainability at Purdue**
  - **Energy Center**
  - **Water Community**
  - **Center for the Environment**
  - **Purdue Center for Global Food Security**
  - **Purdue Climate Change Research Center**
- Advanced Computational Center for Engineering and Sciences
  - Cyber Center
  - Computing Research Institute
  - Rosen Center for Advanced Computing
- Oncological Sciences Center
- Regenstrief Center for Healthcare Engineering

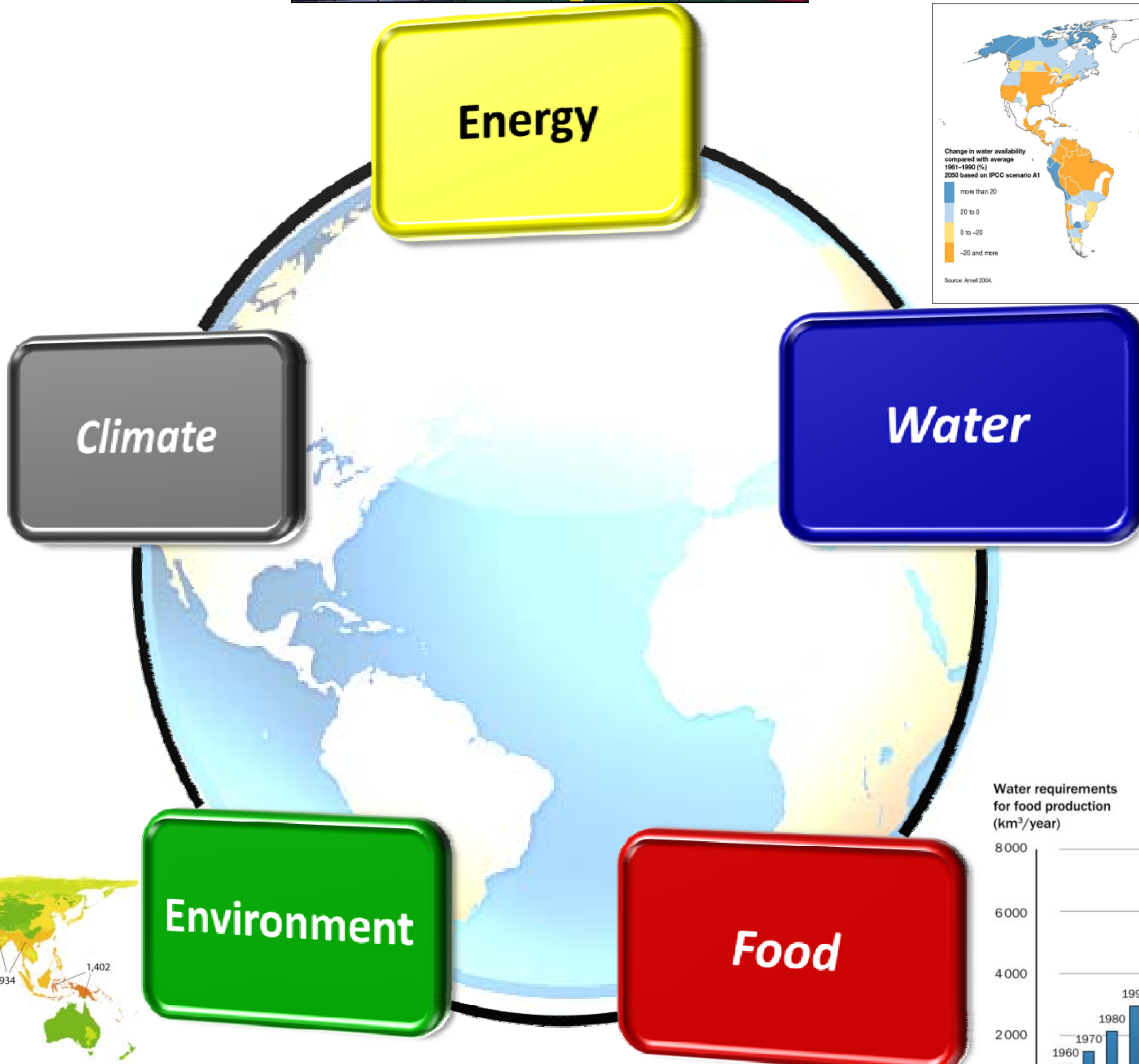
PURDUE UNIVERSITY
Discovery Park

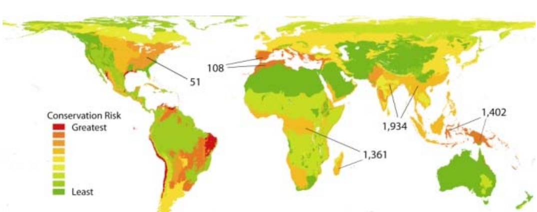
Global Sustainability Initiative at Purdue

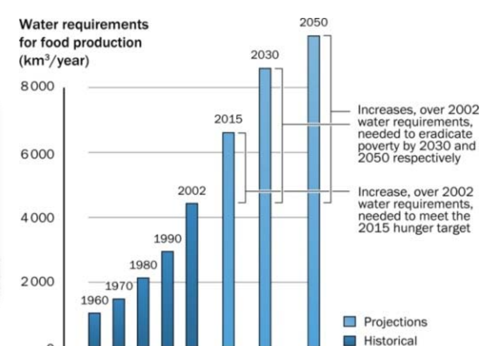










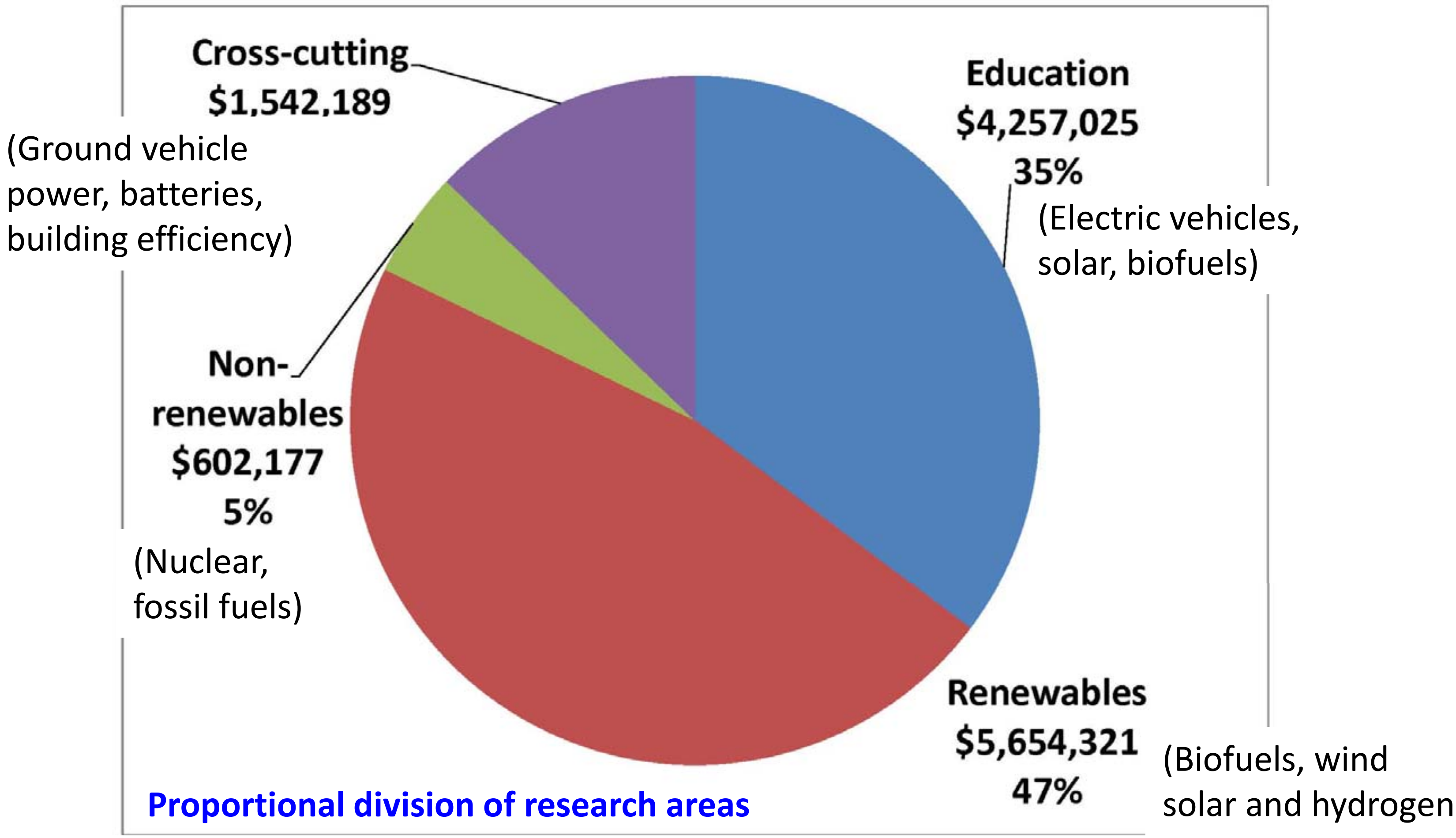


Purdue Energy Center

Discovery with delivery in energy sciences and engineering

Purdue Strengths

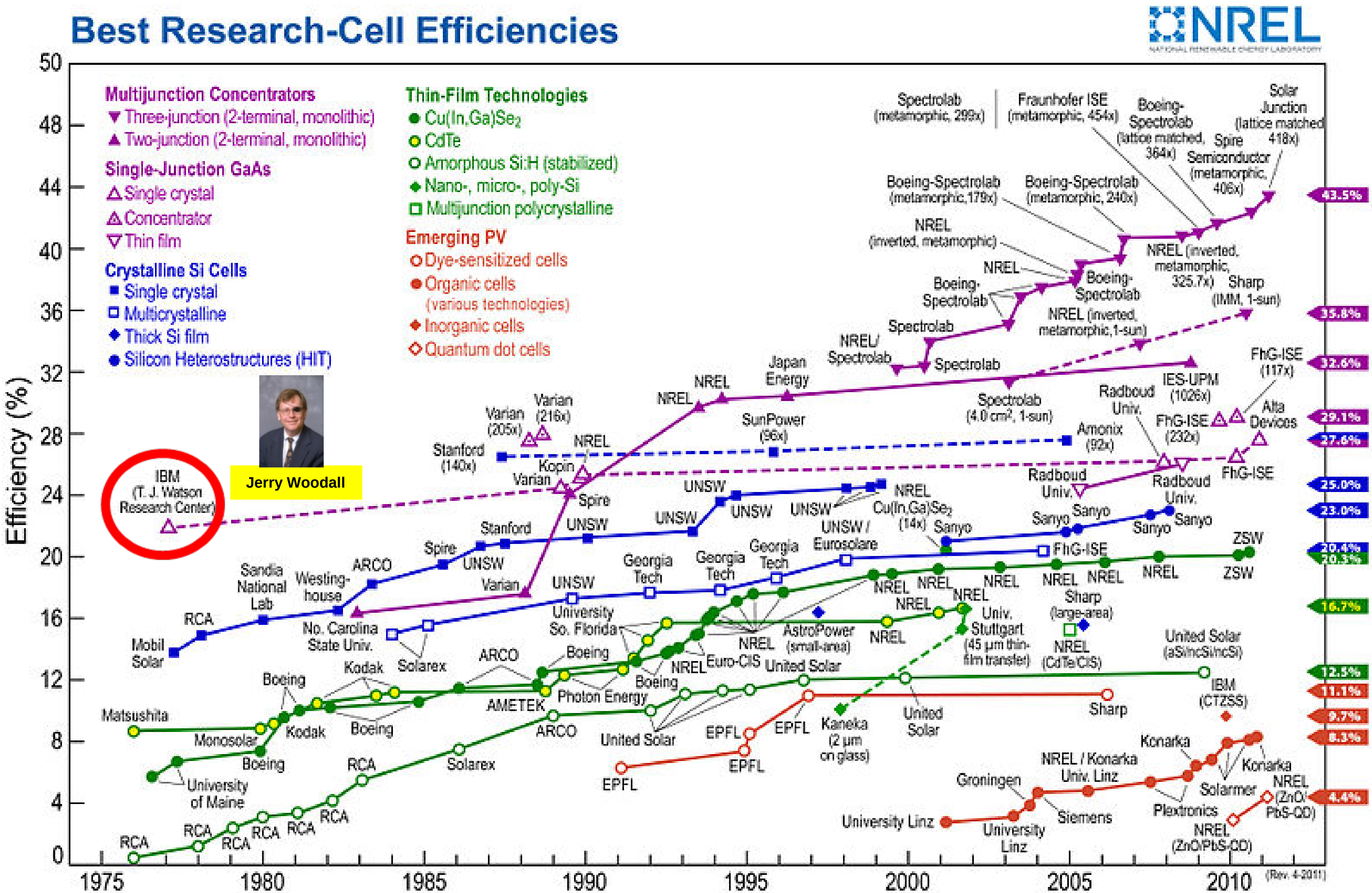
Transportation (biofuels, aviation engine testing, electric vehicles, ground vehicle power, transportation systems)
Power generation and storage (solar, wind, nuclear, smart grid, energy efficiency, state utility forecasting)



Every $1M in research dollars generates 7-10 jobs directly and impacts up to 30 indirectly

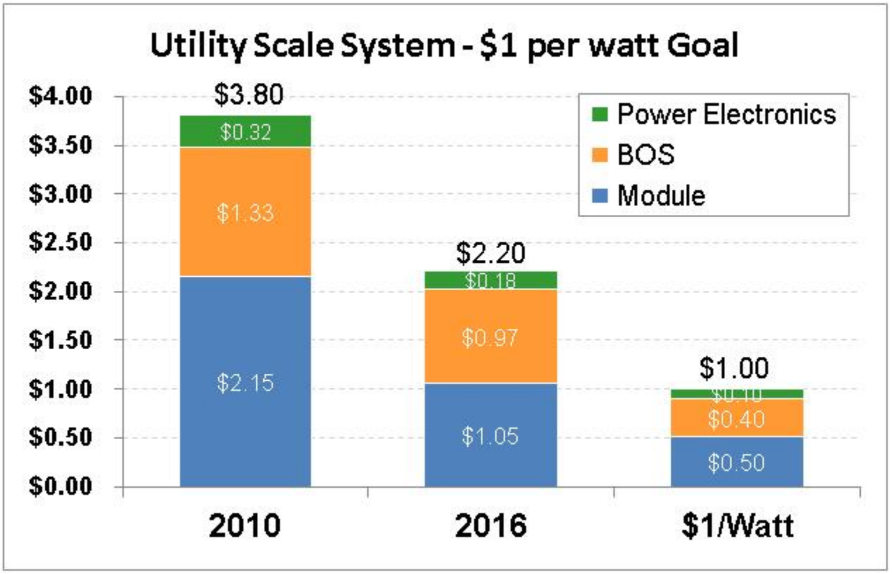
Cell Efficiencies'

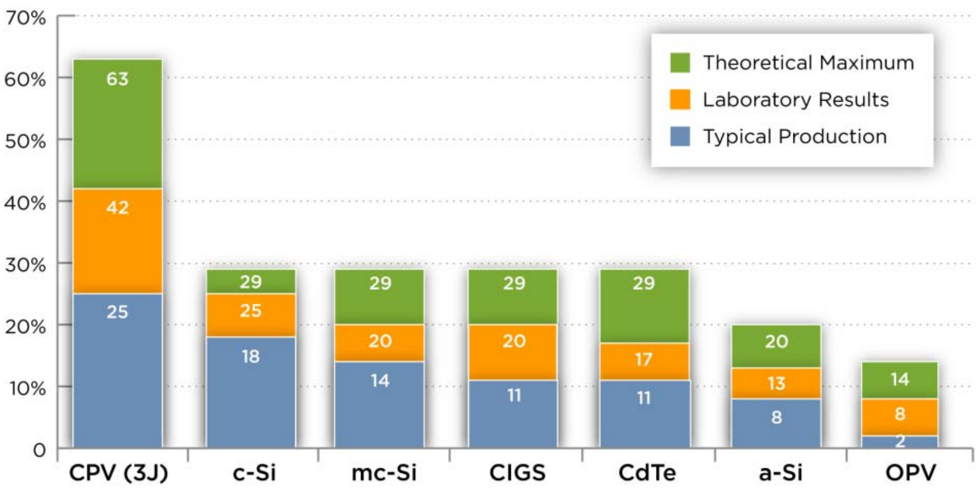
Next Generation of Materials

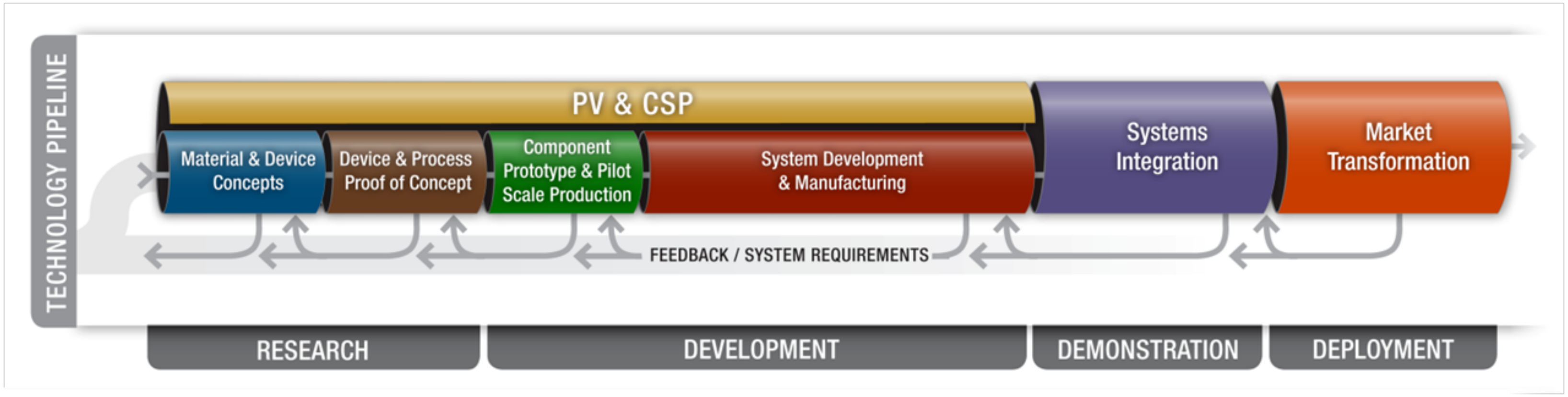


Challenges, Barriers and Opportunities

Cost; Efficiency; Novel Materials/Next Generation; Work Force Development







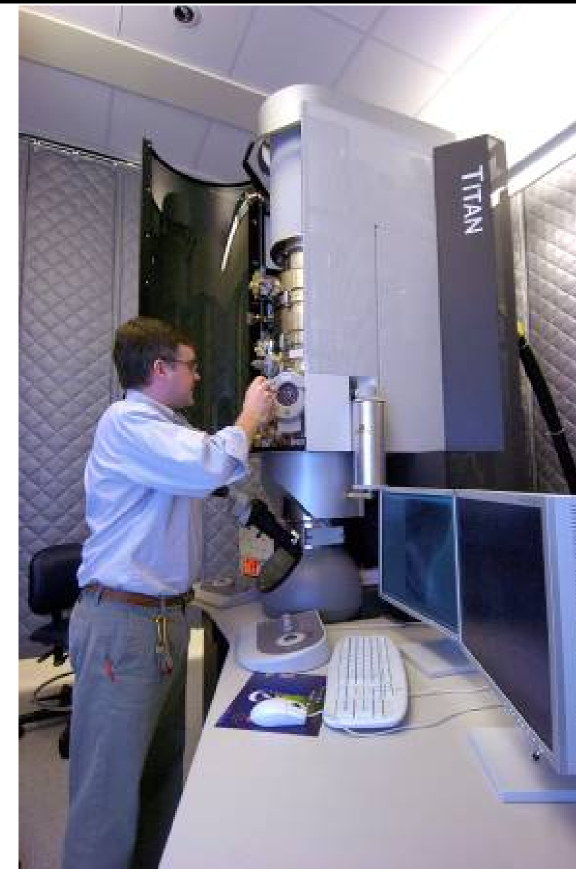
Facilities

Facility: Birck Nanotechnology Center

Turning the Promise of Nanoscience into New Technologies

- 187,000 ft^2, \$58M + ~\$25M in equipment
- First integration of bio-pharma and semiconductor cleanroom
- Exceptional quality cleanroom – 25k ft^2; 45% Class 1(ISO Class 3)

- Low Vibration (NIST A in cleanroom and A-1 in Hall lab)
- “Nanotechnology Grade” DI water plant (<15 ppt boron)
- 1, 0.1, and 0.01°C control
- Nanotech incubator



FEI Titan TEM/STEM with environmental/growth stage and atomic

Leica VB-6 electron beam lithography tool with 6nm-in-resist capability

Omicron surface analysis cluster

Facility: Solar Energy Utilization Laboratory

Rakesh Agrawal, ChemE/CoE

Objectives

To facilitate access to a suite of state-of-the-art instruments to enhance the development of new solar energy utilization materials and devices

To enable Purdue and the broader state-wide solar research community to be on the cutting edge of developing new solar energy conversion devices.

Capabilities

1. Solar simulator capable of reaching high sunlight concentrations
2. Spectroscopic instruments for quantitative photoluminescence and transient absorption
3. Ability to conduct all characterizations under controlled environmental conditions;
4. Equipment for vapor phase deposition (via molecular beam epitaxy)

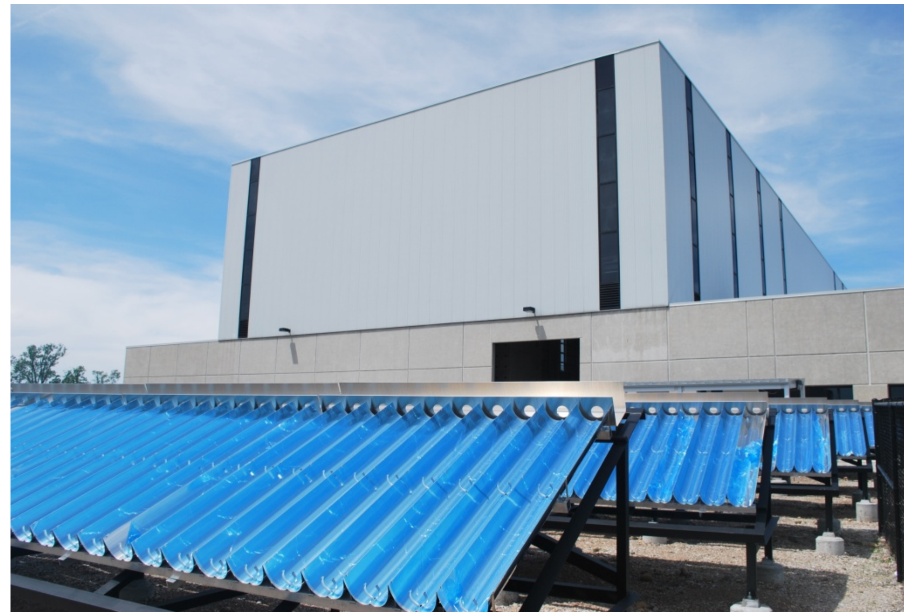
Rakesh Agrawal, Hugh Hillhouse*
Solar Energy Research Group
Chemical Engineering
* Adjunct at Purdue

Facility: Solar Cooling & Heating System at Bowen Lab

Ming Qu, Civil Engineering/CoE

Technical Specifications

- 100 meter sq/stationary parabolic collectors
- 23 kW absorption chiller



Project Outcomes

1. Harvest solar energy to contribute to development of sustainable buildings
2. Demonstrate feasibility for high temperature cooling technology
3. Develop evaluation platform to quantify life cycle cost, energy payback, and carbon footprint of solar thermal system

Sponsored by

NSF

EXPO 2010 SHANGHAI CHINA | 远大 BROAD

上海世博会全球合作伙伴
GLOBAL PARTNER OF SHANGHAI EXPO

GRUNDFOS

AUTOMATEDLOGIC CORPORATION

Facility: Applied Energy Laboratory

William (Bill) Hutzel, Mechanical Engineering Technology/CoT

Main Features

- 1,800 square feet that accommodates up to 36 students
- Equipment for teaching lab-based UG thermal/fluid science courses
- Solar photovoltaic and solar thermal systems that are remotely accessible over the internet

Support from

NSF KMC CONTROLS AEL Carrier AUTOMATEDLOGIC CORPORATION

http://www2.tech.purdue.edu/met/facilities/knoy427/remote/nsf/index_rev.htm

Large Programs

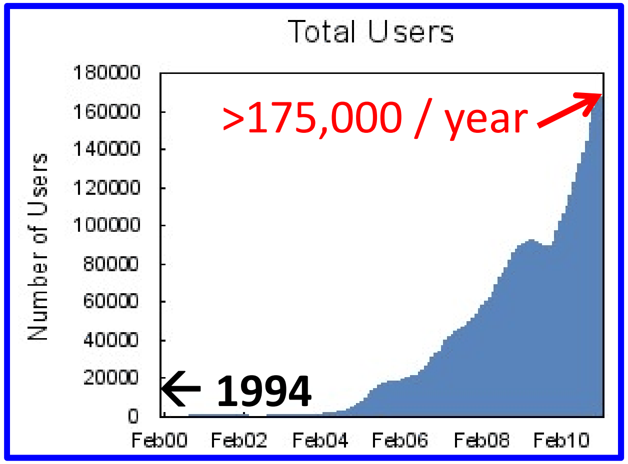
Program: Network for Photovoltaic Technology

Theory, Modeling and Simulation; PI Mark Lundstrom and Ashraf Alam, ECE/CoE

Research Areas

- Materials and Processes
- Device Simulation and Modeling
- Characterization for Predictive Modeling
- Physics-based Reliability
- PV Systems
- Software Platform

30% US / 24% Eur. / 35% Asia / 10% other

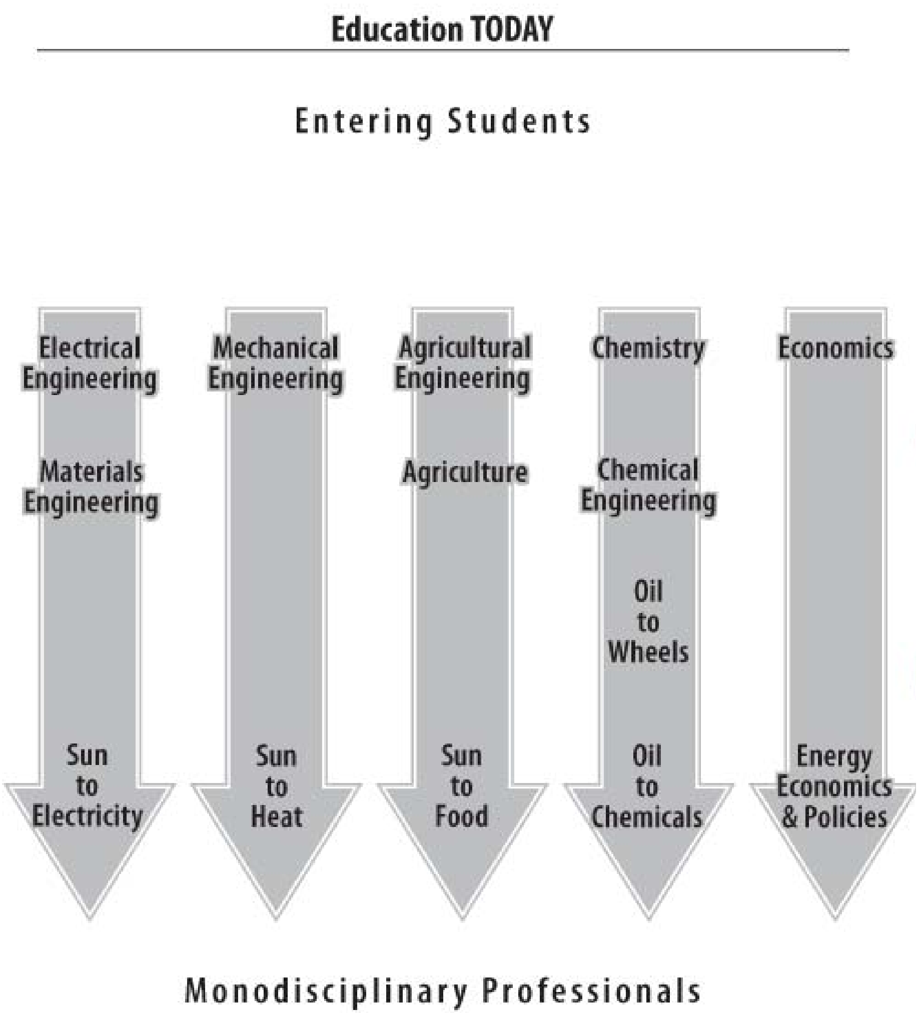


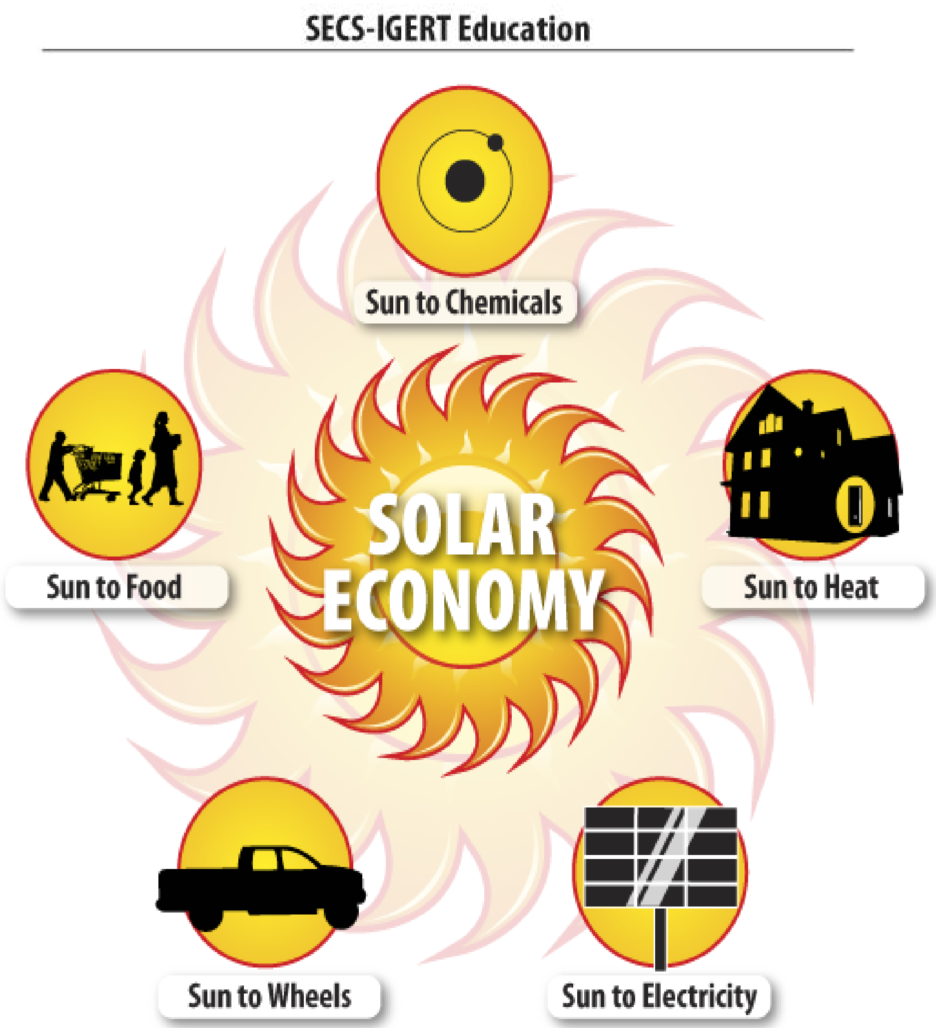
Member Companies

Program: Solar IGERT

NSF: Integrated Graduate Education, Research and Training; PI Rakesh Agrawal, ChemE/CoE

Training the next generation of energy scientists and engineers in interdisciplinary research





Program: Inhome

DOE Solar Decathlon: $650,000 Project Budget; PI William (Bill) Hutzel, MET/CoT

Guiding Principles

- Net Zero; Attractive; Affordable; Comfortable; Midwestern

Project Outcomes

- Design Innovations; Community Outreach; Broader Societal Impacts; Cross Campus Collaboration; Meet Educational Outcomes; Launch Industry Collaboration.

Member Companies

Team Purdue INHOME

U.S. Department of Energy Solar Decathlon

Ingersoll Rand Inspiring Progress

NREL National Renewable Energy Laboratory

ihcda Indiana Housing & Community Development Authority

Thermocore

GE imagination at work

Grabill

R.E. Dimond and Associates, Inc. Consulting Engineers

The Hill Group

Kolbe Windows & Doors

Research PV

Research: Synthesis of Nanocrystal Ink for High Efficiency Solar Cells

Rakesh Agrawal, Chemical Engineering/CoE

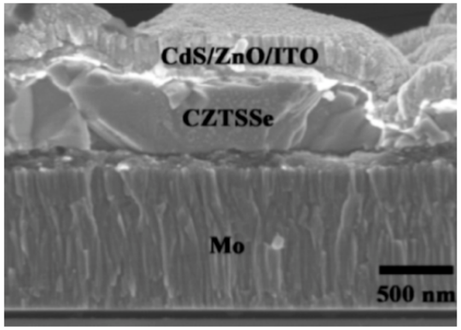
Key Problems

- Low cost fabrication
- High efficiency
- PV devices ($CuInSe_2$, $Cu(In,Ga)Se_2$, and $Cu(In_{1-x},Ga_x)S_2$.) use critical materials
- Limited supply of In/Ga and increasing price of rare earth elements

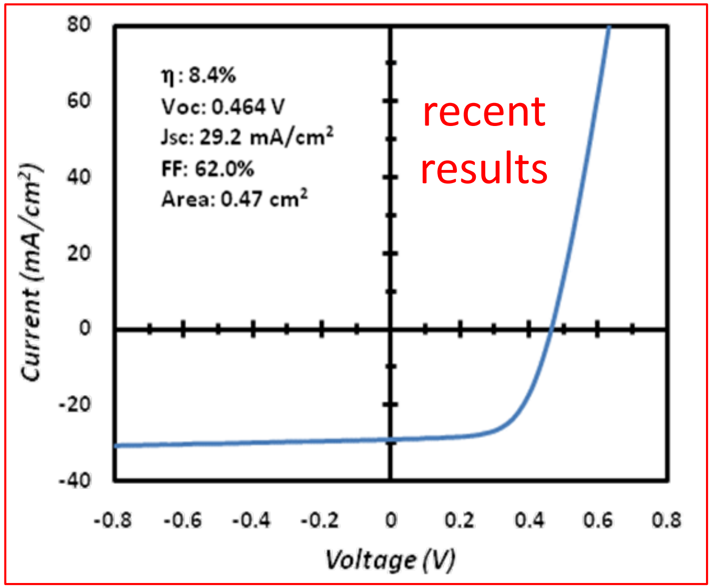
Approach

- Use Zn and Sn as they are naturally abundant (e.g. CZTSSe). Theoretical efficiency limit is 32%
- High material utilization; higher absorption coefficient; low material/module cost; safe-to-handle chemicals; easily scalable to coat large area; elimination of high vacuum equipment

$Cu_2Zn(Sn,Ge)(S,Se)_4$ Cells



"Fabrication of 7.2% Efficient CZTSSe Solar Cells Using CZTS Nanocrystals," Qijie Guo, et al., *JACS*, 2010



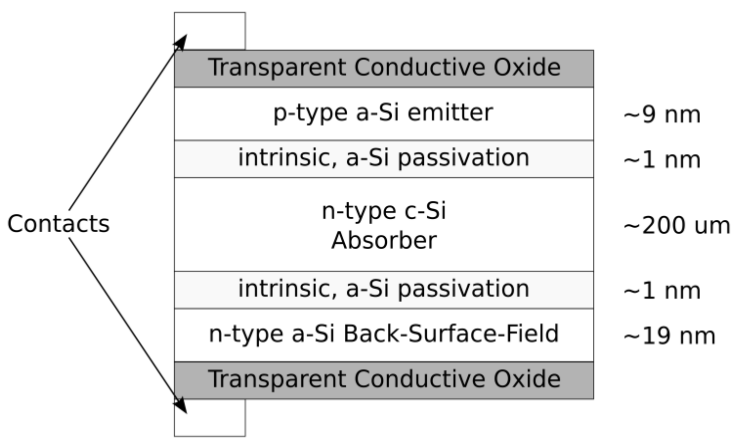
Research: Improving Efficiency Understanding by Numerical & Device Modeling

Jeffrey Gray and Richard Schwartz, Electrical and Computer Engineering/CoE

Areas of Research

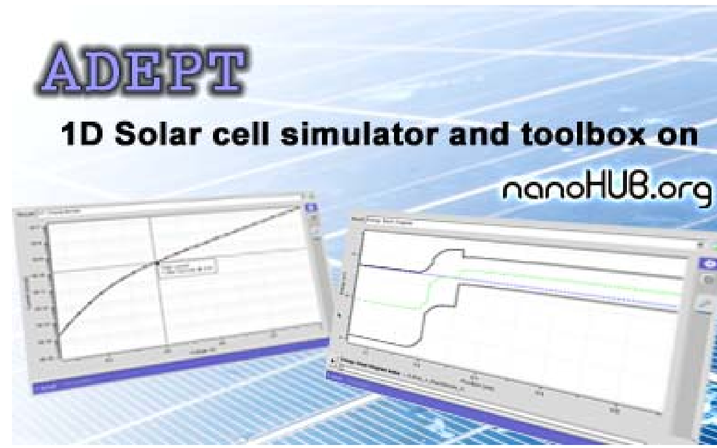
- Photon Recycling – to improve solar cell efficiency by reducing recombination/ reverse leakage current
- Modeling of concentrator photovoltaic systems
- Optimizing number of junctions to achieve peak system efficiency

- Modeling and Simulation of Si-Heterojunction and Poly-Emitter Solar Cells



Modern HIT^{TM} Device Structure

ADEPT
A Device Emulation Program, and Toolbox



Numerical Modeling of Solar Cells
a-Si, $CuSe_2$, CdTe and others

ZnO/CdS/CIS, ZnO/CdS/CIGS, CdS/CdTe, a-Si, Si, AlGaAs/GaAs, GaSb, InP

1. *Fundamental physics*
2. *Material models*
3. *Spatial dimensionality*
4. *Numerical methods*
5. *Device analysis*
6. *User interface*

http://nanohub.org/tools/adept/

Research: High Precision Scribing of Solar Cells by Laser

Yung Shin, Mechanical Engineering, and Gary Cheng, Industrial Engineering

Solar Cells

- To reduce manufacturing cost
- To improve efficiency of converting sunlight into an electric current

Obstacles

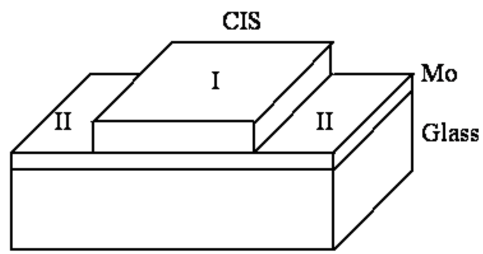
- Micro channels need to be interconnected by a series of solar panels to improve device output
- Conventional "scribing" by mechanical stylus are slow/expensive and produce imperfect channels

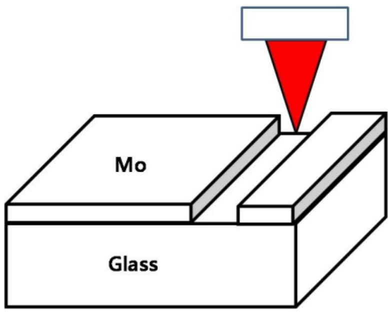
Approach

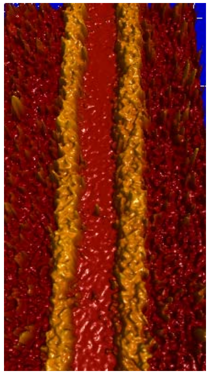
- Use "ultrashort/picosecond" pulse lasers
- It creates clean microchannels
- Reduces cost and improves efficiency

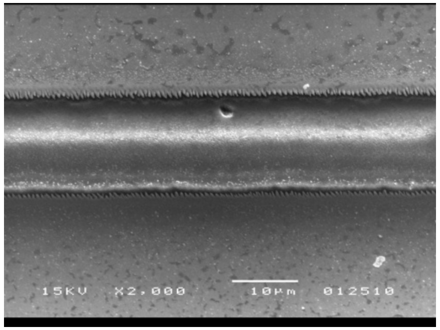
$425,000 grant

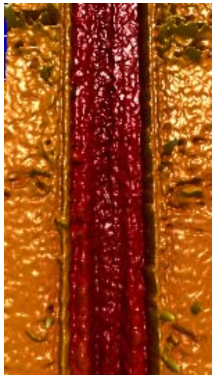
Solar Cell Scribing






Slot on CIS


SEM image of slot on Mo


Slot on Mo

Research: Metal-Insulator-Semiconductor Solar Cells

Jerry Woodall, Electrical and Computer Engineering/CoE

Issues and Approach

- Metal-semiconductor (MS) solar cell is easy to fabricate but it has large saturation current ->V_{oc}
- Insert an insulator (oxide or wide band gap semiconductor) between a transparent metal and a semiconductor to increase open circuit voltage
- Photo-generated minority carriers tunnel through ultra thin oxide to the metal contact obviating the need for a metal contact to a real" doped n or p layer to form a p-n junction

Advantages and Disadvantages

+ good short wavelength response
+ better V_{oc} than MS
+ only one conductivity type needed
+ potentially low-cost
- V_{oc} and J_{sc} trade-off
- barriers to minority carriers
-inversion layer needed for max performance

Looking at GaAs for single junction and GaP for use in multijunction

Blue Men: Here, next to the solar panels atop Purdue's Knoy Hall, are Jeff Gray (front), Dick Schwartz (sports coat), and Jerry Woodall. This trio of electrical and computer engineering researchers has spent their collective careers looking toward blue sky and the promise of solar energy.

Research: Novel Electrodes and Electrolytes for Battery

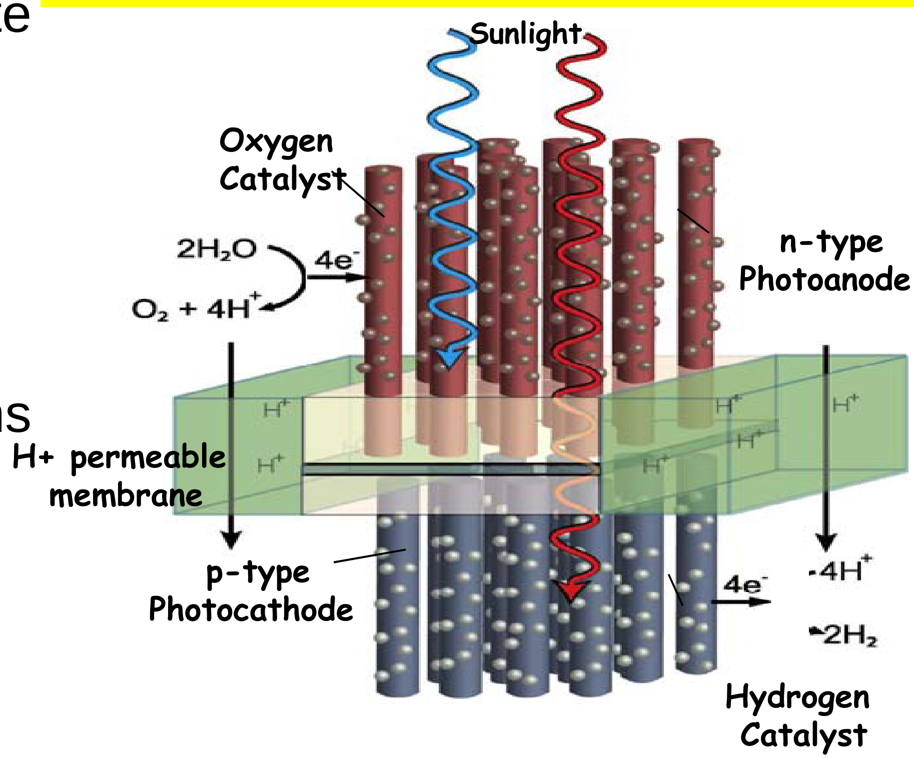
Solar Water Splitting

Kyoung Choi, Department of Chemistry/CoS

Novel chemistries for improved batteries: Constructing optimum electrode architectures to enhance desired properties and stabilities of electro/photo-chemical devices

- Control of semiconductor and catalyst morphologies to investigate morphology dependent photoelectrochemical properties.
- Site Selective Integration of catalysts on photoelectrode surfaces
- Photoelectrode-catalyst interactions

Construction of a High Performance Solar Water Splitting Cell
Hydrogen Production by Photolysis of Water



Kyoung Choi Group

NSF Chemical Center for Innovation at Caltech
Powering the Planet: Production of Fuel from Sunlight

To develop membranes that can accept the holes and electrons from the photovoltaic membrane and convert them into O_2 and H_2.

Research: Self-repairing Solar Cells

Jong Hyun Choi, Mechanical Engineering/CoE

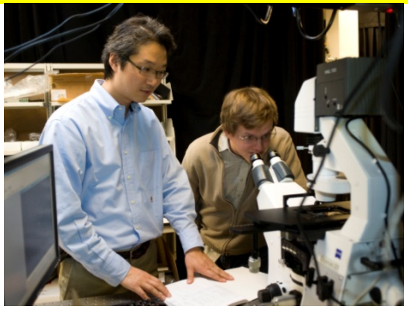
Key Problem

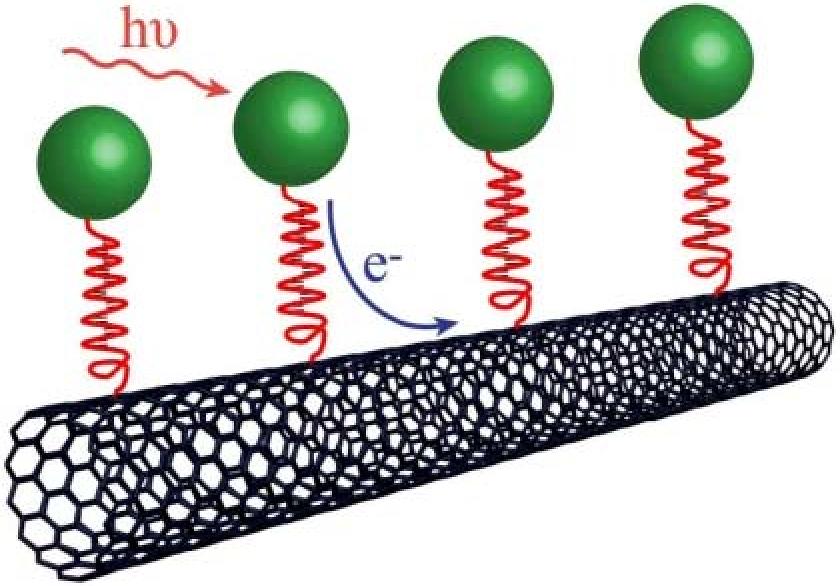
- How to increase life and reduce cost?

Approach

- In nature, photochemicals cell convert sunlight into electricity. The cells contain light-absorbing dyes called chromospheres that degrades due to exposure to sunlight. The nature replaces photo-damaged dyes with news ones.
- CNTs have extraordinary electron accepting and conducting properties
- Use of carbon nanotube (CNT) to create artificial photosystems to harvest solar energy for electrical power
- CNT provides a platform to anchor strands of DNA. The DNA is engineered to have specific sequence of building blocks called nucleotides, enabling them to be recognize and attach to chromospheres after kicking off damaged dye molecules.
- Use synthetic water soluble dye called 'porphyrins' as donors

Light Harvesting
Single-Wall Carbon Nanotube Hybrids





Schematic of nanohybrid. Oligonucleotides (red) mediate interactions between carbon-nanotube acceptor (black) and donors (green).

Research Thermal

Research: Solar Thermal Energy Storage

Suresh Garimella, Mechanical Engineering/CoE; Purdue Cooling Technology Research Center

Advantages

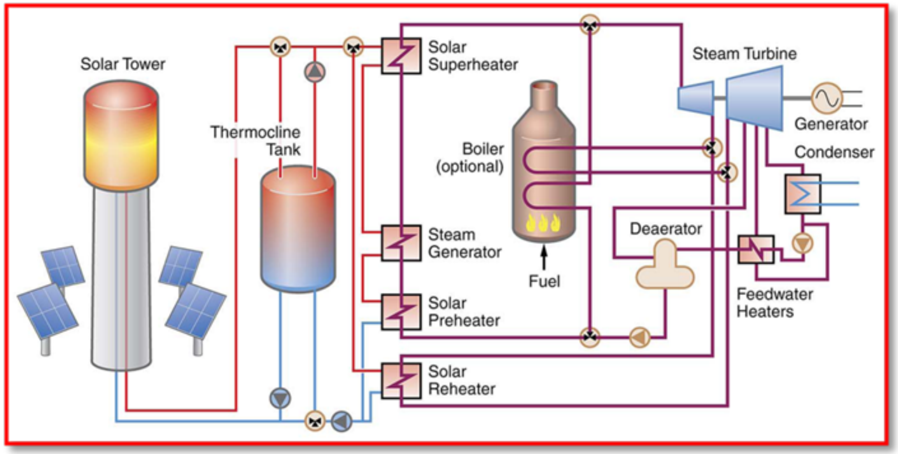
- Provides clean, renewable, cost-competitive power
- Delivers electricity without fossil fuel back up and to meet peak demand independent of weather fluctuations (day and night time)

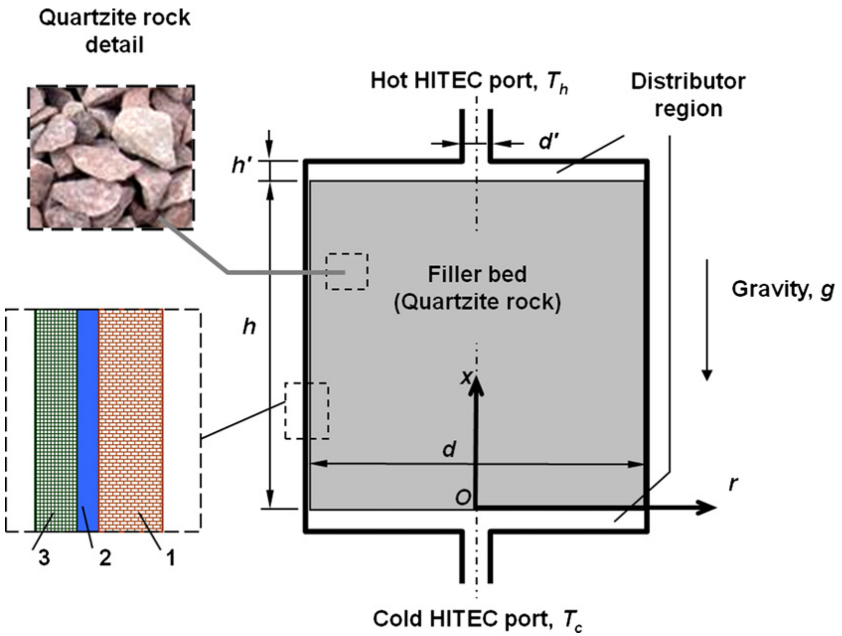
Approach

1. Heat transfer fluid such as oils as limited operating temperature of 400 °C
2. Use of molten salt (operating temperature up to 500 °C.). Potassium nitrate (53%), sodium nitrate (40%), sodium nitrate (7%)
3. It has low vapor pressure, non-flamable/toxic, environmental friendly compared to oil, cheaper, higher heat storage temperature/ capacity and improves efficiency
4. Use quartz to reduce inventory of expensive molten salt storage system and use as primary thermal storage material

Results

- Maximize internal insulation to minimize stresses due to thermal ratcheting
- Use of smaller quartz particle increase thermal discharge efficiency





Thermocline Tank
Composite of firebrick (1), steel (2) and ceramic (3)

Educational Programs

Purdue Electric Vehicles Club

Purdue Student Organization

Purdue student builds solar motorcycle, launches club to push more electric vehicle breakthroughs…

- *Purchased Suzuki motorcycle for $50*
- *Retrofitting and designing with $2,500. Uses a lead battery that can be charged from plug-in AC current*
- Received a provisional patent
- Cut down cost penny per mile
- Constant acceleration
- 24 miles per charge
- 45 mph

Solar Motorcycle

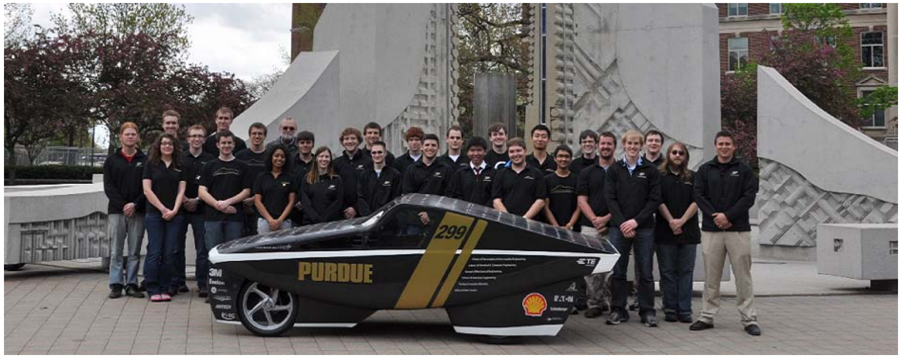
Purdue student Tony Danger Coiro invented a street-legal solar powered motorcycle. He's working to upgrade the penny per mile commuter vehicle into a 100 horsepower, 100 mph thriller.

Purdue Solar Racing

Purdue Student Organization

Objectives

1. *Building and racing a competitive solar powered vehicle and educating the public about the possibilities of renewable energy.*
2. *Through teamwork and innovation each team member will gain knowledge in every aspect of the vehicle while helping the world take a step in the right direction for meeting our future energy needs.*



International Competition
Shell EcoMarathon

To Design and Build Most fuel-efficient Vehicles

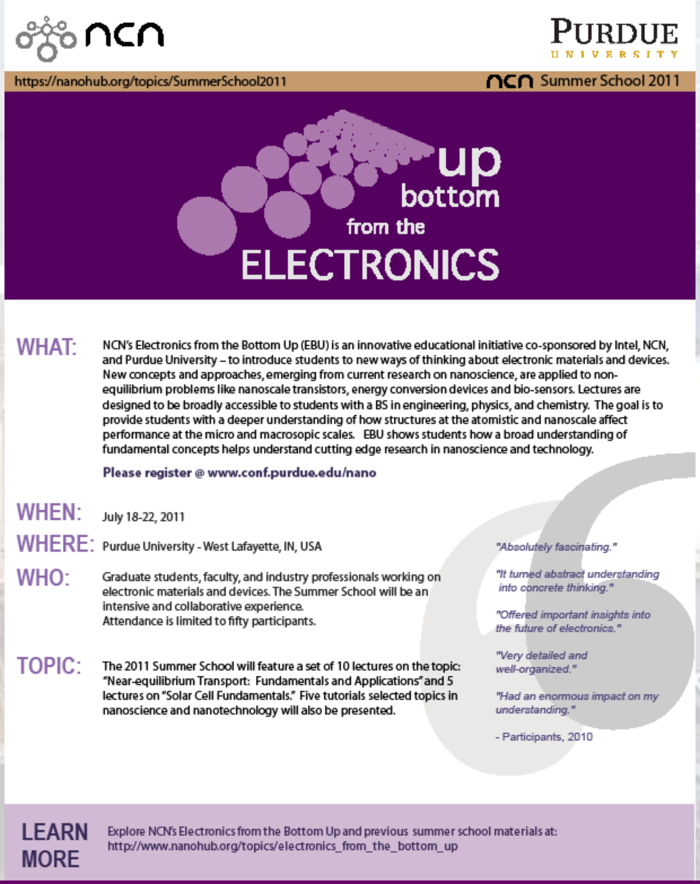
1. *First place in solar-power category*
2. *Won ‘People’s Choice Award’; and ‘Communication Award’*
3. *Achieved 64.5 mile/kWh (2,200 mpg)*

Ted Pesyna (left) President of Purdue Solar Racing
Brian Kelley (right), Computer Engineering
with vehicle Celeritas

Courses

Examples

- **PHYS 54700 - Physics Of Semiconductor Devices**
- **CHE 45000 - Design And Analysis Of Processing Systems**
- **CHE 59700 - Special Topics In Chemical Engineering**
- **ECE 30500 - Semiconductor Devices**
- **ECE 32400 - Introduction To Energy Systems**
- **ECE 40700 - Semiconductor Measurements Laboratory**
- **ME 41800 - Engineering Of Environmental Systems And Equipment**
- **ME 42700 - Sustainable Energy Sources And Systems**
- **ME 47900 - Solar Engineering Systems**
- **ME 50700 - Laser Processing**
- **ME 60600 - Radiation Heat Transfer**


ncn PURDUE UNIVERSITY

https://nanohub.org/topics/SummerSchool2011 ncn Summer School 2011

up bottom from the ELECTRONICS

WHAT: NCN's Electronics from the Bottom Up (EBU) is an innovative educational initiative co-sponsored by Intel, NCN, and Purdue University – to introduce students to new ways of thinking about electronic materials and devices. New concepts and approaches, emerging from current research on nanoscience, are applied to non-equilibrium problems like nanoscale transistors, energy conversion devices and bio-sensors. Lectures are designed to be broadly accessible to students with a BS in engineering, physics, and chemistry. The goal is to provide students with a deeper understanding of how structures at the atomistic and nanoscale affect performance at the micro and macrosopic scales. EBU shows students how a broad understanding of fundamental concepts helps understand cutting edge research in nanoscience and technology.

Please register @ www.conf.purdue.edu/nano

WHEN: July 18-22, 2011

WHERE: Purdue University - West Lafayette, IN, USA

WHO: Graduate students, faculty, and industry professionals working on electronic materials and devices. The Summer School will be an intensive and collaborative experience. Attendance is limited to fifty participants.

TOPIC: The 2011 Summer School will feature a set of 10 lectures on the topic: "Near-equilibrium Transport: Fundamentals and Applications" and 5 lectures on "Solar Cell Fundamentals." Five tutorials selected topics in nanoscience and nanotechnology will also be presented.

"Absolutely fascinating."

"It turned abstract understanding into concrete thinking."

"Offered important insights into the future of electronics."

"Very detailed and well-organized."

"Had an enormous impact on my understanding."

- Participants, 2010

LEARN MORE: Explore NCN's Electronics from the Bottom Up and previous summer school materials at: http://www.nanohub.org/topics/electronics_from_the_bottom_up

Solar Cell Fundamentals

(Alam and Lundstrom)

Introduction to solar cells

Physics of crystalline solar cells

Simulating solar cells

What's different about thin-film solar cells

Organic photovoltaics

International

Global Collaborations

Australia

The University of Queensland Australia — Sustainability

Monash University — Sustainability

Brazil

University of Viscosa — Bioenergy

Universidade de São Paulo — Bioenergy

China

US-China Ecosystem/Environmental Change

绿色合作伙伴计划 ecopartnerships.gov

U.S. Department of State & China National Reform and Development Commission

Zhejiang University 1897

Clean Coal and Biomass Feedstock

Tsinghua University 1911

Bio/Nuclear/Solar Energy

India

Jawaharlal Nehru Centre for Advanced Scientific Research

Nanomaterials for Energy

Indian Institute of Science

Solar Energy

Indian Institute of Technology Bombay

Solar Energy

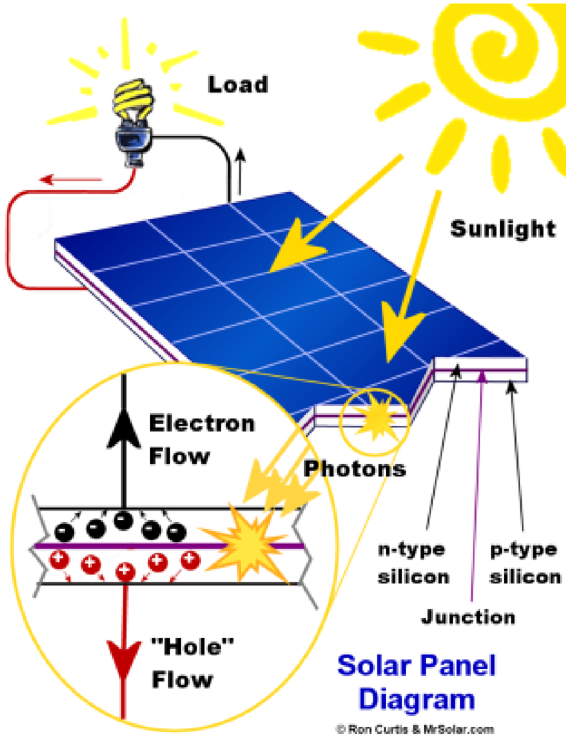
Forthcoming Research Workshop

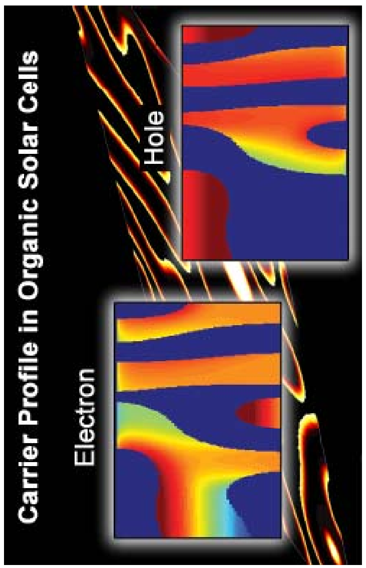
Challenges in Photovoltaic Science, Technology, and Manufacturing

A Research Workshop on the Role of Theory, Modeling, and Simulation, September 2011

Objectives

1. Identify technical challenges in PV
2. Identify state-of-art/practices of theory, modeling and simulation (TMS) in PV
3. Identify successful models for research, software development and dissemination and industry university collaboration
4. Identify computational challenges in multi-scale/physics/disciplinary materials to modules PV simulation
5. Discuss opportunities & approaches to increase TMS in PV

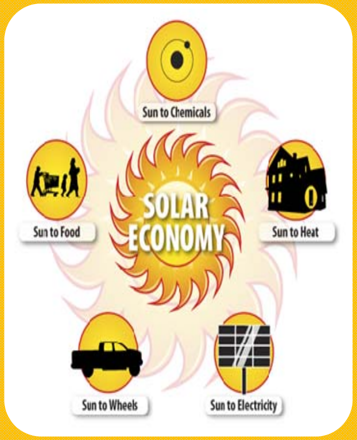




Possible Sponsors and Participants

National Lab, Universities, Industry

Summary



Purdue has over one dozen researchers working at the cutting edge research to reduce cost, develop novel materials, improve efficiency of solar PV/thermal and manufacturing

Purdue has several state-of-the-art research facilities to support discovery with delivery in solar energy sciences and engineering

Purdue has several courses to train work force for the 21st Century solar economy

Purdue is developing international research linkages to address the grand challenge of global green energy

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