Energy and Environment Research Initiative

Indian Institute of Technology Kanpur
Launched by

The Honourable Prime Minister

Dr. Manmohan Singh

ON

3rd July, 2010
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Grid connected Solar-PV
Off-grid Solar-PV (islanded)
It is a proud moment for us at the Institute as we make a deliberate move towards research and technology development in all aspects of solar energy - its conversion, and utilization. Our faculty has made individual contributions towards improving device efficiency, new materials, thermal management, power electronics, and energy storage. Considerable effort is on towards developing non-silicon based organic solar cells. Faculty from the management studies have shown that a solar-enabled campus would earn significant carbon credits on one hand, while a solar charging station can transform the evening markets of the neighboring villages. While I laud all of the progress, what I find noteworthy is the spirit of collaboration that characterizes the solar initiative being launched on 3rd July 2010.

The plan of developing a comprehensive solar power plant as a technology demonstrator that will ultimately serve as a research station is truly exciting. Design and installation of a solar plant represents challenges in system integration, calling for expertise at the highest level of engineering. I am delighted to see scholars from a variety of disciplines embark on this monumental task. Our experience will, indeed, be in the public domain – be it in the form of design, selection, or models. The service provided by this activity to the society is immeasurable.

It will be a delight to see the solar energy research initiative emerge as a success story of IIT Kanpur.
World over, it is clear that energy and environment have become the focus of research. In our country, the stakes are higher as we need to ensure the energy requirement for industrial growth while preserving our surroundings. National Missions of Renewable Energy and the National Plan for Climate Change are steps in the right direction. The role of technology institutions such as ours is central to the discussion. IIT Kanpur has earned credits in areas such as biofuels, photovoltaics, and power electronics on one hand and energy markets policy, arsenic removal from drinking water and chemical and biological sensors, on the other. The time is right to advance our effort to a new level. We have brought together two multidisciplinary teams – the Solar Energy Research Enclave and the Center of Environmental Science and Engineering to take on the challenge.

The Solar Energy Research Enclave will conduct high quality research, build competence through technology demonstrators, thereby providing knowledge base and technology leverage to the Indian industry that aspires to be globally the best. Today, we are honored to have our Honorable Prime Minister, Dr. Manmohan Singh who will be launching the interdisciplinary initiative on Solar Energy – our humble contribution to the Jawaharlal Nehru National Solar Mission.

I wish the mission total success in all its endeavors.
TRACKER WITH HIGH EFFICIENCY TRIPLE JUNCTION SOLAR CELL IN CONCENTRATION MADE
SUPPORT

- Ministry of New and Renewable Energy
- Department of Science and Technology
- Council of Scientific and Industrial Research
- Ministry of Environment and Forests
- UNICEF
- Engineers India Limited
- Norwegian Institute for Air Research
- Japan International Cooperation Agency
- National Resource Centre, Ministry of Rural Development
- Indo-U.S. Science and Technology Forum
- HHV Solar
- Defence R & D Organisation
- Moserbaer Photovoltaic
- Reliance Industries Limited, Solar Group
- Bergen Electronics
- Tata BP Solar
- Sinsil International
- Corus Technology BV, The Netherlands
- National Mission on Power Electronics Technology, DIT
- CDAC, Trivandrum
- WBREDA, Kolkata
- Planning Commission
- University of Cambridge, Cambridge (UK)
- Asian Institute of Technology (AIT), Thailand
- United Nations University/Institute for Advanced Studies (UNU/IAS), Tokyo
- World Bank

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Solar Energy Research Enclave
The challenge to meet increasing demand of energy amidst energy shortages and concerns for local and global environment has attracted attention of technologists as well as policy makers. With the gradual depletion of fossil fuels, renewable energy sources particularly the solar and wind energy have gained the spotlight. Most part of India are relatively well endowed with solar energy. While the solar energy is virtually unlimited, conversion of solar energy to readily usable form is yet to become commercially viable. Furthermore, reliable solar technology has to be complemented by energy storage system to accommodate the daily and seasonal variations in the solar energy. Expertise in power electronics is crucial to develop efficient and responsive grid interaction, and interface various electrical components. Adoption of renewable energy including solar energy resources is influenced by economic, policy and regulatory aspects governing the same. IIT Kanpur has undertaken a multidisciplinary approach to strengthen ongoing research and initiate research on new and challenging areas of solar energy development. Towards this end, the institute is setting up a Solar Energy Research Enclave, which would include a solar photovoltaic technology demonstrator with various modular component and associated laboratories. These facilities would serve as a research platform to address the future energy needs of the nation.
Our objectives are:

a) To establish a modular multi-technology demonstrator 1 MW (peak) solar power station in two phases.
   - It will supplement electricity requirement of IITK campus during day time (8 hrs) and thus help in reducing dependence on grid power.
   - This will also generate useful data for future implementation of such projects in the region.
   - Modules in the solar power station will be used for research and as test platforms for large scale solar energy technologies.

b) To initiate new and augment the existing programs for long term research & development in solar power generation, storage, distribution, management and policy making at the institute.

c) To provide practical input for graduate and undergraduate teaching programs.

d) To serve as a regional nodal centre for promoting research in solar energy.

e) To assist policy and regulatory process governing renewable energy particularly solar energy.

f) To develop outreach and capacity building programs to meet the growing demand for skilled human resources.

g) To increase the awareness of green technologies amongst the public.

Being a developing country with a huge burden of fuel import, the need of solar energy research and development in India cannot be over-emphasized. The geographical location of India is also quite favorable for solar energy implementation. However, a densely populated country like India, with a fragmented electricity market, poses endless challenges to the scientists and entrepreneurs. The nature of Indian electricity market is also quite unique, and cannot be compared directly with other countries. Unlike USA or Japan, India has numerous villages and islands unconnected from the main grid, spatial and seasonal variation in agricultural demand, and cottage- to large-scale industrial sectors. Our country, therefore, requires solar energy development at different scales such as, small (~W) to large (~MW), grid-connected to islanded, supplemented with some energy-storage to no-storage capabilities. Also important is the hybridization of solar energy with other renewable sources.

Considering this socio-economic scenario, the present state of solar energy technology in India stands far from being adequate, but several initiatives are being planned. On 30th June 2008 the Prime minister of India, Dr. Manmohan Singh, announced the National Plan for Climate Change. This includes a National Solar Mission to “significantly increase the share of solar energy in the total energy resources while recognizing the need to expand the scope of other renewable and non-fossil options such as nuclear energy, wind energy, and biomass”. To contribute to the National Solar Mission, a broader inter disciplinary group, Solar Energy Research Enclave, is formed at the institute level aiming to develop short and long term technology in the area of power electronics component and system design, solar energy materials, supplementary energy storage and conversion devices and policy. The Ministry of New & Renewable Energy has consented to support solar energy research at IIT Kanpur on a large scale. This includes work on organic photovoltaics and creation of a centre that addresses research and education issues.
To achieve seamless integration of grid-connected and autonomous micro-grids within the overall national energy map as well as to incorporate various modes of renewable energy sources, a new paradigm in energy distribution is conceptualized and actively spearheaded by IIT Kanpur. A research project, sponsored by the National Mission on Power Electronics Technology (NaMPET) under the aegis of the Department of IT, Government of India, is underway to establish a delivery system for a remote island village (see graphic below), in collaboration with CDAC, Trivandrum and WBREDA, Kolkata.

Specifically, a universal front-end converter has been researched and its hardware and controls designed at IIT Kanpur for coupling solar PV, wind and bio-mass generation and battery storage on a common AC micro-grid. Schemes to synchronize this micro-grid to the utility supply are being investigated to form a holistic model for remote, rural, semi-urban and urban locations.

The hardware has been subsequently engineered and fabricated at CDAC, Trivandrum and is being installed at site by WBREDA. A 30 kW grid-connected variant (see inset for photograph) of this solution for rooftop PV is successfully operational since February 2010 at the WBREDA headquarters in Salt Lake, Kolkata.
It is initially proposed to have about 500 kW (peak) Solar Power Plant at Shivli, IIT Kanpur. The salient features of the proposed power plant are as follows:

- Facility to test different solar energy technologies.
- The architecture will facilitate research.
- It will provide a learning platform for setting up new plants.
- It will augment the power needs of IITK and grid.

The power plant will have 10 modules of 50 kW (grid connected) and a 5 kW module of test bed as shown in the figure below. Each module will have energy meters and will be connected to the 11 kV bus through interface transformers.

Proposed Power Plant Architecture at Shivli, IIT Kanpur
INNOVATIONS IN PHOTOVOLTAIC TECHNOLOGY

Photovoltaic or PV in short, is a solar power technology that uses solar cells or solar photovoltaic arrays to convert light directly into electricity with no emission of dangerous gases and with least amount of industrial waste. The main issue with the technology is its affordability. Intense R&D efforts are being made world over to find new materials, processes, and device structures to increase power conversion efficiency of basic unit of solar cell so as to bring down cost of solar generated power. At IIT Kanpur, we are working toward this end.

Among the various solar PV technologies, silicon is the dominant one. Almost 90% of solar cell modules presently used are made of silicon. We at IITK have been working in silicon devices for a long time. We have the working lab for silicon device design, device simulation, processing and fabrication. Large numbers of B.Tech., M.Tech. and Ph.D. students completed their theses in this area. A number of sponsored projects on the development of different silicon devices have been undertaken and completed successfully. The state of the art PIN, Quadrant, APD have been developed and proto-types have been delivered to the sponsoring agencies. PIN for hard X-ray radiation has been developed and delivered to sponsoring agency and the technology has been transferred to a manufacturing unit. The technology of High Voltage bipolar transistor, high voltage diode (>1000V) with reduced storage time has been developed. Photographs of processing facility and devices developed are shown here.

We have hands-on experience in various silicon processes for different device fabrication. These processes are mostly used for developing high efficiency silicon solar cells. Our initial objective is to develop small area high efficiency (>20%) silicon solar cells. Besides giving a pathway to the development of large area high efficiency silicon solar cells, these devices are particularly suitable for application in moderate level of concentration (100X). A 2-D tracker with high efficiency (34%) small area triple junction solar cells in concentration mode has been installed and monitored on line at IITK.
The manufacturing of III-V and silicon solar cell is expensive due to the high capital and processing cost. Several thin film technologies have demonstrated lower cost of manufacturing; however, they suffer from low efficiencies (5%-8%). A lower Rs./Watt-peak is critical for mass adoption of solar photovoltaic. In order to drive the Rs./Watt-peak metric lower, both high efficiencies and low cost processing are needed. Polymer solar cell is one of the emerging technologies with lots of prospect of low cost manufacturing. We have been working in polymer solar cells for quite some time under various sponsored projects. We have established the integrated facility for processing small area polymer solar cells. A picture of the facility is shown here.

Polymer solar cells of about 4% efficiency have been developed in our Labs. Solar cell modules on 5x10 cm$^2$ area have also been developed. These devices and modules are stable for about 12 months. The stability is as good as achieved in state of the art devices elsewhere. Presently, these modules are capable of driving small electronic gadgets like calculator, watches and LEDs etc.

Over the years, we have gained enough experience in organic small molecules and polymer large molecules material processing for device fabrication. A number of organic materials have been synthesized in our labs. Further research and development efforts will be made to improve efficiency, lifetime, and synthesize better organic materials to reduce cost as to suit the technology for general usages. We plan to develop large area polymer solar cells on flexible substrates like metal foils and polythene sheets. This will lead to roll to roll solar cell process and thus reducing and bringing the cost of electricity generation from solar cells to grid parity.
Traditionally, batteries are the storage technology that is considered for back up power. In a battery, the electrical energy is stored using a chemical redox couple, which is the fuel for the battery, is usually in the solid form and are enclosed along with an ion conducting electrolyte. The battery life is determined by the number of charge-discharge cycles and the entire unit (redox couple/electrolyte) needs to be replaced after certain number of cycles. In contrast to this approach, it is possible to have electrical storage devices in which the chemical redox couple (i.e. the fuel) are supplied continuously, and such devices are called fuel cells.
Two central factors that determine the quality of an energy storage device are the power density and the energy density. While these two factors are comparable for batteries and fuel cells (see figure), the periodic replacement of the storage unit is not necessary for a fuel cell. Due to this and other factors, there has been a resurgence of interests in fuel cell technology as a potential replacement for batteries, especially when the back up requirement is quite large. Some solar PV farms already have fuel cell technology as the energy back up device. Depending on the nature of the fuel and the nature of the ion conducting electrolyte, a variety of fuel cell configuration is possible as shown here.

**Storage technologies demonstrations, research and development**

We plan to demonstrate an energy storage system comprised of polymer electrolyte membrane fuel cell, solid oxide fuel cell system and integrated with the fuel generation unit and the PV modules.

The research development efforts are in the following areas:

a) Indigenous membrane development: We have developed and patented a membrane that can serve as the replacement for one of the most expensive component of the PEMFC-the Nafion membrane. The developed membrane is also very effective in a PEM electrolyser and can generate hydrogen from water very efficiently.

b) Control and dynamic modulation of fuel cell voltage: One of the major challenges in fuel cell is its generating a time invariant voltage. The complicated catalytic and transport processes also increase the time constant for voltage variation. We are working on novel methods to generate steady voltages and modulate cell voltage dynamically.

c) Fuel cells operating on renewable fuels: A major research and development emphasis is on development of energy conversion devices that can convert the renewable fuels like bio-diesel to electrical power. We are pursuing the development of solid oxide fuel cells that can enable this.

d) Cost and efficiency: Methods to increase efficiency and decrease costs like novel methods of catalysts deposition, thermal control and water hydration of stacks are also being pursued.
Economics, Policy and Regulatory issues influence the development of energy sector including renewable energy. Economic behaviour of consumers as well as producers response could be influenced by the policy and regulatory initiatives. Investment in the sector is often guided by conditions as well as the risk-adjust return the investors expect to make. The economic and policy analysis would assist policy makers in choosing appropriate set of options on the basis of economic efficiency while being able to achieve the desired objectives.

The traditional approach to promote renewable energy resources include fiscal incentives, feed-in-tariff, renewable portfolio obligations. Market-based approach like the Renewable Energy Certificate (REC) enhances participation and brings economic efficiency. The National Mission on Enhanced Energy Efficiency proposes to introduce a ‘Perform, Achieve and ‘Trade’ (PAT) mechanism to help achieve targets under the National Action Plan on Climate Change (NAPCC). It is also important to set out a strategy to achieve the objectives under the Jawaharlal Nehru National Solar Mission at the least public cost.

Economic, policy and regulatory issues that have been analysed include the following

- Power sector Reform and Regulation
- Renewable Energy Certificates
- Climate Change and the Indian Power Sector
- Renewable Energy and Rural Electrification
- Policy and Regulatory Environment and Investment in the Power Sector
- Power Market Development
- Economics of Iran-Pakistan-India Natural Gas Pipeline
- Economics of Nuclear Power for India
- Informal Market for Electricity
- Performance Analysis of Electric Distribution Utilities
- Financing India’s Infrastructure Sectors

Policy / Regulatory Contributions:

- Member, Working Group on Power for the 11th Five-Year Plan (Sub-groups on Policy and Regulatory Issues and Financial Issues), Planning Commission, Government of India.
- Member, State Advisory Committee, UP Electricity Regulatory Commission.
### Strategy for Policy Implementation: Policy on Agricultural Pump Sets

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TERI - GRIHA Award
Centre for Environmental Science and Engineering
India’s rapidly growing economy and development of industry, infrastructure, and transport sectors pose greater human and ecological health challenges leading to depletion of environmental resources. With the specific objective of integrating the engineering science, medicine and biology to address environmental issues, IIT Kanpur has taken the initiative to create a research center for environmental science and engineering (CESE). This Center will bring together experts from various disciplines to focus on providing solutions to specific environmental problems as also to environmental health issues. The CESE has been generously funded from the MPLAD scheme of Government of India.

**CESE Mission: Technology Development for Cleaner Environment**

The Centre for Environmental Science and Engineering is to carry out high quality interdisciplinary research, leading to technology development and competency building in various areas related to environmental problems, thereby providing solutions to Indian industry, medical professionals and policy makers.
OBJECTIVES

**Sensor Technology**
Sensors for efficient and quick in situ detection of environmental analytes.

**Pollution Control**
High performance filters and membranes, new catalysts and adsorbents. Cleaner processes and environmental considerations in product-design.

**Human Health**
Impact of environmental pollution on human health.

**Alliances**
Tripartite relationship between industry, academia and government agencies.

**CESE: Concept and Organization**
This facility of national importance is meant to focus on the research in various realms of environment i.e. air, water, and the impact of human interference with the objective of solving problems. There are several features like eco friendly products in construction, energy efficient features and power saving sensors. Use of non-conventional energy sources (solar), passive cooling techniques and proper landscaping are the basic features of the building. The building is designed to be environment friendly. It is heartening to note that the building has been rated as a five star based on the parameters of green features under TERI –GRIHA (Green Rating for Integrated Habitat Assessment) System. Specifications for the building were specially prepared so that building is certified as a green building. A very stringent quality control and assurance mechanism was introduced to ensure energy savings and environmental friendliness of the building.
There are ten laboratories at the CESE which are equipped with state-of-the-art equipment and instrumentation. These laboratories are: basic chemical analysis, sample preparation, biology and health effects, prototype fabrication, remediation technologies, trace level diagnostics, sensors and device fabrication, library and outreach and data analysis. The laboratories are equipped to develop technologies and analysis of organics and inorganic at trace levels.

Basic Chemical Analysis Lab
Biology and Health Effects Lab
Trace Level Diagnostics Lab
Trace Levels Diagnostics Lab
Sensor Technology Lab
Remediation Technology Lab
CURRENT PROJECTS AND TECHNOLOGY DEVELOPMENT

The current research projects at the CESE:

- Removal and recovery of pharmaceutical compounds from effluent by micro/nano polymerized (carbon) bead
- Development of carbon nano-fibre for arsenic removal from wastewater
- Immobilization of arsenic in ground water of Kanpur area
- Chromium and cadmium removal from waste studies on the removal of arsenic and fluoride from ground water using low cost adsorbents
- Development and demonstration of nano-sized TiO2-based photocatalytic oxidation technology for controlling VOCs
- Long-term risk assessment of benzene, toluene and xylene exposure in CNG and non-CNG-fuelled cities: A biomarker and PBPK model study
- Preparation, evaluation of electrospun biopolymeric nanofiber membrane for treatment of As contaminated drinking water
- Fabrication and evaluation of domestic defluoridation units using smart novel biopolymer composite
- Effects of As exposure on health, focused on pregnancy outcome & child development, and mechanism of arsenic GWC contamination in the Ganges Medium Basin in India
- Sensors for early disease detection

**Nano-sized particle TiO2 Photocatalytic Reactor for VOC Decontamination**
The prestigious Green Globe Foundation Awards (GGFA) are given to honor organizations and individuals that have made an extraordinary contribution to making our environment a much greener place. The Centre for Environmental Science and Engineering, IIT Kanpur bagged this year’s GGFA in the category Best Practices in Green Design and Architecture.

Green Globe Foundation Award
From Left to Right (1st row) Nishith Verma, Raj G. Pala, Tarun Gupta, Raghbir S. Anand, Partha S. Sensarma, Mukesh Sharma, B. M. Shukla, Phoolchand Gond, Monica Katiyar


Not in picture: S. S. K. Iyer, Malay K. Das, Ashok Kumar, Nalini Sankararamakrishnan