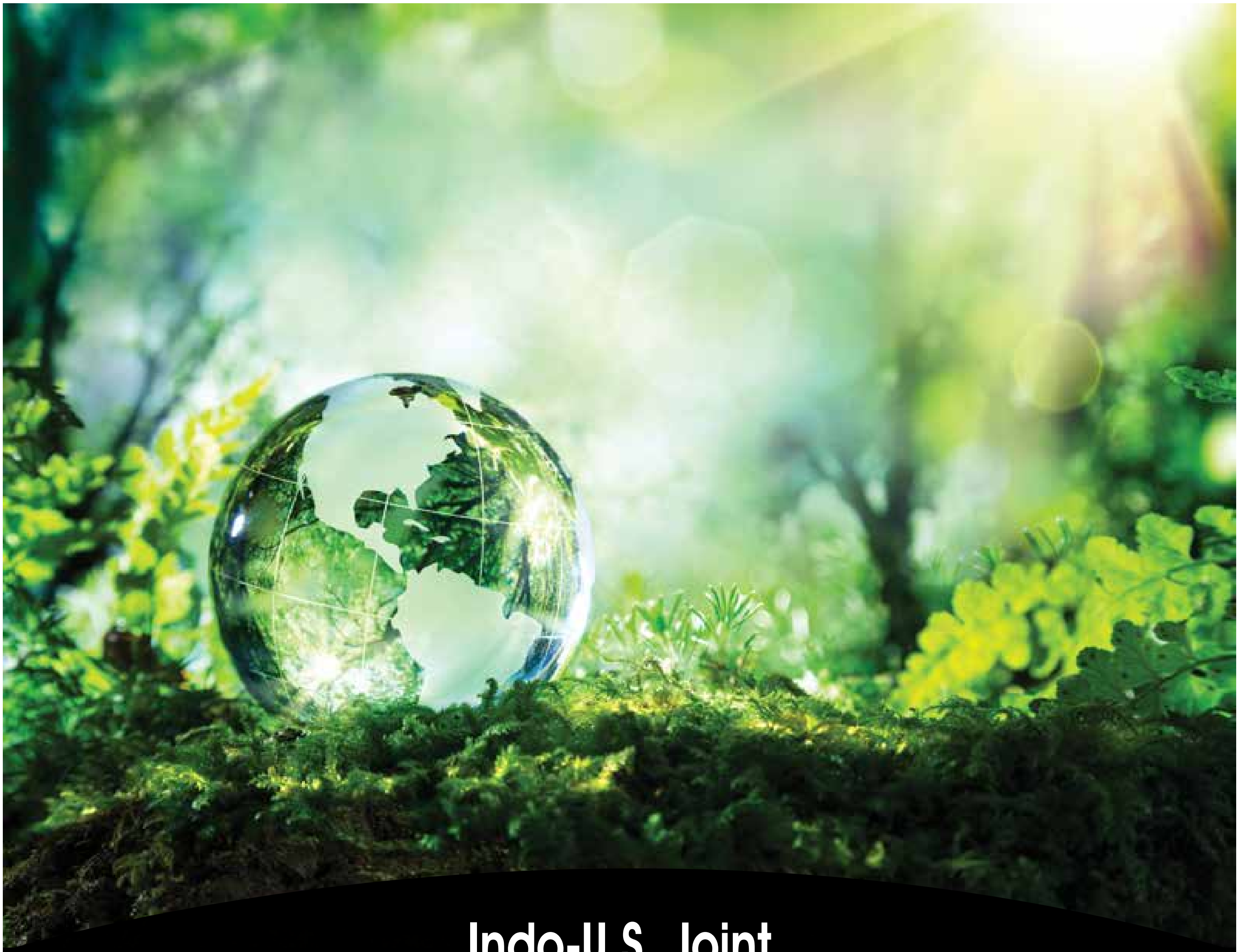


Indo-U.S. Joint
Clean Energy Research and Development Center

Status Report

September 2015

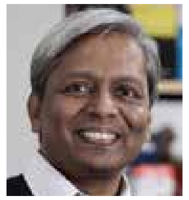
सत्यमेव जयते

Ministry of Science and Technology
Government of India

Recognizing the need to address climate change, ensure mutual energy security, and build a clean energy economy that drives investment, job creation, and economic growth; India and the United States launched the U.S.-India Partnership to Advance Clean Energy (PACE) on November 24, 2009 under the U.S.-India Memorandum of Understanding to enhance cooperation on Energy Security, Energy Efficiency, Clean Energy and Climate Change. As a priority initiative under the PACE umbrella, the U.S. Department of Energy (DOE) and the Government of India signed an agreement to establish the Joint Clean Energy Research and Development Center (JCERDC) on November 4, 2010. The JCERDC is designed to promote clean energy innovation by teams of scientists and engineers from India and the United States.

According to the Joint Statement issued on January 25th 2015 - ''Shared Effort; Progress for All''; Prime Minister Modi and President Obama emphasized the critical importance of expanding clean energy research, development, manufacturing and deployment, which increases energy access and reduces greenhouse gas emissions. The leaders announced actions to advance India's transition to low carbon economy. India intends to increase the share of use of renewable in electricity generation consistent with its intended goal to increase India's solar target to 100 gigawatts by 2022.

The Joint Statement clearly builds upon the success of the JCERDC by taking its activities and progress to the next level. To quote the Joint Statement – "*The United States intends to support India's goal by enhancing cooperation on clean energy and climate change, to include expanding the Partnership to Advance Clean Energy Research (PACE-R): A renewed commitment to PACE-R, including extending funding for three existing research tracks of solar energy, building energy efficiency, and biofuels for an additional five years and launching a new track on smart grid and grid storage.*"



Dr. K. VijayRaghavan
Secretary, Department of Biotechnology
Govt. of India

"Our two nations share the common goal of transitioning to a low-carbon economy and the Indo-U.S. Joint Clean Energy Research and Development Center is a giant step towards making that a reality. This would be accomplished by successfully harnessing the expertise of our highly skilled, multi-disciplinary teams of scientists and engineers. Of one thing we can be certain - when the finest scientific minds meet, our demands for clean energy would be more than adequately met!"

Dr. Ashutosh Sharma
Secretary, Department of Science and Technology, Govt. of India

"The Indo-U.S. Joint Clean Energy Research and Development Center is a unique model that stands testament to the commitment of our two nations to design and deliver high-quality sustainable energy solutions not only for India and the United States, but the world at large."

Joint Clean Energy Research & Development Center (JCERDC)

Objective

The overall aim of the JCERDC is to facilitate joint research and development on clean energy to improve energy access and promote low-carbon growth. To achieve this objective, the Indo-US JCERDC supports multi-institutional network projects using a public-private partnership model of funding.

Funding Mechanism

	Contribution per year	Total Contribution for 5 years	Total for 5 years
US Government *- Department of Energy (DOE)*	$ 5 million	$ 25 million	$ 100 million (or more)
Indian Government *- Department of Science & Technology (DST)* *- Department of Biotechnology (DBT)*	Eqv. to $ 5 million	Eqv. to $ 25 million	
The Consortia partners would contribute the matching amount or more			

The JCERDC is funded by the Indian **Department of Science and Technology (DST)** and **Department of Biotechnology (DBT);** and the **U.S. Department of Energy**. The program is being administered in India by the **Indo-U.S. Science and Technology Forum (IUSSTF).**

Priority Areas and Government Funding

Solar Energy

Solar Energy ($12.5 million over five years from each side) encompassing solar electricity production, nanoscale designs of interfaces and cells, advanced photovoltaic technologies, concentrating solar power technologies, etc.

Second Generation Biofuels

Second Generation Biofuels ($6.25 million over five years from each side) covering conversion technologies for advanced biofuels, optimal characterization for ligno-cellulosic feedstock, algal biofuel, standards and certification for different biofuels and co-product with end-use applications, etc.

Energy Efficiency of Buildings

Energy Efficiency of Buildings ($6.25 million over five years from each side) including building heating and cooling, cool roofs, advanced lighting, energy-efficient building materials, software for building design and operations, building-integrated photovoltaics, etc.

Intellectual Property Management

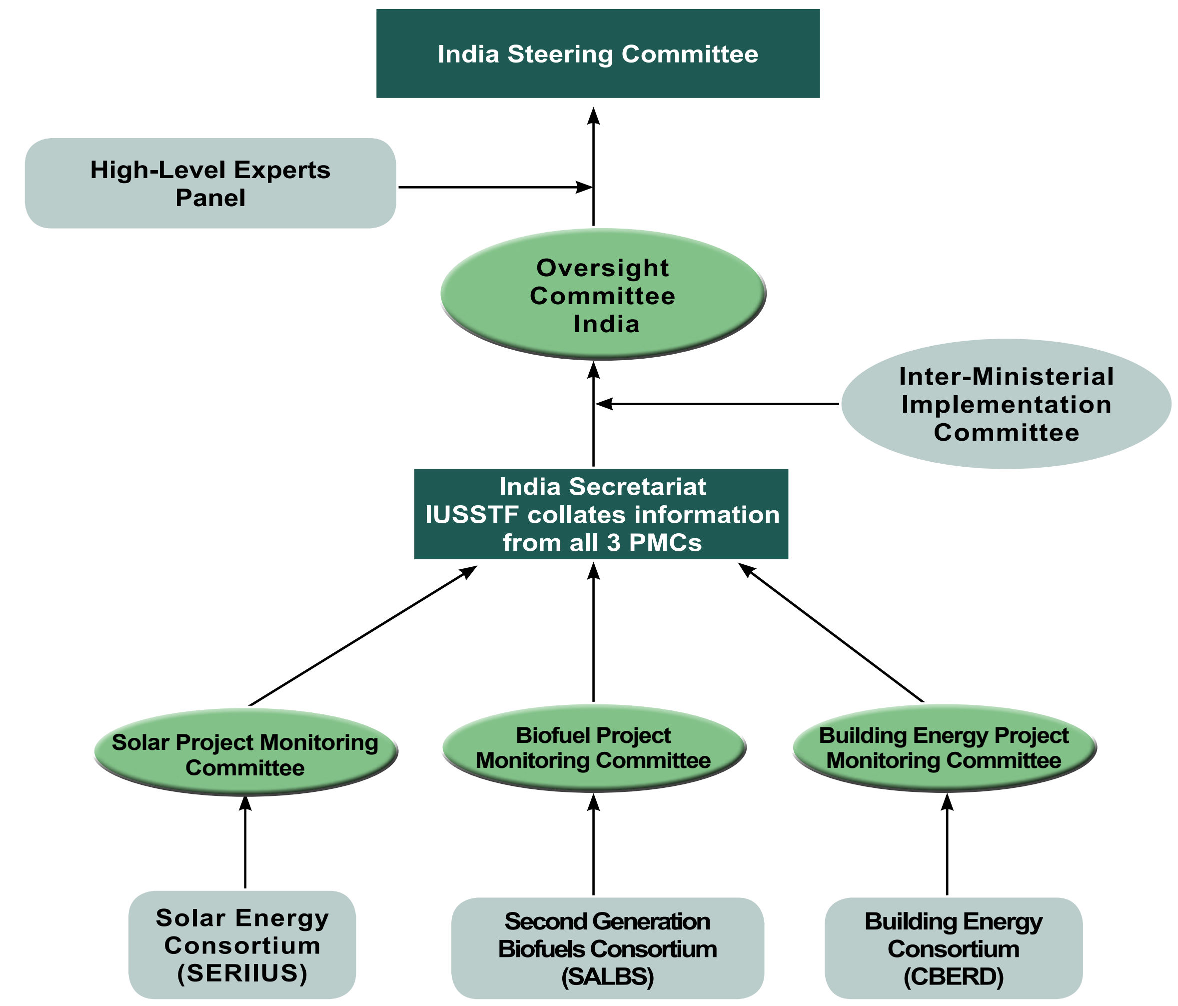
Intellectual Property Rights (IPR) are subject to the IPR Annex of the Agreement on Science and Technology Cooperation between the Government of the United States of America and the Government of the Republic of India (S&T Agreement; 2005), the respective standard IPR provisions of the Parties and the project annexes of the participants to the extent it is not in contravention with the IPR annex and the associated IP framework allocation document.

Management Mechanism

The **Indo-U.S. Steering Committee on Clean Energy Science and Technology Cooperation** provides high-level review and guidance for the activities.

Joint High-Level Experts Panel of twelve eminent experts from private and public sector provide critical suggestions and insights and also act as an advisory body for the Steering Committee.

Project Monitoring Committees (PMC) have been set up – one in each priority area – to monitor the consortia progress in conformity with the outputs, milestones, targets and objectives of the project. PMC for each consortium comprises of eminent experts from the relevant fields, representatives of Govt. of India and the IUSSTF. Till date, three PMC review meetings have been held for all the three consortia.



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

Principal Investigators


Kamanio Chattopadhyay
Indian Institute of Science
Bangalore, INDIA


David S. Ginley
National Renewable
Energy Laboratory
Golden, USA

Background

The vision of the ***Solar Energy Research Institute for India and the United States (SERIIUS),*** co-led by the Indian Institute of Science at Bangalore (IISc.) and the National Renewable Energy Laboratory (NREL), is to create an environment for cooperation and innovation "without borders" to develop and ready emerging and revolutionary solar electricity technologies toward the long-term success of India's Jawaharlal Nehru National Solar Energy Mission and the U.S. DOE SunShot Initiative.

The overall goal of SERIIUS is to accelerate the development of solar electric technologies by lowering the cost per watt of photovoltaics (PV) and concentrated solar power (CSP) through a binational consortium that will innovate, discover, and ready emerging, disruptive, and revolutionary solar technologies that span the gap between fundamental science and applied R&D, leading to eventual deployment by sustainable industries. SERIIUS will address critical issues in fundamental and applied research, analysis and assessment, outreach, and workforce development. Throughout this joint effort, a key element is engaging a significant base of Indian and U.S. industry that is dedicated and committed to developing solar energy for both countries.

Objectives

- Focus efforts on high-impact fundamental and applied R&D to create disruptive technologies in PV and CSP.
- Identify and quantify the critical technical, economic, and policy issues for solar energy development and deployment in India.
- Overcome barriers to technology transfer by teaming research institutions and industry in an effective project structure, cutting the time from discovery to technology development and commercialization, through effective coordination, communication and intellectual property management plans.
- Create a new platform for bi-national collaboration using a formalized R&D project structure, along with effective management, coordination and decision processes.
- Create a sustainable network from which to build large collaborations and foster a collaborative culture, including the use of existing and new methodologies for collaboration based on advanced electronic and web-based communication to facilitate functional international focused teams.
- Create a strong workforce development program in solar energy science and technology.

Collaborating Institutions - India	Collaborating Institutions - USA
Lead Institution Indian Institute of Science, Bangalore	**Lead Institution** National Renewable Energy Laboratory
Other Academia Partners	**Other Academia Partners**
Indian Institute of Technology, Bombay Indian Association for the Cultivation of Science, Kolkata International Advanced Research Centre for Powder Metallurgy and New Materials, Hyderabad National Institute of Solar Energy, Gurgaon Indian Institute of Technology, Madras Center for Study of Science, Technology and Policy, Bangalore	Lawrence Berkeley National Laboratory Arizona State University Binghamton University 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 RAND Corporation Sandia National Laboratory
Other Industry Partners	**Other Industry Partners**
Thermax Ltd. Clique Developments Ltd. Hindustan Petroleum Corporation Ltd. Moser Baer India Ltd. Wipro Ltd. Bharat Heavy Electrical Ltd.\	Corning Inc. Semlux Technologies, Inc. SunEdison, Inc. Solarmer Energy Inc. Underwriters Laboratories

Research Thrusts

SERIIUS carries out fundamental and applied research, analysis and assessment, outreach, and workforce development through specific bi-national projects in three distinct yet interconnected Research Thrusts:

Sustainable Photovoltaics (PV)

Sustainable Photovoltaics Research Thrust focuses on three coupled activities designed to significantly accelerate the development of disruptive photovoltaic technologies in India and the U.S. and to provide a foundation on which a future Indian PV industry can be bulit.

- PV based on earth-abundant, available materials with performance potential comparable to, or exceeding, existing thin-film systems.
- Novel process and processing technologies that can produce cells and modules with low production and capital cost, low thermal budget, and environmental sustainability (e.g., non-vacuum deposition processes).
- Characterizing materials and devices in real-world environments, reliability and performance studies in harsh environments that can feed predictive models to iteratively improve and predict materials and device reliability.

Multiscale Concentrated Solar Power

Multiscale Concentrated Solar Power Research Thrust focuses on high-efficiency, scalable, distributable CSP. For solar plants, the capital cost of setting up a plant is a major contributor to the levelized cost of energy (LCOE). In CSP plants, the cost of solar field is typically about 60% of the total cost. Accordingly, the SERIIUS approach toward significant reduction in LCOE is two-pronged:

- ➢ Increase the power block cycle efficiency.
- ➢ Decrease solar collector cost with innovative designs and optical materials.

This thrust comprises three research activities to meet these objectives over a range of scales:

- Development of distributed CSP for high solar insolation areas based on Supercritical CO_2-Brayton cycle having >50% cycle efficiency at relatively low receiver temperature (700-800ºC) (100-kW to 1-MW size); development of test loop, receivers, heat exchangers, cost-effective heliostat design and tracking system for Indian conditions.
- Medium-temperature Organic Rankine Cycle (ORC) operating at <300°C to develop cycle efficiency >20% (25-kW to 1-MW size), development of test loop; optical coating materials, high efficiency positive displacement ORC expanders, heat exchangers, and cost-effective parabolic trough solar collector with optical efficiency >70%.
- Thermal storage and hybridization, to develop hybridized storage systems for the diverse temperature ranges of the Brayton and ORC converters.

Solar Energy Integration

The Solar Energy Integration (SEI) Thrust focuses on the identification, analysis, and assessment of technical, economic, environmental, and policy aspects for developing and executing solar technologies in India including understanding resources, infrastructure, constraints, scale, deployment scenarios, and policy needs.

The major research activities are:

- Technology road-mapping, analysis, and assessment.
- Solar-energy integration and storage analysis.

Consortium Management

SERIIUS has implemented an effective and efficient management plan overseen by highly experienced scientific leaders to enable high-impact R&D as well as coordination and communication among diverse teams across the three research thrusts. The consortium has established a SERIIUS Council—comprising the directors, research thrust leaders, competency coordinators, and industry board members—to monitor, review, and recommend adjustments of technical activities.

The organization and management structure is designed to facilitate a successful execution of the vision, objectives, and strategy. The underlying fundamental principle is that all work and responsibilities are co-shared by individuals and organizations from both India and the United States. Empowered India-U.S. partnering is the culture of SERIIUS. The scientific leaders of SERIIUS are empowered by an energetic, leading-edge research and problem-solving environment within an organizational structure that assures a focused, flexible and agile research effort.

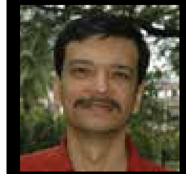
SERIIUS has an **Executive Oversight Board (ESB)** composed of the leadership of the key organizations engaged in the consortium. ESB ensures that consortium operations conform to standards, ethics, legalities, environmental safety and health quality of participating organizations, and provide a commitment to excellence, cooperation, and facilities use from key entities. SERIIUS governance structure has an empowered management component (SERIIUS Council) within the central leadership framework that ensures conformity with SERIIUS objectives and a shared, transparent, and equitable decision-making. The Industry Board is composed of core industry partners to provide their expert guidance for accelerated commercialization of relevant industry-driven research, and to establish and co-fund projects of interest directly. The Technical Advisory Board (TAB) of research authorities is the independent technical review and guidance arm of the institute. During the first year, TAB has been constituted and the first meeting between TAB and the consortium leadership team has been held through webinars and teleconferencing.

SERIIUS
Consortium Leadership

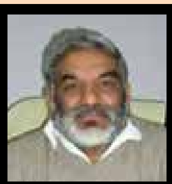
India	U.S
Co-Director Kamanio Chattopadhyay, IISc-Bangalore	**Co-Director** David Ginley, NREL
Deputy Managing Director Pradip Dutta, IISc.-Bangalore	**Deputy Managing Director** William Tumas, NREL
Research Thrust Leaders	**Research Thrust Leaders**
Sustainable Photovoltaics Juzer Vasi, IIT- Bombay	Sustainable Photovoltaics Maikel Van Hest, NREL
Concentrated Solar Power Pradip Dutta, IISc.-Bangalore	Concentrated Solar Power Subhash Shinde, SNL
Solar Energy Integration Anshu Bharadwaj, CSTEP-Bangalore	Solar Energy Integration Aimee Curtright, Rand Corporation

PROJECT MONITORING COMMITTEE, INDIA
Solar Energy Research Institute for India and the United States (SERIIUS)

Anil Kakodkar
Chairman
INAE Satish Dhawan Chair of Engineering Eminence
Bhabha Atomic Research Centre, Mumbai

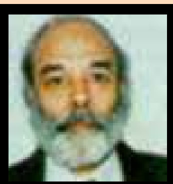


R. Banerjee
Indian Institute of Technology, Bombay



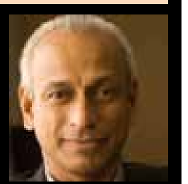
Suresh Chand
National Physical Laboratory, New Delhi

Vikram Kumar
Indian Institute of Technology, Delhi



S. C. Mullick
Indian Institute of Technology, Delhi

K. S. Narayan
Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore



Reji K. Pillai
India Smart Grid Forum, New Delhi

B.V.S.S. Prasad
Indian Institute of Technology, Madras

C. Ranganayakulu
Aeronautical Development Agency, Bangalore

A. K. Raychaudhuri
S.N. Bose National Centre for Basic Sciences, Kolkata

Bhim Singh
Indian Institute of Technology, Delhi

J. Srinivasan
Indian Institute of Science, Bangalore

K. Vijaymohanan
Central Electro Chemical Research Institute, Karaikudi

Research and development is organized under Research Thrusts, with cross cutting competencies under the Competency Gateway, both of which report directly to the Co- Directors. The research projects are coordinated by Project Leads, who are accountable to the Thrust Leaders.

Collaborative Aspects

The SERIIUS management plan has been developed and designed to encourage and facilitate partnering between Indian and U.S. institutions—from management and administration through the activities of the co-led research projects and cross-cutting competencies.

The SERIIUS web gateway provides information about the consortium to the public, establishing a special and secure "Consortium Collaboration Tool" for sharing research information among SERIIUS partners, and social media links (facebook and twitter). Consortium communications have advanced with teleconference and video conference schedules established for leadership, research thrusts, and research projects. SERIIUS has also implemented a new teleconference structure where each thrust has either a teleconference or video conference, twice a quarter. These events include both thrust leaders and all project leaders. Inter-SERIIUS-partner organization visits have also begun to blossom, and are key to ensuring research interactions, sharing of results, and fostering relationships.

To nurture the work force for the furure, SERIIUS Fellowship Program has been initiated by SERIIUS, McDonnell Academy Global Energy & Environmental Partnership (MAGEEP), with Sun Edison providing funding for eight student s or post-doctoral researchers per year for research visits through an exchange program coordinated by MAGEEP at Washington University-St. Louis. Students are engaged in SERIIUS research in PV, CSP, and solar energy integration, with opportunities for Indian participants to visit the U.S. and vice-versa. This provides SERIIUS with enhanced India-U.S. collaborations through exchanges and priority work force development. 24 candidates have benefited from this fellowship in the last three years. An"All Hands SERIIUS" internal review meeting was held at New Orleans, USA on June19-20,2015. Close to 100 Inter-SERIIUS partner organization exchanges materialized during second and third years.

IP generation

- One invention disclosure from Arizona State University: "*A novel method to prevent potential induced degradation of photovoltaic modules during manufacturing or after field installation*";
- One invention disclosure from Stanford University "*Solar Cells Having Selective Contacts and Three or More Terminals*";
- Two invention disclosures from HPCL, "*A Process for Preparation of Homogenous Mixture for Thermal Storage and Heat Transfer Applications*", and, "*A Method for Preparation of a Composition containing Nanoparticle for Thermal Storage and Heat Transfer Applications*".
- An application from ARCI-Hyderabad on solar selective absorptive coating is under preparation.

Key Deliverables

- Sustainable Photovoltaics (PV) based on earth-abundant, available materials using novel process and processing technologies with performance potential comparable to or exceeding existing systems.
  - » Non Silicon (CIGS, CZTS, Organic Photovoltaics etc.) Solar Cells materials and devices of efficiency greater than current state of art.
- High-efficiency, scalable, distributable multi scale Concentrated Solar Power (CSP) for high as well as moderate solar in insolation areas in deviation from conventional steam based CSP, which are efficient only at large scales (>50 MW), and require high source temperature (high DNI).
  - » Development of distributed CSP (100 kW – 1 MW) for low solar insolation areas based on Supercritical CO_2 Brayton cycle having >50% cycle efficiency at relatively lower receiver temperature and pressure (500-600ºC,70-200 bar).
  - » Organic Rankine Cycle (ORC) systems (25 kW-1 MW) for moderate solar insolation areas including two stage scroll expansion to achieve efficiency >70%; Cost efficient parabolic trough solar collector for ORC systems with targets as cost of collector <Rs 5000/m^2; Optical efficiency >70 %; Temperature of operation: 200° to 230°C; and thermal loss <2%; Non-flammable and environmentally friendly organic fluid mixtures.
- Solar Energy Integration (SEI)
  - » Technology roadmaps, techno-economic and environmental analysis, and assessment reports.
  - » Solar-energy integration and storage analysis.

SERIIUS

Achievements thus far

SUSTAINABLE PHOTOVOLTAICS

- A 6.5 % Copper Zinc Tin Sulfide (CZTS) solar cell on flexible Willow® glass from Corning has been achieved; Phase pure CZTS has been achieved on fluorine-doped Tin Oxide (FTO) and Molybdenum (Mo) coated glass substrates; Single phase copper indium gallium selenide (CIGS) films has been achieved via electro deposition; Phase purity was achieved by optimizing the annealing conditions. Devices being made/ in process of testing; 8.0% (7% average) CIGS nanoparticle based solar cell has been fabricated on flexible Corning Willow® glass. This efficiency has been achieved by rapid thermal processing of the coated CIGS nanoparticle film in selenium. During the last 6 months, work on aqueous dispersion processed Copper Zinc Tin Sulfide-Selenide (CZTSSe) solar cells has yielded a 4.1% device.
- Two new Organic Photovoltaic (OPV) materials with absorption >650 nm have been designed at NREL and synthesized at IISc.; a >4% OPV module has also been developed. Work has focused in the last 6 months on OPV on flexible Willow® glass, attaining 5.67% on based OPV cells at Solarmer, and 2.8% at IISc.
- Dye-Sensitized Solar Cells (DSSC) with 8% efficiency have been fabricated as reported earlier. Si nanowire fabrication has been standardized and fabrication of preliminary Si nanowire based solar cells initiated. During the last 6 months, Niobium (Nb) doped titania has been synthesized by aerosol synthesis; the effect of multiple sintering, which helps DSSC cell performance has been studied; thylakoid sensitized DSSC cells were fabricated and a 3X enhancement in photocurrent was observed with respect to titania. For Si nanowire solar cells, the use of Titanium dioxide (TiO_2) as a carrier selective contact is being explored.

- As reported earlier, solar cells have been fabricated with 15.9% efficiency on 6” wafers received from Sun Edison and process of recovery of silicon from kerf dust is being optimized. During the last 6 months work on recovery of kerf dust has been progressing. Amorphous Si (480 cm-1) was detected in Raman after wafering. Residual stress exists in Si swarf after cutting process. Stress distribution is narrow in the beginning of the cutting process whereas the variability increases at the end of the cutting process.
- As reported earlier, a series of coordinated measurements and simulations have been made on Heterojunction with Intrinsic Thin-layer (HIT) solar cells obtained from Moser Baer. During the last 6 months, particular emphasis has been put on Deep-level transient spectroscopy (DLTS) measurements.
- Corning’s flexible Willow® glass continues to be shipped. It has been used to fabricate CZTS and CIGS solar cells. During the last 6 months, OPV on Willow glass has also been made, and study on flexural stress in these devices undertaken.
- Modeling work on PV from materials to devices to modules is under way, including band structure calculations; modeling and simulation of HIT cells from Moser Baer; modeling improvement in efficiency for perovskite solar cells. During the last 6 months, a model for process-to-panel level performance estimation of HIT cells has been taken up for development. The a-Si process model developed at MIT has been coupled with the device simulations at Purdue to estimate the effect of a-Si deposition conditions on eventual panel level performance. On perovskite modeling, it has been shown that it is indeed possible to design devices which show valid superposition between the dark and the light IV, thus leading to better fill factor (FF). Simulations show the path to realizing ~ 27% efficiency perovskite solar cells.
- Field data obtained from installations in different climatic zones in India and USA continues to be taken and analysed alongside solar PV development for rural and commercial applications. During the last 6 months, degradation analysis of PV power plants in a hot-dry climate (Phoenix, AZ) using the metered kWh data supplied by the utility companies has been performed, and compared with rates obtained by three other methods. Also, risk priority number analysis of failure has been undertaken. IIT Madras and ASU are jointly working on the reliability evaluation of UDPM developed by IIT Madras.
- Work on improved encapsulants with improved water vapor transmission rate (WVTR). Al doped ZnO films developed for TCO applications; Work on dust mitigation. During last 6 months, Nanocomposite films with MgO developed at LBNL showing very good WVTR are being tested at IISc. p-type Cu:ZnS developed at IITB and LBNL show sheet resistance <2500 ohm/> and transparency> 85% at 500 nm. Films show stable performance over a period of 3 months. Artificial soiling apparatus and performance loss evaluation has been developed while the analysis of dust from different locations in India is under way.

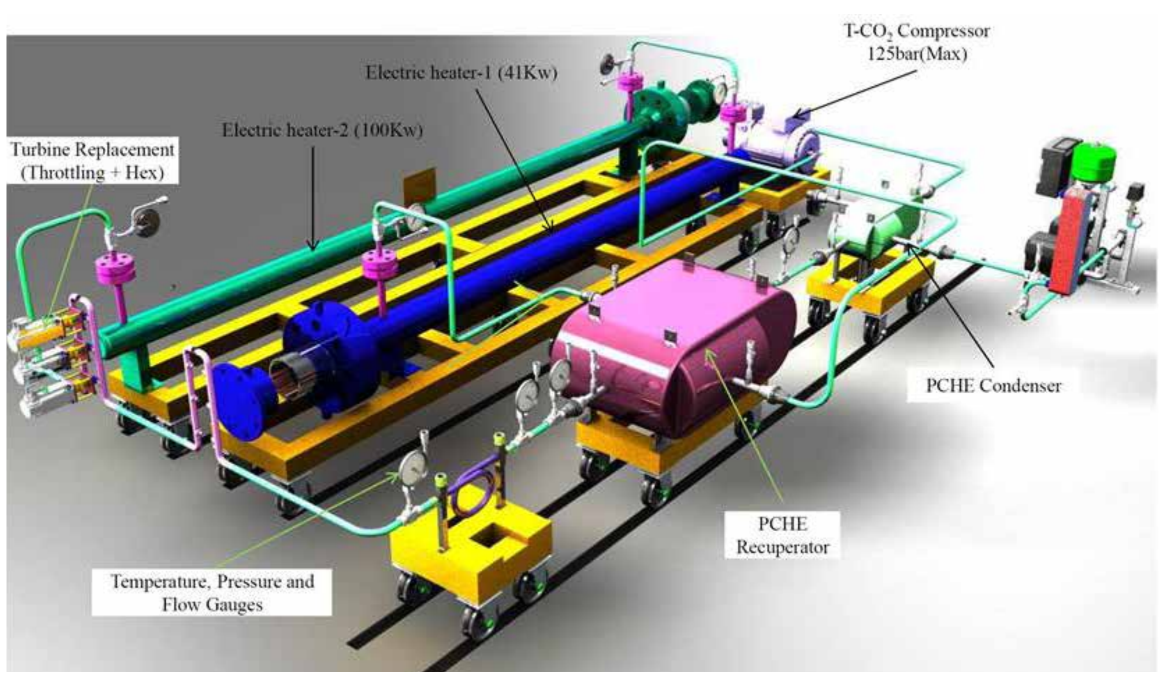
MULTISCALE CONCENTRATED SOLAR POWER

- Optimization of ORC and Supercritical CO_2-based cycles based on thermodynamic analysis; Completed technical design of a research

Achievements thus far

(laboratory scale) supercritical CO_2 test loop for closed Brayton cycle. Procurement of components is in progress. During the past 6 months, the S-CO_2 laboratory has been made ready, and all the critical components for the loop have been fabricated. It is expected that the test loop will be up and ready by October 2015. Design of a tubular serpentine receiver; CFD model predicting efficiency >90% is ready at Sandia National Labs. CAD designs of hybrid tubular and cavity receiver for S-CO_2 receiver is ready and a small prototype is planned to be tested at IISc. facility.

- Development of the first 4m^2 heliostat prototype with 2-axis tracking, with high reflectivity AIS glass, linear actuator for elevation, and geared motor for azimuth motion. First heliostat prototype gives us insights in to the actual cost, weight and other requirements of a heliostat. Test protocols and guidance for setting up optical test facilities at Thermax are being provided by NREL and Sandia.
- Development of a (Cu-Sn)-based novel hemispherical highly reflective intermetallic mirror material with> 93% reflectivity; Development of High thermally stable absorber coating with high corrosion resistant property has been achieved. A W/WAIN/WAION/Al_2O_3-based coating which exhibits an excellent solar selective property with an absorptance of 0.959 and emittance of 0.08 has been fabricated by reactive DC and RF magnetron sputtering method. The reflectance property of the selective coating has been studied by UV-Vis-NIR in the wavelength range of 0.25-2.5 µm and by Fourier Transform Infrared Spectroscopy (FTIR) in the wavelength range of 2.5- 25 µm. The multilayer absorber deposited on SS substrates exhibited high solar selectivity ($\alpha s/\varepsilon T$) of 0.932/0.08 even after heat-treatment in air up to 500°C for 2h. At 550°C, the solar selectivity decreased significantly on SS substrates ($\alpha s/\varepsilon T$ = 0.820/0.50).
- Optimization of scroll geometries for small-scale ORC is complete. Completed machining of scroll elements for first prototype is complete. A 'burn-in' test rig is being designed to improve tolerances on scroll elements. The components are now ready and the scroll expander assembly is expected soon.
- Assessment of thermal performance of dual-media thermocline tanks, with quartzite rock as filler material, and single-media thermocline tanks with only molten salt as high temperature thermal storage options for CSP. Completed design of a laboratory scale molten-salt-loop system to test storage option for high temperature CO_2 Brayton cycles. During the past 6 months, the molten salt laboratory has been made ready, and all the critical components for the loop have been fabricated. It is expected that the test loop will be up and ready by end of September 2015.
- A new Core project with BHEL has commenced on the development of a ceramic volumetric receiver for S-CO_2. A design concept of a volumetric receiver with Silicon Carbide (SiC) ceramic as the absorber material has been finalized, geometric modeling completed, and a test material has been fabricated. A laboratory scale open cycle test s-CO_2 loop for testing the receiver module has been designed at BHEL. In the past 6 months, the open cycle test loop with compressed air has been completed, and the volumetric receiver is being tested at IISc facilities with a fresnel lens as concentrated solar heat source.



Summary of Innovations

New Materials

Intermetallic reflective material (IISc., Sandia)

- Absorber material for PTC (ARCI, Thermax, NREL)

Prototypes Fabricated (first versions)

- Low cost heliostat – structure and tracking system – first prototype (Thermax, IISc., NREL, Sandia)

Achievements thus far

- Cost effective PTC to test the new reflector and absorber materials (Thermax, NREL)
- Scroll geometries for R-245fa (MIT, IISc, USF)
- Small scale ceramic volumetric receiver (BHEL, IISc.)

Prototypes / Test Rigs

- First s-CO_2 test loop for CSP (IISc., Sandia)
- Tubular volumetric receiver for (s-CO_2; Sandia, IITB)
- Pumped molten salt test loop for CSP (IISc., Purdue, HPCL)

Invention disclosures/Patents

- A process for preparation of homogenous mixture for thermal storage and heat transfer applications (HPCL)
- A method for preparation of acomposition containing nanoparticles for thermal storage and heat transfer applications (HPCL)

SOLAR ENERGY INTEGRATION

Roadmapping and Policy Assessment (CSTEP, RAND)

Report on resource assessment and technology roadmap frameworks for PV and CSP in India:

- A detailed report on ''Solar Resource Assessment and Technology Roadmap'' was submitted. Projections of solar power capacity in India in 2031-32 were made based on three scenarios-Planning Commission's Low Carbon Growth Study, Steady Renewable Purchase Obligation Growth and ICF International's Green Scenario.
- Land and solar resource assessment using NREL's satellite data and limited ground measurement data from Karnataka were conducted.
- An overview of Indian solar manufacturing industry was conducted. This comprised of analysis of the impact of Domestic Content Requirement and imposition of Anti-Dumping duties on domestic manufacturing.
- A detailed policy overview of solar energy in India including central and state policies for grid connected plants, roof top PV, rural electrification schemes and decentralized solar applications was completed along with identification of policy gaps and recommendations to bridge these.
- An evaluation of innovative financing schemes for solar projects in India was also conducted
- SERIIUS quarterly newsletters were compiled and uploaded on SERIIUS web site for informing the consortium and wider audience about SERIIUS activities, government's solar policies and solar news in general.
- Manufacturing process analyses of CIGS and polysilicon were conducted in detail.
- The capital and operating costs of establishing a CIGS manufacturing facility, and the corresponding cost/Wp of producing CIGS modules, was ascertained. An assessment of scope of cost reduction also is being conducted.
- Similar analyses were done for polysilicon. Availability of materials in the Indian context was also determined from various secondary sources.

Detailed Roadmaps (R&D priorities):

- A detailed technical assessment of thin film solar cells based on CIGS, CZTS and perovskite materials was carried out. The study reviewed the three solar cell technologies based on these materials, their fabrication processes and final device properties.

Computational Tools for Economic Assessment, Bankability and Deployment (CSTEP, RAND, IISc, NREL):

- A computational tool, CSTEM (CSTEP's Solar Techno-Economic Model) for estimating the optimized solar multiple for parabolic trough plants was made available through the SERIIUS website.
- A comprehensive review of the solar tower technology was conducted with respect to the performance, cost, merits and de-merits of different variants under Indian conditions, and a report based on this work (Global Review of Solar Tower Technology) was published as a journal article.
- A detailed engineering model for the reflected image from the heliostat was developed. An overall gross methodology for estimating the solar tower height for a given capacity was established.
- A Graphical User Interface (GUI) model for energy estimation of solar PV for fixed, N-S axis tracking and azimuth axis tracking was also completed.
- Completed the base version of the PV model for assessment of Grid connected PV systems. The model performs an hourly evaluation of the system performance and considers a bottom-up approach for the financial assessment. This model also takes into account the effect of shadowing, degradation factors etc.
- In the solar tower area, a detailed model has been developed for assessment of Annual Efficiency Factor of the heliostat field considering an external cylindrical receiver. This factor is based on the cosine losses, shadowing and blocking effects of each heliostat. For any heliostat size & position, with respect to the tower, the model can determine the hourly, daily and annual field efficiencies.

Grid Integration and Energy Storage (NISE, IITB, CSTEP, IISc.,WUStL, CMU):

Engineering – economic assessment of the storage options :

- Completed a detailed report on "Energy Storage for RE Deployment in India: Potential, Economics and Technology Options". The report includes storage requirement estimation and economics for i) rural microgrid, ii) telecom sector, iii) roof-top PVs, and iv) Power grid. The analyses involved overall demand assessment of energy storage technologies in India, economic assessment against current practices such as net-metering schemes for roof-top PV and diesel use in villages and telecom sector aspects.
- Analyzed and prioritized different storage technology options across above four sectors and proposed a strategic roadmap for India.
- Similar analyses with respect to major climate zones of India have been initiated.
- Based on above studies, few storage technologies were identified for R&D analyses: Na-S, Li-ion, flow batteries and hybrid capacitor systems are among these.Further, an analysis of the ground data of solar resource in Gujarat for grid related studies was initiated.
- Conducted autonomy and battery utilization studies for micro grid sector.
- Base version of the technical model of the hybrid (PV-wind)-battery system based on NREL satellite data for solar irradiance and wind speed has been developed.
- Performed quantitative analyses of the smoothing of geographically distributed PV plants as a function of time scale. This was based on one year solar ground data of Gujrat (CMU)
- Studied dispatching, autonomy, and battery sizing/utilization for microgrids and solar+battery/solar+wind+battery applications (WUStL, CSTEP)

Achievements thus far

Assessment of options to enhance the life of sodium-sulfur rechargeable battery:

- Na-S battery is one of the most deployed battery systems globally in the renewable energy sector. Two approaches are being pursued in parallel under a SERIIUS milestone, with regard to solving the corrosion issue of Na-S battery which limits the life, thereby increasing the cost per unit of electricity from Na-S integrated solar station.
- First approach is design of a novel corrosion resistant coating for the molten sulphur electrode container (316L Stainless Steel). This involves understanding the corrosion pathway and then coming up with a suitable low cost coating system.
- Initiated atomistic scale modeling on corrosion of 316 steel and are making progress towards understanding corrosion phenomenon encountered under operating conditions.
- Corrosion studies on Na-S systems – Assessment on the effect of sulfur on the SS container initiated. The ex-situ spectroscopic measurements provide initial information on the possible coatings to be used to improve corrosion resistance properties of SS containers used in Na-S batteries.
- Initial experimental studies on corrosion pathway involved in Na-S battery systems indicate the possible coatings to be used in actual systems
- The second approach is design of novel low temperature electrolyte that will help avoid high temperature corrosion situation all together. A new low temperature capable Na based electrolyte was predicted through quantum mechanical simulations and is currently under review as a journal article.

Studies of Li-ion, Super Capacitor and Unitized Regenerative Fuel cells (URFC) for grid scale applications: Modeling and select experiments:

- Detailed experimental as well as modeling studies on select Li ion battery cathodes (oxides, phosphates, silicates, vanadium oxide, a few other systems) and anodes of select chemistries were completed and published in high quality journals (IITB, CSTEP)
- Hybrid capacitors based on exfoliated graphite and Pb oxide were constructed and characterized; corresponding modeling work based on Monte Carlo simulations was also initiated. A simulation tool to study various combinations of electrode/electrolytesisunder progress (IISc, CSTEP).
- URFC prototypes were fabricated and test stations were developed for performance evaluation (IITB).

Development of Novel Storage Materials for Solar-Hydrogen Produced by PV Electrolytic System (HPCL, IISc.):

- Metal Organic Framework (MOF) materials to store hydrogen has been studied.
- A few benchmarkMoF compounds have been synthesized and characterized.
- Two MOFs synthesized by using novel organic linkers and their characterization completed (HPCL, IISc).
- High & Low pressure hydrogen sorption studies at room temperature currently under progress (HPCL).
- As of April 2015, 142 conference presentations and 74 journal papers came out of the work accomplished on the PV, CSP and SEI projects of SERIIUS. Additionally, 4 disclosures/patents have been filed.

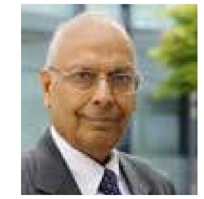
Deployable tools and technologies under PACE – R

- SERIIUS is setting up the first super-critical CO_2 laboratory scale test loop for CSP at IISc. Bangalore in collaboration with Sandia National Labs. The main purpose of the small-scale facility, with 50 kW of heat input, is to demonstrate the technical viability (i.e., the cycle thermodynamic state points) and controllability of the S-CO_2 Brayton cycle and to provide a platform to test small-scale components such as solar receivers and heat exchangers. Intermediate-or prototype-scale demo of S-CO_2 cycle through the PACE-D program is needed to establish commercial viability.
- Two small-scale solar receivers for S-CO_2 have been designed and fabricated for testing in the IISc. loop. Development of scaled up versions of these concepts, after testing and proof of concept, can be taken up under PACE-D program.
- SERIIUS has developed a 4m2 heliostat prototype that is significantly smaller than the standard 36 m2 heliostat, with a lower projected cost per unit area. This product has potential for deployment, post field testing.
- A new absorber coating material with high thermal stability and high corrosion resistant property has been demonstrated on SS 304 tubes for use in parabolic trough system for ORC cycle. This product has potential for deployment after field and weather testing.
- Prototype of a new scroll expander with optimized geometry being fabricated for testing in an Organic Rankine Cycle (ORC) rig in Florida. This product can be deployed for off-grid small-scale ORC applications.
- A novel molten salt-based heat transfer fluids with enhanced thermal properties have been developed. Two patents have been filed.
- Reliability studies for photovoltaics in India: One of the important activities of SERIIUS is the study of reliability of PV modules in India and USA. Preliminary results of studies being conducted through SERIIUS, as well as other projects show that the life of modules in hot climates like India and Arizona are less than in temperate climates. The results of this research will potentially be included in new test protocols for PV modules to certify their usability in a hot climate, like India's.
- Soiling mitigation for PV modules: SERIIUS studies have shown that as much as 10% power loss can occur per month if the modules are not cleaned regularly. A study of cleaning protocols is being started to assess best cycles for different regions. Work on PV module surfaces to minimize soiling and enhance cleanabiity is also underway.
- Use of Flexible Glass for Substrates and Encapsulation: The research has opened up the possibility for roll-to-roll processing of solar cell using corning willow glass giving very high throughputs and lower costs. Also, since capital costs for roll-to-roll processing systems would be less than standard vacuum and high-temperature processing systems, they are better suited for manufacturing in India. Finally, flexible glass is also an attractive encapsulant / sealant for various thin film cells, which is also being tried out in SERIIUS.

For latest updates on SERIIUS, please visit us at:
www.seriius.org

U.S.-India Joint Centre for Building Energy Research and Development (CBERD)

Principal Investigators



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Background

India's economic growth in recent years has demonstrated that the building sector needs urgent attention of policy makers to reduce its negative impact on environmental conditions. Commercial building and high-density residential construction industry is experiencing an explosive growth. India is expected to add about 700-900 million M^2 of built floor space each year (McKinsey, 2010). The United States is one of the largest energy consumers in the world. Buildings account for over 70% of total electricity consumed in the US.

The potential for building energy savings in both nations is enormous. Number of research studies have demonstrated that building envelop and energy systems-level integration through innovative design and technologies can reduce energy consumption by at least 60% in new construction in India, and at least 10-30% in retrofits in the U.S. relative to local norms and practices. By drawing on the research and technological capabilities of the U.S. and India, substantial energy savings can be achieved.

Objectives

The U.S.-India Joint Centre for Building Energy Research and Development (CBERD) is engaged in collaborative research and promotion of clean energy innovation in the area of energy efficiency in buildings with measurable results and significant reduction in energy use in the US, and in India. CBERD has its focus on the integration of information technology with building physical system technology with an aim to bring energy efficiency in commercial and multi-family residential high-rise buildings.

CBERD is dealing with multiple aspects of building energy efficiency in a coherent manner. However for ease of carryout R&D it has divided project in to following six distinct yet inter-connected tasks.

- Building energy model & energy simulation
- Monitoring and energy benchmarking
- Integrated sensors and controls
- Advanced HVAC system
- Building envelopes
- Climate responsive design

In addition to the above tasks CBERD is also working on crosscutting task of addressing cost-benefit framework for energy investments adopting the triple bottom line approach.

This outcome-based ongoing R&D effort will result in significant energy savings by driving forward the development of cost-effective scalable technologies and their implementation across buildings. CBERD's vision is to build a solid foundation of collaborative knowledge, technologies, and human capabilities that position U.S. and India for a future with high-performance buildings, along with measurable reduction in energy consumption. With focus on the highest growth sectors i.e. commercial and high-rise multi-family buildings, CBERD targets primarily new construction in India and retrofits and operations in the U.S. While this approach will create the maximum impact, the results will have welcome spill-over benefits for other building industry segments as well. CBERD is relying on its partners' collaborative R&D strengths and commercial experience to meet the goals of the JCERDC. CBERD is aligning its vision with US Department of Energy (U.S. DOE Multi-year Plan, 2011–2015) and Government of India (IPC, 2011).

CBERD is attempting to gain an in-depth knowledge of performance of buildings in India and the U.S. with aim to create a Lifecycle Performance Assurance Framework (LPAF)that supports building system integration throughout the building's design, construction, and operation stages. The overall R&D strategy at CBERD is structured and prioritized to provide guidance on the selection of key technologies and components for each building system to meet the desired performance levels, and cost-effective solutions.

Knowledge Gaps or Critical Barriers	CBERD Objectives	CBERD Methodologies
Research and Development		
Lack of building systems integration throughout the design, construction, and operation processes	Evaluate and optimize the integration of building systems using the whole-building approach across the building lifecycle to advance high-performance buildings	Develop a Lifecycle Performance Assurance Framework that stakeholders can use to ensure optimal integration of building IT systems with building physical systems through a building's lifecycle
Lack of specific energy efficiency solutions that will apply to diverse building types	Formulate Building EE R&D strategies targeted to the wide diversity of building types in the commercial including new construction and retrofits	Conduct research and develop guidelines and best practices for building prototypes
Lack of efficiency technologies and applications customized for regional application	Develop a suite of R&D strategies customized for U.S. and Indian applications to help leapfrog transitional technologies while developing and advancing appropriate regional and local low-energy practices and technologies	Develop bilateral transfer of technologies and products between the U.S. and India to help speed the development of regional practices normalized to weather, materials-construction techniques, systems and occupant comfort
Lack of universally accepted, standardized processes for achieving building energy performance targets for technology R&D	Enhance pathways to meet or exceed building standards and codes through decision tools, design specification algorithms, and best practices that are supported by measured data	Establish milestone-driven, short-term, tangible results and long-term goals using comprehensible, actionable data from emerging technologies and their integration
Team Innovation		
Building energy researcher, designer, and developer knowledge limitations in the U.S. and India	Boost the knowledge and capability levels of building energy stakeholders through documentation, education/ training, and demonstration	Facilitate & enable collaboration & information exchange among key academic & research institutes to disseminate building efficiency knowledge broadly among stakeholders
Building industry fragmentation inhibits energy efficiency	Accelerate building efficiency R&D and deployment through a solid, functioning consortium with bilateral public-private partnerships	Establish on-going, sustainable joint consortia that draw on core research and commercial strengths of both nations, with well-defined cooperative responsibilities and roles

Participating Institutions

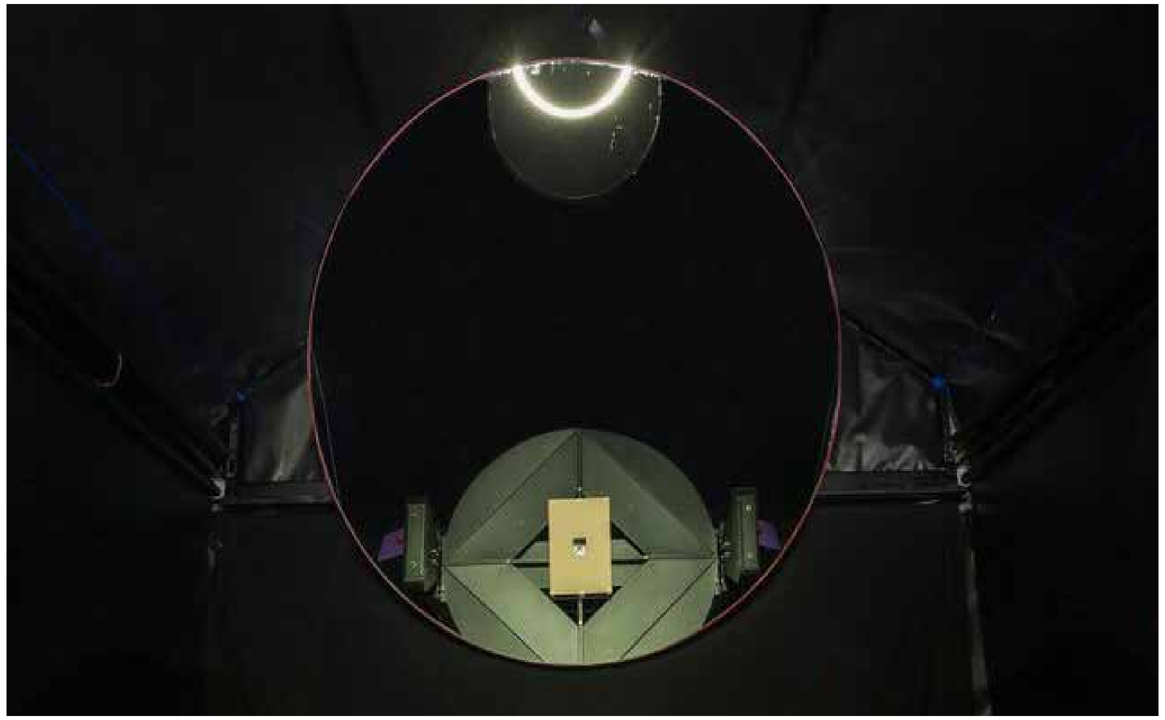
India	U.S.
LEAD INSTITUTION	**LEAD INSTITUTION**
CEPT University, Ahmedabadd	Lawrence Berkeley National Laboratory, Berkeley
OTHER PARTNERS	**OTHER PARTNERS**
International Institute of Information Technology, Hyderabad Malaviya National Institute of Technology, Jaipur Indian Institute of Technology, Bombay Indian Institute of Management, Ahmedabad Auroville Center for Scientific Research	Oak Ridge National Laboratory, Oak Ridge University of California Berkeley Carnegie Mellon University, Pittsburgh Rensselaer Polytechnic Institute, Troy
INDUSTRY PARTNERS	**INDUSTRY PARTNERS**
Asahi India Glass Biodiversity Conservation India Infosys Technologies. Neosilica Technologies Oorja Energy Engineering Services Paharpur Business Centre PLUSS Polymers Philips Electronics India Saint Gobain Corp Schneider Electric India Sintex Industries Limited Skyshade Daylights Wipro EcoEnergy	Autodesk, Inc. California Energy Commission Delphi enLighted Inc. Honeywell Ingersoll-Rand/Trane Lighting Science Group Corp Nexant Saint Gobain Corp SAGE Electrochromics SynapSense
SUPPORTING ORGANIZATIONS	**SUPPORTING ORGANIZATIONS**
Indian Green Building Center, CII Indian Society of Heating Refrigeration and Air Conditioning Engineers Rajasthan Electronics and Instruments Limited Indian Society of Lighting Engineers Glazing Society of India	Bay Area Photovoltaic Consortium City of San Jose HOK Architects Natural Resources Defense Council

Consortium Management

CBERD Consortia Management Office provides core management support to achieve project objectives, consortium effectiveness and quality at every stage of technology development. It allows coordination of consortia's expertise at different levels, which helps to guide R&D priorities over the five-year period. The management team evaluates technologies and systems during each stage of the CBERD project to meet performance requirements to ensure R&D success through scientific collaboration. Another goal is to provide oversight efficiently while optimizing management/travel costs. Both LBNL and CEPT have formed joint CBERD Management Offices (CMOs) led by the CBERD Principal and Co-Principal Investigators, supported by the Project Directors (PDs) and CBERD Intellectual Property Offices (CIPO).

In particular CMO focuses on:

1. Communication with the U.S. Department of Energy (DOE) and Government of India (GOI) through the Indo–U.S. Science and Technology Forum (IUSSTF) for project updates, management, and reports (quarterly report to the DOE, semi-annual report to the GOI/IUSSTF, annual reports to both) Coordination with:
   - R&D partners: review of partners' task performance and reports;
   - Industry partners to facilitate R&D, technology transfer;
   - Project Monitoring Committee instituted by US and Indian government.
2. Feedback from monitoring committee meetings and partner meetings
3. Coordination for reports, event and briefings
4. IP management, technology transfer issues
5. Budgeting and tracking of expenditure



PROJECT MONITORING COMMITTEE, INDIA

Center for Building Energy Research and Development (CBERD)

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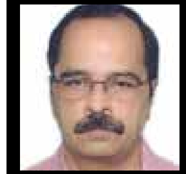

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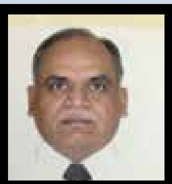

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Key Deliverables

- **Lifecycle Performance Assurance Framework (LPAF) of Buildings:** Holistic decision support system to assess and optimise performance of building in terms of thermal comfort as well as energy efficiency during building design, construction and operation stages.
- **R&D Suite Managing Climate Diversity:** Strategy options based on occupant needs, regional weather, regional materials, prevailing building codes, regional building practices and integrating innovative passive design low energy comfort technologies.
- **Tool Development:** Early design stage building energy simulation tools, code compliance tools and implementable design specifications for benchmarking tool based on measured data.
- **Infrastructure Development:** Design and develop equipment and test bed facility to evaluate low energy technologies.

CBERD in numbers

- 33 papers (in peer reviewed journals and conferences).
- 2 patents filed.
- 4 tools (available in public domain).
- 32 research exchanges.
- 15 joint workshops.
- Establishment of 7 infrastructure facilities and test beds.

Progress thus far

CBERD has categorized progress so far in three easy to comprehend categories.

1) **Creation of Knowledge:** This part contains work which has added knowledge into existing pool of knowledge or has created new knowledge and / or technology. This Includes:

   - Model Predictive Control method for enhanced savings through low-energy radiant cooling.
   - Development of a graduated approach for benchmarking, usable for market-facing deployment activities.
   - Development of PoE based blind controls for shading, smart luminaire controller; and implementation of dual loop mechanism to control light on task plane.
   - Enhanced design for energy efficient, lower mass micro-channel heat exchanger from small unitary HVAC systems, supported by industry partner Delphi.
   - Hygrothermal characterization of Phase Change Materials (PCM); inter-lab comparisons. Development of PCM tiles for ceiling and deployment of it in test for evaluation.
   - Natural Exposure of Cool Roofing Products in India to study the Weathering and Aging Process: Protocol finalization and test runs.
   - Characterization of laser-cut panel that allow deep daylight penetration through test apparatus and evaluation of technology in India and development of easy to use tool to predict daylight penetration.
   - Development of algorithms to be included in EnergyPlus for calculation of resultant SHGC in presence of non-coplanar shading devices.
   - Indoor environmental performance evaluation of thirteen naturally-ventilated

Progress thus far

/ mixed-mode Indian buildings being monitored and data undergoing analysis; five US buildings identified for monitoring, supported.

2) **Deployment of Existing Knowledge for Performance Evaluation:** CBERD activities are establishing pathways towards testing, demonstrations and deployment of tools and technologies, creation of standards. Such activities include:

   - Expanded tools for rapid design, modeling, and optimization, e.g. eDot, COMFEN India, Cool roof calculator.
   - Launch of EIS Springboard Program.
   - sMAP 2.0 data exchange platform bench-deployed and studied for integration of various building sensor data in India.
   - Design integration of DOAS with HVAC systems.
   - Online thermal comfort surveys administered amongst about 1000 subjects in Indian buildings.

3) **Infrastructure development, equipment design, construction and test beds for technology evaluation:** Technology testing and development is an important part of the CBERD R&D. A strong focus has been around technology enhancement while getting transferred, and capacity building for test –beds and new equipment towards the enhancement of building science in India. Activities include:

   - Fault Detection and Diagnostic Lab at IIIT-Hyderabad.
   - Earth Air Tunnel technology evaluation laboratory at MNIT – Jaipur.
   - Micro Channel Heat Exchanger and Dedicated Outdoor Air System testing laboratory at IIT-Bombay.
   - Establishment of Hygrothermal characterization of building materials characterization at CEPT University, Ahmedabad.
   - Design and construction of Mirror Box and Single Patch Sky Simulator for daylight performance evaluation of design strategies at CEPT University.
   - Cool Roof test apparatus for standardized testing of cool roofs in four climate zones in India.
   - Thermal Comfort Chamber to carry out studies of elevated air temperature and air velocity at CEPT Uni., Ahmedabad.

Deployable Outcomes by CBERD under PACE-R

- COMFEN India: A building design assistance tool to predict daylight availability inside building in Indian context. *(Ready for deployment).*
- eDOT: A building design assistance tool to understand complexity of operational end use energy. Tool helps identify various building components such as walls, roofs, windows and HVAC system responsible for higher energy consumption. *(Ready for deployment).*
- Phase change material ceiling tiles: Phase change material contained, false ceiling tiles help increase internal thermal mass. Such measures help save energy by the increased possibility to operate buildings in naturally ventilated mode and at the same time help reduce HVAC operation hours. *(Prototype ready, under field test).*
- Laser Cut Panels: Laser cut window panels help transport daylight deep inside a building without using any electricity. *(Performance enhancement under CBERD, ready to deploy).*
- Dedicated Outdoor Air System: Dedicated Outdoor Air System (DOAS), with indirect evaporative cooling of fresh ambient air using exhaust from conditioned spaces. Low energy cooling technology meeting adaptive thermal comfort standards saves cooling energy considerable. *(Ready for deployment).*
- Indirect evaporative space cooling: Diabetic rotating contacting device based evaporative cooling technology for water. This technology saves operational energy where water is used in close loop for space cooling. This technology has more potential to provide thermal comfort in hot and dry climates. *(Ready for deployment).*
- Low energy wireless motion sensor: This is a wireless device which can be used to switch on/off an air-conditioner or any other gadget which has IR controlling interface such as TV, music system etc. based on the human occupancy in a given space. *(Prototype ready, under field test).*
- Affordable smart power strip: WiFi communication based Smart power strip monitors connected devices and provides details such as device IDs, usage time, location, and power consumed. This provides the load profile of the plug loads in a building to help in developing strategies for plug load management. Smart strip also allows users to manage connected device. *(Prototype ready, under field test).*

For latest updates on CBERD, please visit us at:
www.cberd.org

U.S.-India Consortium for Development of Sustainable Advanced Lignocellulosic Biofuel Systems

Principal Investigators

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BACKGROUND

The Energy Independence and Security Act (EISA, 2007) mandates that the United States must use 21 billion gallons of second generation biofuels per year by 2022, while the National Biofuels Policy of India approved on December 24, 2009 proposed an indicative target of 20% blending of biofuels by 2017. In order to achieve the common goals on development of sustainable, replicable feedstock production, logistics, processing and biofuels distribution systems in these two countries, a well-coordinated and synergistic approach is needed. The present project addresses this through the **U.S.-India Consortium for development of Sustainable Advanced Lignocellulosic Biofuel Systems**, emphasizing sustainable feedstock cultivation and supply, biochemical conversion technologies for production of second generation biofuels with minimal environmental impact, and analysis of overall sustainability and supply chain of feedstock.

The major goal of this project is to develop and optimize selected non-food biomass based advanced biofuel systems and bio-based products for the U.S. and India. The project is expected to benefit both nations by delivering a working model for feedstock production and supply, biochemical conversion approaches and technologies that have been validated on pre-commercial scale systems, and the overall economics and sustainability of biofuel production and supply systems.

Objectives

- Improve feedstock (production potential and feedstock quality) using genomics and breeding tools and identify locally adapted cultivars and their optimization for large-scale production.
- Develop production logistics and identify soil and environmental criteria to ensure a commercially successful advanced feedstock production system.
- Development of biocatalysts for production of advanced biofuels and co-products and optimization of pretreatment and fermentation processes.
- Minimizing environmental impact and maximizing revenues from bio-refinery waste streams.
- Analysis and development of certification protocols and sustainability standards.
- Assessment of energy requirements and emissions.
- Supply chain management analysis.

Collaborating Institutions, India	Collaborating Institutions, USA
Lead Institution: Indian Institute of Chemical Technology, Hyderabad	**Lead Institution:** University of Florida, Gainesville
Other R &D Institutions and Academia Partners	**Other R & D Institutions and Academia Partners**
International Crops Research Institute for the Semi-Arid Tropics- Hyderabad	University of Missouri, Columbia
Directorate of Sorghum Research-Hyderabad	Virginia Tech, Blacksburg
Jawaharlal Nehru Technological University-Hyderabad	Montclair State University, Montclair
Tamil Nadu Agricultural University, Coimbatore	Texas A&M University, College Station
Rajamatha Vijayaraje Scindia Krishi Vishwa Vidyalay, Gwalior	
Centre for Economic and Social Studies, Hyderabad	
Indian Institute of Technology-Delhi, New Delhi	
Indian Institute of Technology-Madras, Chennai	
Industry Partners	**Industry Partners**
Abellon Clean Energy	Show Me Energy
Hindustan Petroleum Corporation Limited	Green Technologies

Collaborative Aspects

- University of Missouri to provide technical help in feedstock matching, i.e. identifying NUE cultivars, *bmr* varieties and developing advanced feedstock production systems.
- ICRISAT to exchange germplasm and provide technical help in developing new flood-tolerant sorghum varieties at University of Missouri.
- Scale-up and process data from cellulosic ethanol biorefinery of the University of Florida to be made available to the Indian consortium.
- Cellulosic biorefinery of the University of Florida to be made available for Indian consortium for training purposes.
- The ethanol conversion technology of the University of Florida to be shared with Indian consortium.
- Development of an integrated biorefinery with a focus on effluent treatment and by-product utilization.
- U.S. Consortium members have been providing technical help to Indian partners towards development of certification protocols and sustainability standards, energy and emission efficiency, supply chain management, and economic analyses to assess viability of advanced biofuels.

Consortium Management

The Indo-U.S. Consortium for Development of Sustainable Advanced Lignocellulosic Biofuel Systems is being led by CSIR-Indian Institute of Chemical Technology (CSIR-IICT), Hyderabad, India, which is responsible for the smooth functioning of the project to achieve the targets with the help of a three-tier management system including an administrative setup, consortium leader and the individual partnering institutes. The administrative setup comprises of a Technical Advisory Committee (TAC) and a Project Steering Committee (PSC). The TAC meets at least once a year (or more if required) and reviews the project work execution and renders technical inputs to achieve the approved milestones and deliverables. The TAC consists of Dr. David Hoisington (Deputy Director General-Research, ICRISAT), Dr. B.D. Kulkarni (Scientist DG Grade, National Chemical Laboratory, Pune), Dr. Pankaj Patel (President and Member on the Board, Abellon Clean Energy Pvt. Ltd., Ahmedabad), Dr. B. Ramachandran (Professor, IIT-Madras, Chennai) and Dr. K. Ramaswami (Vice Chancellor, Tamil Nadu Agricultural University, Coimbatore).

PROJECT MONITORING COMMITTEE, INDIA

US-India Consortium for development of Sustainable Advanced Lignocellulosic Biofuel Systems (SALBS)

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(Chairman), Former Director
Institute of Forest Genetics and
Tree Breeding-Coimbatore

Jayant Modak
Indian Institute of Science, Bangalore

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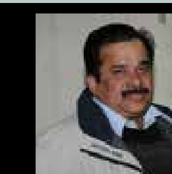
Jawaharlal Nehru University, New Delhi



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V. V. Ranade
National Chemical Laboratory, Pune

The PSC consists of Dr. David Hoisington (Deputy Director General-Research, ICRISAT, Patancheru, Hyderabad), Dr. B.D. Kulkarni (NCL, Pune), Dr. Pankaj Patel (Abellon Clean Energy Pvt. Ltd., Ahmedabad) and Dr. P. Gunasekaran (Thiruvalluvar University, Vellore). The PSC meets once a year to review the overall progress and suggest suitable opinions to meet the proposed milestones.

The Project Coordinator, Dr. Ahmed Kamal coordinates the project implementation, while the task leads - Dr. A. Ashok Kumar (Work Package 1), Dr. C. Ganesh Kumar (Work Package 2), and Dr. Beena Patel (Work Package 3) coordinate the execution of the respective Work Packages by closely interacting with the investigators. Each principal investigator is responsible for meeting the deliverables/ milestones defined in their respective work package(s).

In the US consortium, WP1 is led by Dr. Shibu Jose (University of Missouri), WP2 is led by Dr. Wilfred Vermerris (University of Florida) and WP3 is led by Dr. Janaki Alvalapati (Virginia Tech).

Key deliverables

- Identify locally adapted high biomass abiotic stress tolerant sorghum, pearl millet and bamboo cultivars.
- Develop a low-input advanced feedstock production system.
- Optimize efficient pretreatment methods and identify biomass-based enzyme formulation for saccharification.
- Develop efficient fermentation processes for high ethanol and butanol recovery.
- Develop standardization and certification protocols and prepare energy, emission, economic analysis and supply chain management report for commercialization of lignocellulosic biofuel production.

Achievements thus far

Work Package 1

Sorghum

- Screening of high biomass sorghum genotypes for various agronomic traits led to the identification of some promising varieties. Most promising genotypes including ICSV 25334, ICSV 25332, ICSV 25333, SBr-9 and NP 3 have been identified producing good grain and stover yields of >40 t ha-1.
- Sorghum genotypes: CSH 13, Gird 36, Gwalior III, ICSSH 28, MP II, NSS 1015A × DSSV 165 and Sel B-Pop performed better at both 10 dsm-1 and 15 dsm-1 levels of salinity.
- Based on the multi-location testing in on-station trials as well as on-farm testing in farmer's fields, the high biomass and high sugar containing sorghum hybrid RVICSH-28 was released in 2015 for commercial cultivation in Madhya Pradesh.
- Transcriptome studies on drought tolerant sorghum varieties, IS 18542 and IS 23143 for identification of differentially expressed genes and assembling of transcriptome is in progress.
- Two high biomass sorghum genotypes, CSH-13 and ICSSH-28, have been identified for higher nitrogen use efficiency (NUE).
- The brown midrib trait associated with low lignin content is being transferred to high biomass sorghum lines. Nineteen BC1F1 varieties were generated in the 2013-2014 post rainy season by backcrossing the 19 crosses developed between high biomass lines and low lignin (*bmr*12) sources with the recurrent parents. Four BC3F1 were generated.Three BC3F1 with *bmr* 12 allele were confirmed genotypically and advanced to BC3F2 and BC4F1 generations.
- The entry (CSV 15 × IS 21891-1-1-1) × (HC 260 × B 35-2-1-1-1) recorded highest dry biomass yield with brown midrib background.
- Seeds of promising high biomass sorghum entries, ICSV 25333, IS 18542, ICSSH 28, CSH 13 and CSH 22SS have been multiplied in post-rainy season of 2013-14 and supplied to partners and farmers
- Large-scale demonstration trials for identification of farmers preferred cultivars for dry stalk yield resulted in identification of ICSV 93046 and IS 18542 as best performing varieties in Gujarat and ICSSH 28 and ICSV 93046 were best performing varieties in Madhya Pradesh.

Pearl millet

- Pearl millet entries, IP 15564, IP 15535 and IP 10077 were selected for high dry stover yield with low lignin percentage.
- In high biomass pearl millet hybrid trials 1 and 2, dry biomass yields of five best performing hybrids were in the range of 14 - 17 t ha-1.
- In high biomass pearl millet population trials 1 and 2, dry biomass yields of five best germplasm accessions were in the range of 15 - 21 t ha-1.
- High biomass pearl millet germplasm accessions, IP-10437, IP-14294, IP-20409, and IP-14542 recorded dry stover yields of 13 t ha-1, IP 22269 recorded about 14 t ha-1, whereas IP-10151 and IP-15556 recorded 15 t ha-1.
- Seed of potential pearl millet hybrids yielding dry biomass of about 15-22 t ha^{-1} in MLT's have been identified and being multiplied.

Bamboo

- Twenty-bamboo germplasms were successfully established as mother plants for further studies at captive land in Modasa, Gujarat.
- *Bambusa balcooa, Dendrocalamus strictus, Bambusa vulgaris, Bambusa ventricosa, Phyllostachys nigra, Melocanna baccifera, Sasa fortuneii, Bambusa wamin, Sasa palmata and*

Achievements thus far

Bambusa multiplex f. variegate were selected for genetic variation studies using molecular approaches.

- *Bambusa balcooa* was found to be more diverse based on cluster and species relationship analyses.
- Bamboo vegetative propagation protocol was established based on PGR application with NAA and IAA at 200 ppm showing new shoots in vegetative propagation.
- Adaptation study of *Bambusa balcooa* has been initiated at three sites, namely Modasa, Khas and Vithalapara.
- Broad range salinity screening has been performed on all 20 bamboo accessions.
- Data collection and monitoring of growth from large-scale cultivation trial of *B. balcooa conducted* on the marginal lands of Lakshmipura (Khedbramha), Aakru (Botad) and Vadod (Limbdi) on farmer's fields are in progress.
- Good bamboo growth has been observed in Vadod, followed by Lakshmipura.

Work Package 2

- Comparative pretreatment experiments were conducted on sorghum biomass using steam explosion in combination with acid, alkali and alkaline peroxide with 10% solid loading and various operating conditions.
- Standardization of o-phosphoric acid pretreatment in pearl millet resulted in 72% lignin reduction, increased glucan content to 39%, xylan reduction to 19% and lowered the ash content by 8%.
- Saccharification of pretreated sorghum biomass resulted in cellulose conversion efficiency of 80% with 40 FPU Sacchari SEB enzyme per gram cellulose at 10% solid loading.
- Fermentation studies using an in-house *Pichia kudriavzevii yeast* strain was found to tolerate high temperatures (48°C) and showed tolerance to various inhibitors.
- The productivity of *Pichia stipitis* increased more than 200% and yielded more than 50% in adaptation studies for inhibitor tolerance in CSTR.
- *S. cerevisiae* consumed glucose rapidly and produced 97% ethanol yield, while *P. stipitis* showed rapid consumption of xylose with 90% ethanol yield.
- Mono and mixed culture fermentation studies were yield out on the simulated hydrolysate mimicking sorghum hydrolysate.
- Fermentation studies on alkali peroxide pretreated and saccharified sorghum biomass hydrolysate produced 15 -16 g/L ethanol.
- Co-fermentation of glucose and xylose by mixed culture of *S. cerevisiae* and *P. stipitis* showed complete glucose utilization at different concentrations.
- Seven potent fungal strains and an in-house xylanase producing bacterial strain showed FPase activity in the range of 19-30 FPU per gds in submerged and SSF fermentation studies.
- HPA-100 spiral wound nanofiltration module was found to concentrate glucose with minimum losses in permeate.
- Indigenous hydrophobic flat sheet membrane enriched ethanol with complete retention of sugars.
- Hybrid process of MBR + RO provided high reduction in COD with potential for low cost treatment of biomass wastewater treatment on industrial scale.
- Analysis of lignin content separated in the extraction process showed 70% recovery in preliminary lignin valorization studies.

Work Package 3

- Marginal target ecologies of Madhya Pradesh and Gujarat were surveyed for current crop practices, yields and market potentials to promote biofuel crops.
- Baseline economic data would be used to evaluate economics and yields of the biofuel crops in contrast to current productivity of crops and market potential.
- Baseline survey has been completed for Gujarat and Madhya Pradesh.
- On the basis of agricultural practices and local conditions, socio-economic and environmental indicators were developed and customized by interviewing key stakeholders such as universities, government departments and farmers to evaluate the certification processes.
- Life cycle analysis (LCA) data sheet has been created manually for the Indian scenario. Carbon emission and energy input / output LCA data sheet has been created and integrated for WP-1 and WP-2 work related aspects.
- A supply chain model is being developed based on the available village and taluka wise marginal lands for biofuel feedstock production and supply to optimum locations and process industries for maximum biomass supply.
- Biofuel crop production models are under development considering maximum resource utilization with integration of policies.

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JCERDC
News

India-U.S. **Energy Dialogue**

11th March 2014, India

The **India-U.S. Energy Dialogue** was held in New Delhi on 11th March 2014. The Dialogue was co-chaired by Dr. Montek Singh Ahluwalia, Deputy Chairman of the Planning Commission, and Dr. Ernest Moniz, Secretary, U.S. Department of Energy. The Energy Dialogue was part of the broader India-U.S. Strategic Dialogue. The Energy Dialogue was launched in May 2005 with the last meeting held in September 2012 in Washington DC. Secretary Moniz led the U.S. delegation comprising of senior officials from the Department of Energy and various national laboratories. India and the United States affirmed that both countries had a strong commitment to collaborating on energy and promoting greater technological innovation, scientific collaboration, trade, research and development, deploying environment friendly technologies and products, and promoting sound regulatory frameworks to deliver energy solutions for sustainable growth.

Officials from the two sides held meetings from 5th March to 11th March, 2014, and reviewed the full range of cooperation under the U.S. – India Energy Dialogue. The Co-chairs of the dialogue, Dr. Ahluwalia, and Secretary Moniz discussed progress made by the working groups in renewable energy and new technologies, cooperation in shale gas, LNG imports, energy efficiency and low carbon technologies. The joint consortia members from the Indo-U.S. Joint Clean Energy Research and Development Center (JCERDC) also presented their progress in solar, advanced bio-fuels, and energy efficiency research projects under PACE-R, a unique program for funding joint research by Indian and US institutes. In their concluding remarks, the two co-chairs expressed satisfaction at the progress made in the energy sector through the co-operative process. They directed the members of the Working Groups to continue their efforts, especially in the newer areas of mutual interest.

India-U.S. **Technology Summit**

18-19 Nov., 2014, India

The robust partnership between India and the United States in science, technology and innovation has benefited both countries immensely. Our collaboration has been vital in achieving shared goals, including creating economic growth and jobs, helping people live longer and healthier lives, finding solutions to challenges affecting both societies and with global benefits. In November 2014, the Confederation of Indian Industry and the Indian Department of Science & Technology partnered with the United States for the **20th Technology Summit and Technology Platform.** The event was held from 18th to 19th November, 2014 in India. The objectives of India-U.S. Technology Summit were to provide a platform for industries, institutions and government agencies from India and the United States to exchange ideas and showcase their expertise; forge new partnerships to increase trade and investment in the knowledge sector; and, bring together leaders from all sectors – government, industry, research, and academia – for high level policy discussions.

Under the aegis of the Technology Summit, IUSSTF organized a Roundtable Discussion on Collaborative R&D in Clean Energy. Keeping in mind the fact that science and technology have since long been an important cornerstone of cooperation between India and the United States; both nations recognize the fact that further collaboration can and would enhance our shared understanding of the planet's climate by expanding efforts to develop new programs to meet environmental and climate challenges. The **Roundtable discussion on Collaborative R&D in Clean Energy** was built on the successful Indo-U.S. Joint Clean Energy Research and Development Center (JCERDC) as a starting point. The activities of the JCERDC would contribute greatly to the sustainability and prosperity of not only our two countries but the world at large by helping diversify energy supply and accelerate the transition to a low-carbon economy.

The session began with invited speakers from India and the United States sharing their views on the importance of collaboration and identifying key areas of mutual benefit. This was followed by the principal investigators of the three JCERDC Projects – Solar Energy, Second Generation Biofuels and Energy Efficiency of Buildings – sharing their experiences about the program and their respective projects.

The Lead Principal Investigators of the **Solar Energy Research Institute for India and the United States** (SERIIUS) project – Prof. Kamanio Chattopadhyay (Indian Institute of Science, Bangalore) and Dr. David Ginley (National Renewable

Energy Laboratory, Golden) – described the work carried out by SERIIUS. This includes fundamental and applied research, analysis and assessment, outreach, and workforce development through specific bi-national projects in three Research Thrusts: Sustainable Photovoltaics; Multiscale Concentrated Solar Power; and, Solar Energy Integration. Prof. Ashok Gadgil (Lawrence Berkeley National Laboratory) and Prof. RajanRawal (CEPT University-Ahmedabad) presented the progress of the ***U.S.-India Joint Centre for Building Energy Research and Development*** (CBERD) project. The consortium conducts collaborative research and promotes clean energy innovation in the area of energy efficiency in building with measurable results and significant reduction in energy use in both nations. CBERD focuses on the integration of information technology with building controls and physical systems for commercial/high-rise residential units. The ***U.S.-India Consortium for development of Sustainable Advanced Lignocellulosic Biofuel Systems*** works on sustainable feedstock cultivation and supply, biochemical conversion technologies for production of second generation biofuels with minimal environmental impact, and analysis of overall sustainability and supply chain of feedstock. The progress of this consortium was presented by the Principal Investigators Prof. Ahmed Kamal (Indian Institute of Chemical Technology-Hyderabad) and Prof. Pratap Pullammanappallil (University of Florida-Gainesville).

After this the session moderator, Dr. Satish Kumar (Energy Efficiency Ambassador - Vice President, Schneider Electric, Global Operations, and, Chairman, Alliance for Energy Efficient Economy) opened the floor for a discussion. The roundtable participants deliberated upon several issues that included the vision to continue research collaboration under current JCERDC beyond its tenure; additional priority areas in clean energy for bilateral engagement; mechanisms to strengthen engagement with various stakeholders including industry; success of JCERDC model (multi-institutional network projects using a public-private partnership model of funding); ways to economically incentivize technology transfer; means to improve technology leapfrog capability; financing options; and, policies and programs for faster deployment of technologies.

Way Forward

Keeping in mind the fact that science and technology have since long been an important cornerstone of cooperation between India and the United States, both nations recognize the fact that further collaboration can and would enhance our shared understanding of the planet's climate.The activities of the Indo-U.S Joint Clean Energy Research and Development Center would contribute greatly to the sustainability and prosperity of not only our two countries but the world at large by helping diversify energy supply and accelerate the transition to a low-carbon economy.

IUSSTF

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