NREL
NATIONAL RENEWABLE ENERGY LABORATORY

INDIAN INSTITUTE OF SCIENCE
Bangalore, India
भारतीय विज्ञान संस्थान
बेंगलूर, भारत

SERIIUS
Solar Energy Research Institute for India and the United States

Solar Energy Research Institute for India and the United States (SERIIUS)

Office of Science, BES Site Visit
NREL, October 26, 2012

Kamanio Chattopadhyay, *IISc-Bangalore*
Lawrence L. Kazmerski, *NREL*
SERIIUS Co-Directors

www.SERIIUS.org

Fundamental R&D Enabling International Collaboration

- Address common goals and grand challenges
- Focus on fundamentals: more “pre-competitive”
- Integrated science: theory, synthesis, characterization, testing
- Significant opportunity for training/education
  - students/postdocs
  - technical exchange/fellowships
  - Note these are both internal and external
    - Student/Faculty Exchange Through Mageep
    - Potential Links to other groups in India/US/Corporations
- Utilize unique facilities and value capabilities
- Understand technology development (& deployment) needs specific to each country

US National Academy: “Our energy system is, after all, much more than a set of technological arrangements; it is also a deep manifestation of society’s economic, social, and political arrangements.”… “collective international action.”

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A Joint Research Consortium for Accelerating Solar Electricity Development

India	United States

Consortium Leads

India	United States
Indian Institute of Science–Bangalore	**National Renewable Energy Laboratory**
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Research Thrust Leadership

India	United States
Indian Institute of Technology Bombay	Sandia National Laboratories
Center for the Study of Science, Technology and Policy	RAND Corporation

Consortium Partners

Institutes and National Laboratories

India	United States
International Advanced Research Centre for Powder Metallurgy and New Materials	Lawrence Berkeley National Laboratory
Solar Energy Center	

University Partners

India	United States
Indian Institute of Technology Madras	Arizona State University
Indian Association for the Cultivation of Science	Carnegie Mellon University
	Colorado School of Mines
	Massachusetts Institute of Technology
	Purdue University
	Stanford University
	University of Central Florida
	University of South Florida
	Washington University in St. Louis

Industry Partners

India	United States
Clique Developments Ltd.	Corning Incorporated
Hindustan Petroleum Corporation Ltd.	General Electric Company
Moser Baer India Ltd.	Cookson Electronics
Thermax Ltd.	MEMC Corporation
TurboTech Precision Engineering Ltd.	Solarmer Energy, Inc.
Wipro Ltd.	

DE-FOA-0000506: U.S.-India Joint Clean Energy Research and Development

Our Team:

Strong Synergy US/India *(PV-example)*

DOE Basic Research Needs/Priority Areas

- Maximum energy from solar photons at low costs
- Nanostructures for solar energy conversion; low cost and high efficiencies
- Materials and architectures for solar energy; assembling complex structures
- Identify and quantify critical technical, economic and policy issues

Critical Barriers called out by DOE for PV

- Understand materials and structures to improve conversion efficiency
- Optimize molecular, polymeric and nanocrystalline structures to produce systems
- High-throughput and continuous (roll-to-roll) processes that do not require high temperature or vacuum

Critical Barriers–India

- Earth abundant and green materials
- Low capital manufacturing at multiple scales
- Distributed power generation and integration
- Degradation mechanisms (reliability, dust)

Some India-Specific Considerations

Nehru Mission for off-grid

- 2000 MW off-grid
- 20 million solar lighting systems

Off-grid/distributed applications

- Land & water requirements
- Water pumping, desalination
- Cottage manufacturing
- Different price points, form factors, performance

Avoid scale-down penalty for small systems (e.g., CSP)

Hybrid systems

Reliability in Indian environment

Manufacturing

- Low capital fabrication approaches
- Design for frugal innovation

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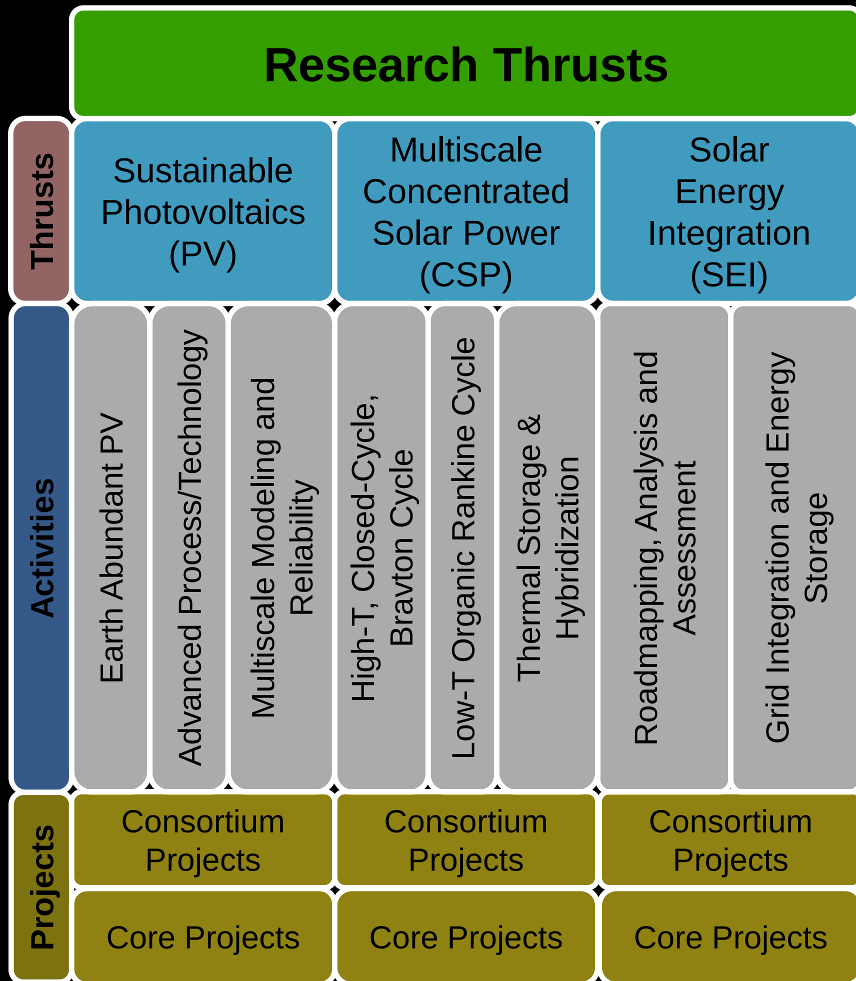
Collaborative Research Thrusts, Activities, and Projects

Research Design

- Analysis- and assessment-driven
- Multidisciplinary, bi-national teams
- Industry integration into multi-institutional projects
- “Use-inspired” R&D



Two-tier Project Structure

- ***CONSORTIUM PROJECTS:*** *disruptive, transformative R&D*
- ***CORE PROJECTS:*** *core industry partner-led and focused*

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Thrust: Sustainable Photovoltaics

Accelerate the development of disruptive PV technologies

Activity
Earth Abundant PV:

Develop new scalable absorbers based on Earth-abundant materials and processes

Projects
- Thin-film absorber materials and processing
- Organic PV materials and devices
- Nanostructured absorbers and electrodes

Activity
Advanced Process/Manufacturing Technology:

Develop ink-based and other advanced processes for PV elements based on new flexible substrates and printing techniques

Projects
- Solar-grade silicon
- Thin-film absorber production
- Flexible substrates
- High throughput processing of thin-film PV

Activity
Multiscale Modeling and Reliability:

Couple materials to module modeling with real-world reliability

Projects
- Integrated modeling
- Reliability
- Novel materials for intrinsic stability in harsh environments

Thrust: Multi-scale Concentrated Solar Power

Increase the power block cycle efficiency and decrease solar collector cost with innovative designs without scale-down penalty for smaller scale (25kW-1MW)

High T Brayton Cycle: Develop scalable supercritical 20-80 bar 600-800^{o}C Brayton cycles with 50% efficiency (100 kW to 1 MW)

- High T, high P CO2 receiver and exchanger
- Heliostats for Brayton

Low T Rankine Cycle: Develop organic Rankine cycle with at < 330^{o}C with > 25% efficiency (25kW-1MW)

- ORC collector
- Small-scale positive displacement expander for ORC
- Small-scale turbo expanders

Thermal Storage and Hybridization: Develop hybridized storage systems for the diverse temperature ranges of Brayton and Rankine converters

- Storage and hybridization

Thrust: Solar Energy Integration

Analysis and assessment of technical, economic, environmental and policy aspects for developing and deploying solar technologies

Technology Roadmapping, Analysis, and Assessment

Analyze the market, policy and technology data to develop roadmaps for bankable deployment options for solar electric conversion

- Roadmapping and policy assessment
- Computational tools for economic assessment, bankability, and deployment

Grid Integration & Energy Storage

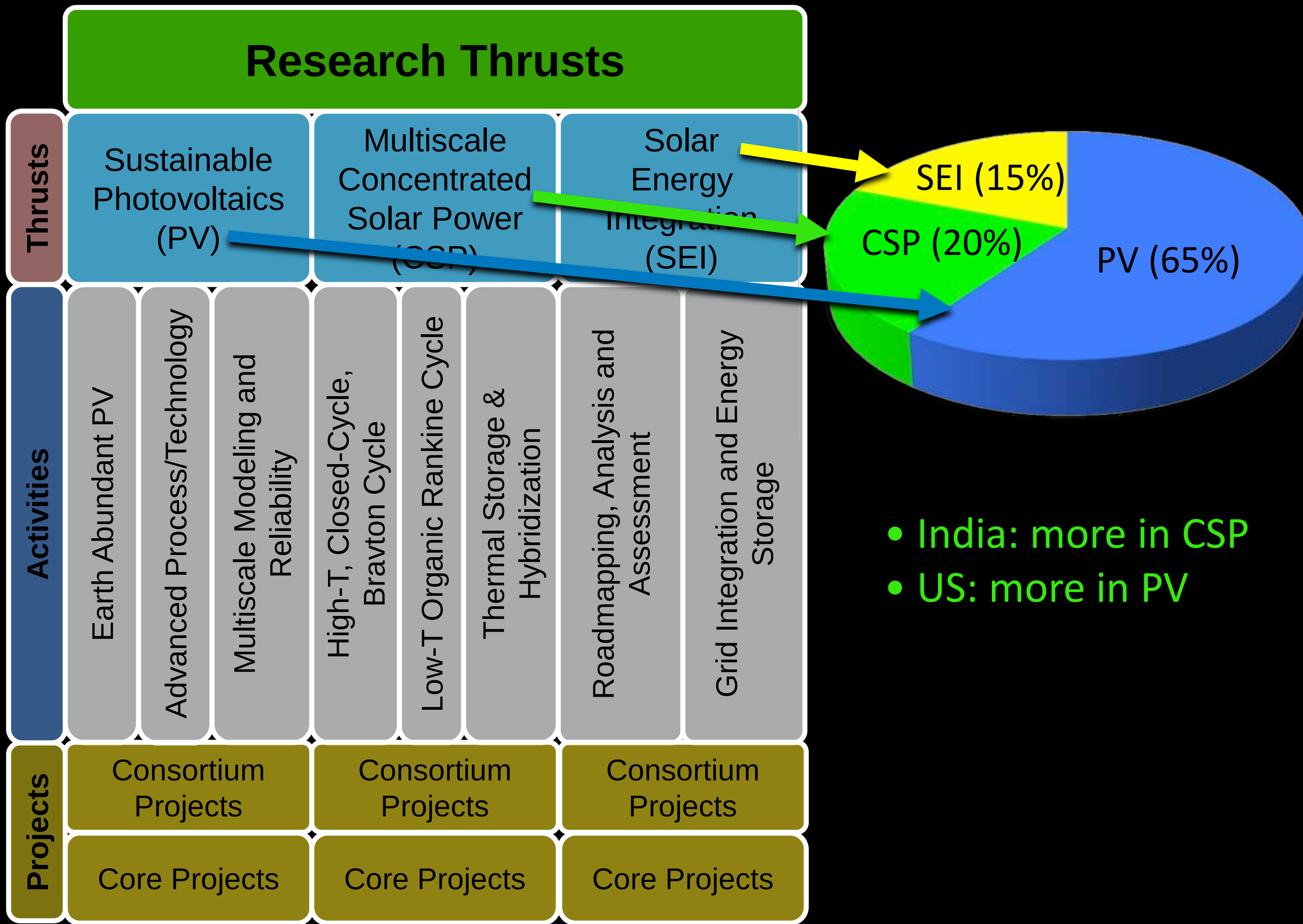
Quantify interactions of solar electricity on the grid in India and predict optimum deployment and interconnection

- Grid integration and energy storage
- Interoperability and compatibility for PV
- Novel Storage Materials for Solar Hydrogen from PV Electrolysis

Collaborative Research Thrusts, Activities, and Projects

Research Design

- Analysis- and assessment-driven
- Multidisciplinary, bi-national teams
- Industry integration into multi-institutional projects
- "Use-inspired" R&D



Two-tier Project Structure

- India: more in CSP
- US: more in PV

- ***CONSORTIUM PROJECTS:*** *disruptive, transformative R&D*
- ***CORE PROJECTS:*** *core industry partner-led and focused*

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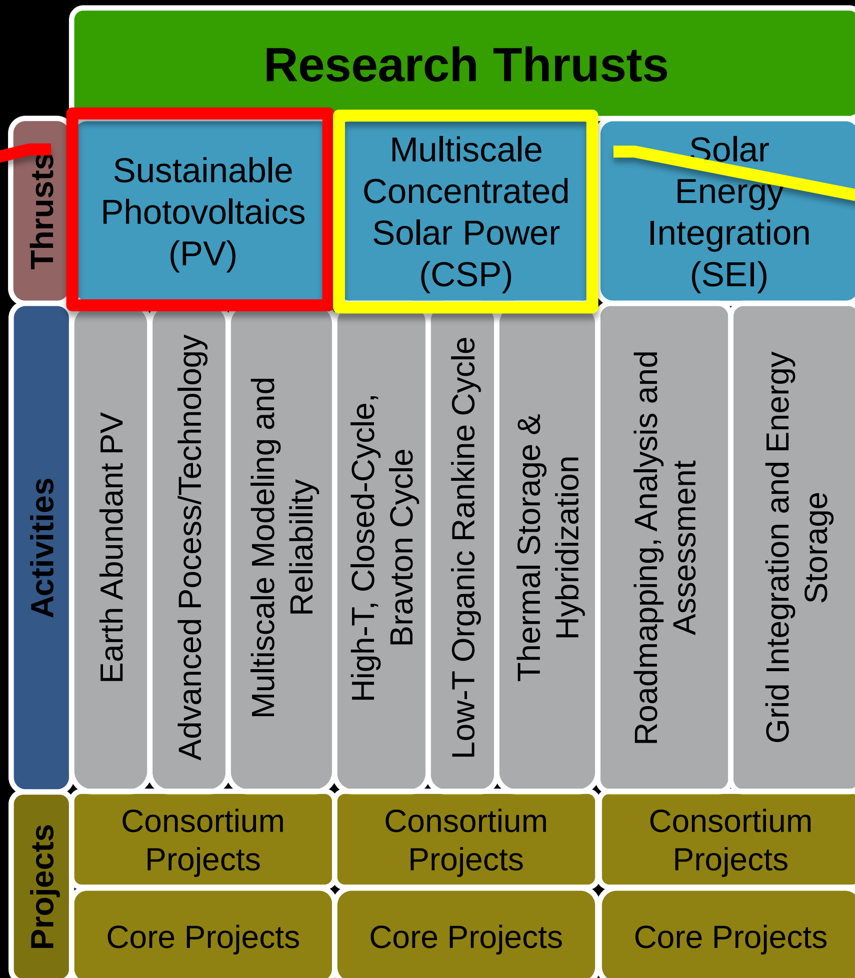
Collaborative Research Thrusts, Activities, and Projects



IMPACT:

- Significantly accelerate disruptive PV technologies
- Provide foundation on which future Indian PV industry can build

IMPACT:

Significantly reduce levelized cost of electricity:

- increasing the power block efficiency
- decreasing the solar collector cost with innovative designs & optical materials.

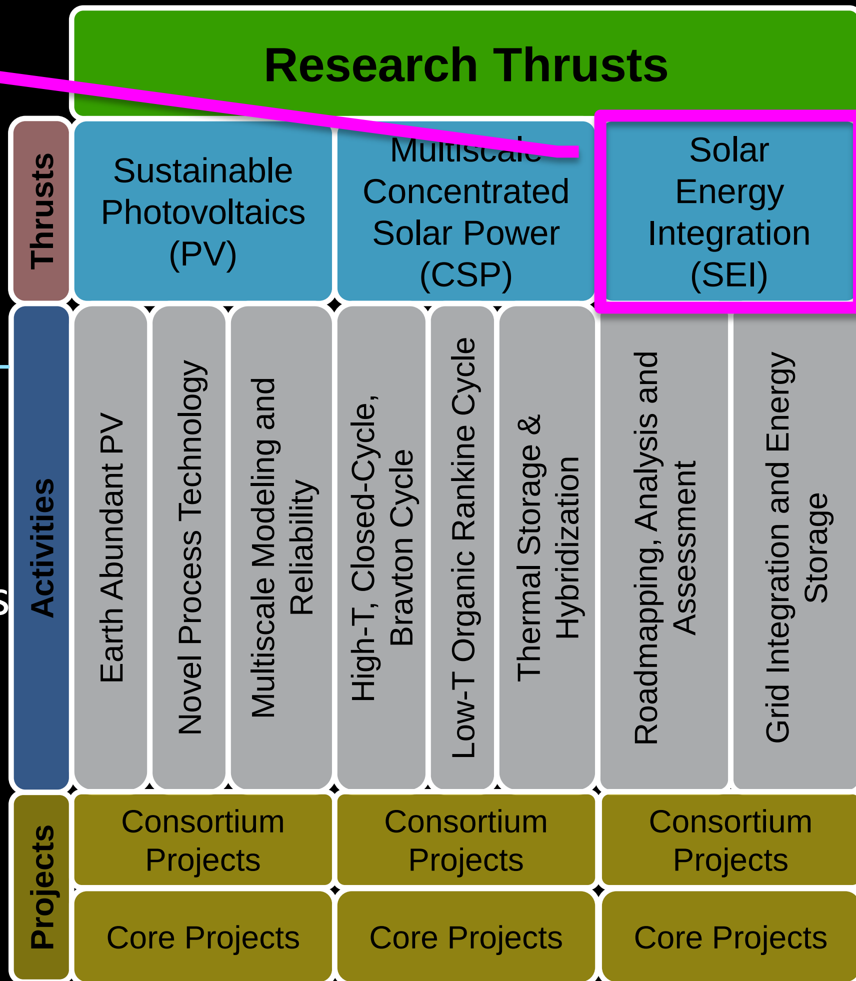
- ***CONSORTIUM PROJECTS:*** *disruptive, transformative R&D*
- ***CORE PROJECTS:*** *core industry partner-led and focused*

Collaborative Research Thrusts, Activities, and Projects

IMPACT:

Provide critical technical, economic, environmental, and policy guidance:

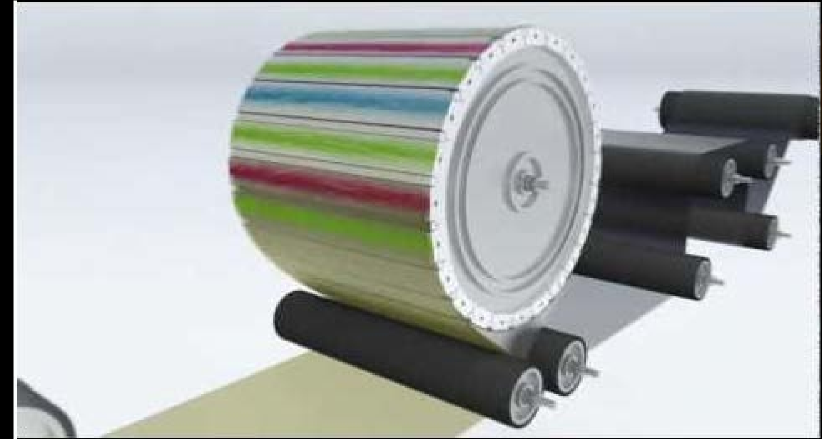
- For SERIIUS research-planning and review to ensure relevance/priorities in meeting objectives
- For stakeholders-critical information with roadmapping and analysis.



- ***CONSORTIUM PROJECTS:*** *disruptive, transformative R&D*
- ***CORE PROJECTS:*** *core industry partner-led and focused*

The Science of Sustainable Photovoltaics . . .

Materials: CIGS, CZTS, and OPV



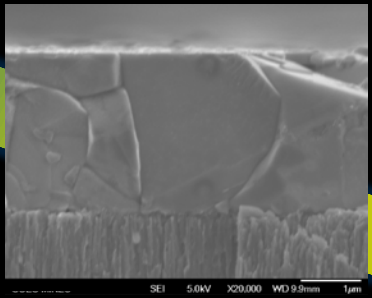
The Technology of Developing Low-Cost Atmospheric Processes . . .

Inks and synthesis

- Understanding metal-organic decomposition
- Molecular precursor design
- Synthesis to desired materials
- Inks:
  - Absorbers
  - Transparent Conductors
  - Contacts/Packaging

Deposition

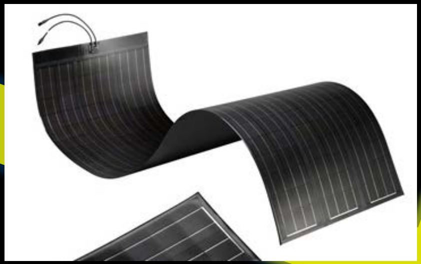
- Desired precursor with no residual organics
- Designed to densify and allow grain growth
- Compatible with other layers



Processing

Device quality:

- Rapid thermal processing
- Optical processing



Integration

- Materials/devices integrated onto flexible substrates

The Science of Multiscale Concentrating Solar Power . . .

Scientific Challenges/Technology Innovations

High-temperature, closed-cycle CO_2-Brayton *(100kW-1MW)*

- High-temperature receivers, expanders, low-cost heliostats and Brayton power cycles to increase the gross cycle efficiency to >50% to meet SunShot goals.

Low-temperature organic Rankine cycle *(25kW-1MW)*

- Low-cost , parabolic trough collectors that have optical efficiencies of >70%, operate up to 230°C, and have <2% thermal loss *(overcome scale-down penalty)*.
- Develop small (25 kWe) turbo-expanders that have greater than 80% isentropic efficiency.

Thermal storage and hybridization

- Advanced, low-cost thermal storage for integration into high temperature Brayton CO_2 cycles and low temperature organic Rankine Cycles

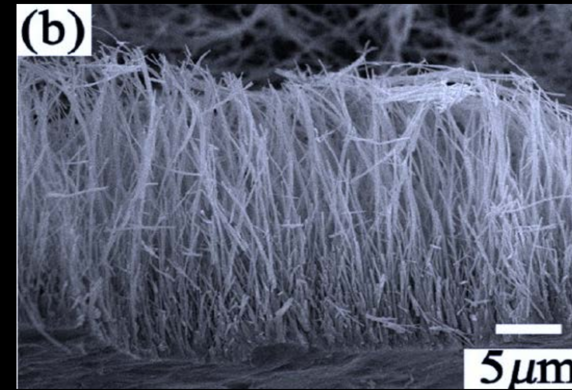
Key Focus: *Water Independent, Hybridization*

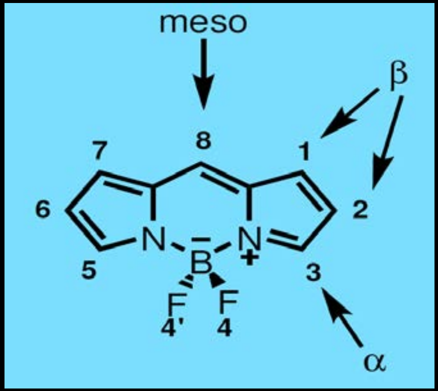
The Science Solar at the Nanoscale . . .

Nanostructured Materials for PV

Coupling novel nano-structures to new dyes for enhanced performance in dye-sensitized solar cells (DSSC)

- Science Challenges:
  - -To develop & integrate dye/ nanostructure
  - -To enhance performance and stability of DSSC
- Shared US-India knowledge:
  - - nanostructured materials from **US**
  - - novel BODIPY dyes from **India**

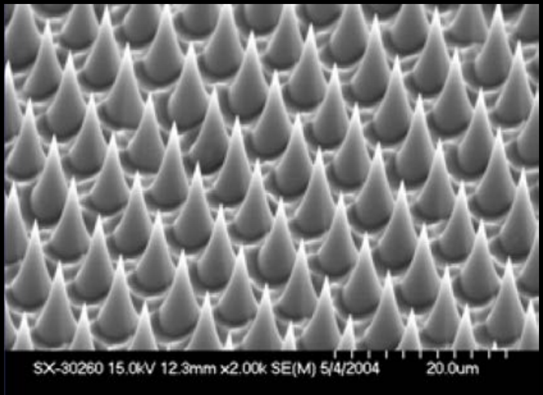




Novel Nanostructured Coatings for CSP and PV Dust Mitigation

New generation dust resistant coatings

- Science Challenge: To develop & validate novel nanotechnology-based, durable superhydrophobic (and superhydrophilic) plasmonic metamaterials
- Low-surface energy metal nitrides (CrN, MoN, TIN, ZrN) as protective films for CSP reflectors (and PV modules)



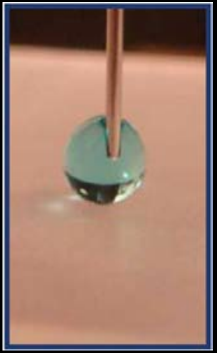


Image of superhydrophobic structure (left) that forms a surface with virtually no contact area with water (right).

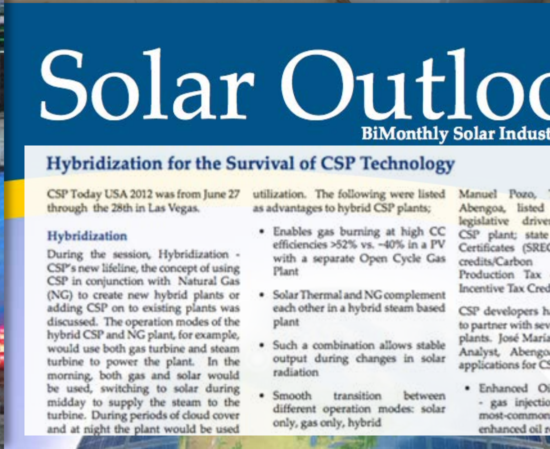
The Science and Technology of Solar Energy Integration (SEI)

Roadmapping

- Barriers to deployment (India *vs.* US)
- Bankability
- Technology/policy assessments
  - grid-connected and off-grid
  - storage requirements
  - hybridization
- Identification of R&D needs

Grid Integration and Dispatchability

- Grid analysis in India
- Rural/off-grid power
- Storage, hybridization



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BiMonthly Solar Indust

Hybridization for the Survival of CSP Technology

CSP Today USA 2012 was from June 27 through the 28th in Las Vegas.

Hybridization

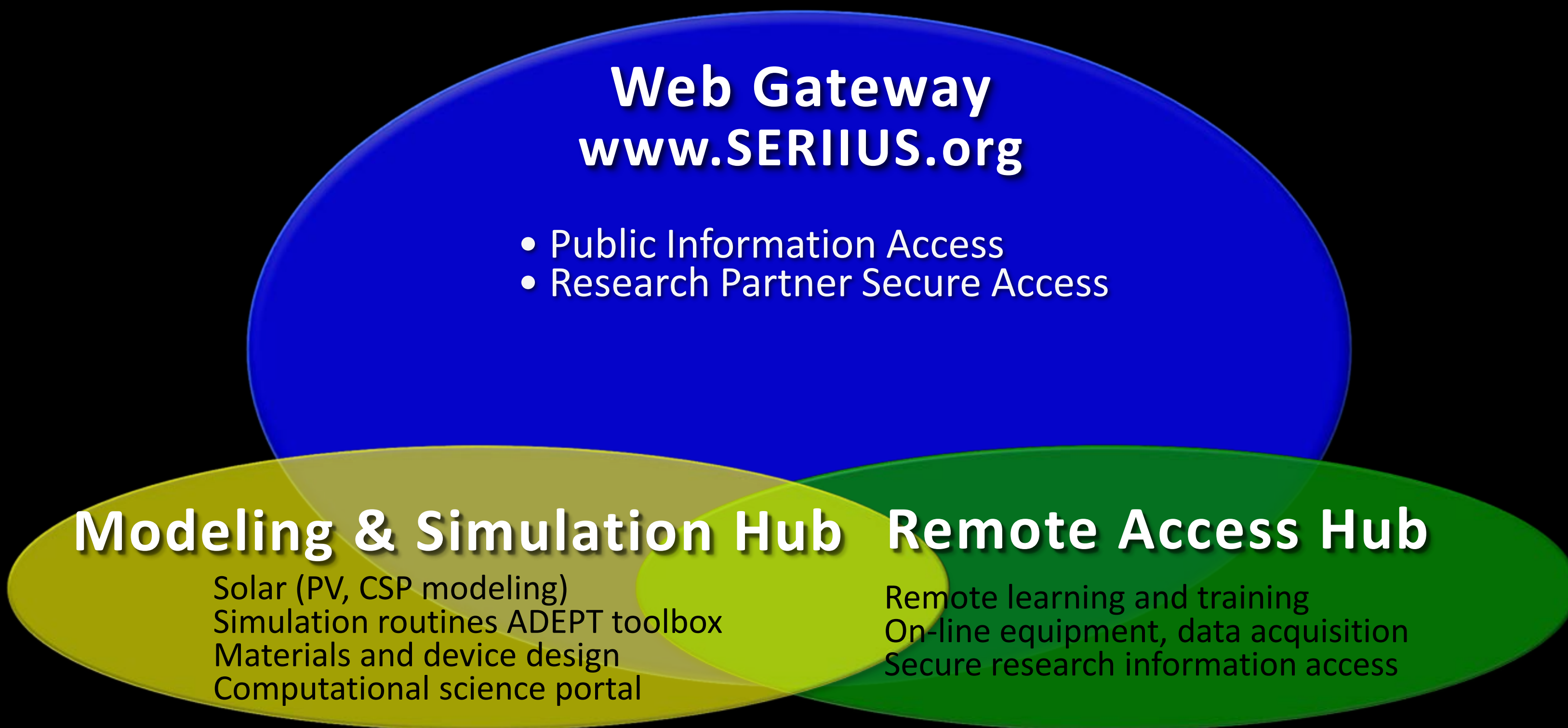
During the session, Hybridization - CSP's new lifeline, the concept of using CSP in conjunction with Natural Gas (NG) to create new hybrid plants or adding CSP on to existing plants was discussed. The operation modes of the hybrid CSP and NG plant, for example, would use both gas turbine and steam turbine to power the plant. In the morning, both gas and solar would be used, switching to solar during midday to supply the steam to the turbine. During periods of cloud cover and at night the plant would be used utilization. The following were listed as advantages to hybrid CSP plants;

- Enables gas burning at high CC efficiencies >52% vs. ~40% in a PV with a separate Open Cycle Gas Plant
- Solar Thermal and NG complement each other in a hybrid steam based plant
- Such a combination allows stable output during changes in solar radiation
- Smooth transition between different operation modes: solar only, gas only, hybrid

Integration and Communication

SERIIUS Web Gateway *(www.SERIIUS.org)*

REAL-TIME INTERNATIONAL RESEARCH PARTNERING



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Please contact us if you are interested in participating in our internship program!

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Thank you • शुक्रिया