AC 2008-386: STRATEGIC ENERGY DIRECTIONS - A CASE STUDY

Russel Jones, World Expertise LLC

Russel C. Jones is the founding president of the Masdar Institute of Science and Technology in Abu Dhabi, United Arab Emirates. His previous academic career included serving as a faculty member at Massachusetts Institute of Technology, department chair at the Ohio State University, dean of engineering at the University of Massachusetts at Amherst, academic vice president at Boston University, and president at the University of Delaware.

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Strategic Energy Directions – a case study

Russel C. Jones, Ph.D., P.E.
President, Masdar Institute of
Science and Technology
Abu Dhabi, United Arab Emirates

Abstract

As the world becomes more concerned about its reliance on oil as the primary source of energy, alternative energy is being explored more vigorously. At least one oil-rich country, Abu Dhabi in the United Arab Emirates, has recognized this trend and has made a strategic decision to broaden its energy activities to include alternative energy. One result of this decision is establishment of a high-level education institution to provide the human capacity to meet its technical needs in the alternative energy field.

Introduction

A combination of circumstances is leading to less reliance on petroleum products as the primary source of energy for the world: environmental concerns over global warming caused by greenhouse gas emissions; increased costs of oil; and the eventual depletion of the oil reserves. These driving forces have stimulated efforts at developing alternative energy sources – solar, wind, biomass, etc.

Oil rich countries have been slow to recognize that the demand and supply of their petroleum reserves is changing. At least one of the richest oil producing countries, sitting on some 10% of the proven reserves in the world, has recognized the impending developments and has chosen a strategic path forward. The emirate of Abu Dhabi in the United Arab Emirates (UAE) has taken action to invest a significant portion of its current oil revenues in developing alternative energy sources for the future.

The Masdar Initiative in Abu Dhabi is focused on developing alternative energy sources as an economic base for the future of the country. It includes the Abu Dhabi Future Energy Company, which is investing in exploiting current alternative energy technologies and the Masdar Institute of Science and Technology, which is developing graduate education and research programs to build human capacity for the future.

The Masdar Institute of Science and Technology is developing masters and doctoral programs, and research activities, relevant to alternative energy. It is to be housed in a green-zone new demonstration city which is designed for zero carbon emissions. This paper describes the plans for these developments, and the current status of implementation.

Masdar Institute

The Government of Abu Dhabi has established the Masdar Institute of Science and Technology to meet the exceptional and progressive goal of transforming its economy from one based on petroleum to one focused on sustainable technology and renewable energy. This new, private graduate Institute positions Abu Dhabi to make an historic transformation and to become a knowledge hub for global innovation.

Developed with the support and cooperation of the Massachusetts Institute of Technology (MIT), the Masdar Institute of Science and technology (MIST) is an independent, not-for-profit, research-driven institution focused on science and technology. MIST will educate a workforce that will be prepared to compete in global markets and participate in research and development with an emphasis on alliances with global corporations and entrepreneurial opportunities.

MIT is assisting the Masdar Institute of Science and Technology in four integral areas: (1) joint collaborative research; (2) development of degree programs; (3) outreach that encourages industrial participation in research and development activities of MIST; and (4) support for capacity-building at MIST in terms of its organization and administrative structure, as well as scholarly assessment of potential faculty candidates for the Institute.

Curricula

When fully developed, MIST will offer ten degree programs. Currently five have been identified and developed: Engineering Systems and Management, Information Technology, Materials Science and Engineering, Mechanical Engineering, and Water and Environment. Master's degree programs will be offered starting in 2009, with doctoral degree programs offered starting in 2011.

Curricula have been developed to prepare graduates to pursue careers in the alternative energy and sustainability fields. Each program is designed to provide substantial technical depth as well as to provide the basis of understanding for current and future developments in energy.

Entering students will required to take ***preparatory courses*** prior to starting regular master's degree courses. These are courses held in summer prior to the start of each new academic year for new students. Students will be required to take two-three courses, depending on their backgrounds.

<u>Mathematical Methods for Engineers I</u>

Review of linear algebra, applications to networks, structures, and estimation, Lagrange multipliers, differential equations of equilibrium, Laplace's equation and potential flow, boundary-value problems, minimum principles and calculus of variations, Fourier series and Fourier integral transfer.

Probability and Statistics in Engineering

Quantitative analysis of uncertainty and risk for engineering applications. Fundamentals of probability, random processes, statistics, and decision analysis. Random variables and vectors, uncertainty propagation, conditional distributions, and second-moment analysis. Introduction to system reliability. Bayesian analysis and risk-based decision. Estimation of distribution parameters, hypothesis testing, and simple and multiple linear regressions. Poisson and Markov processes. Emphasis on application to engineering problems.

Introduction to Numerical Analysis

Basic techniques for the efficient numerical solution of problems in science and engineering. Root finding, interpolation, approximation of functions, integration, differential equations, direct and iterative methods in linear algebra. Knowledge of programming in Fortran, C, or Matlab helpful.

Introduction to Computers and Engineering Problem Solving

Fundamental software development and computational methods for engineering, scientific and managerial applications. Emphasis on object-oriented software design and development. Active learning using laptop computers (available on loan). Assignments cover programming concepts, graphical user interfaces, numerical methods, data structures, sorting and searching, computer graphics and selected advanced topics. The Java programming language is used.

Principles of Microeconomics

Introduces microeconomic concepts and analysis, supply and demand analysis, theories of the firm and individual behavior, competition and monopoly, and welfare economics. Applications to problems of current economic policy.

Introduction to Hydrology

Introduction to the global water and energy cycles and the earth system including the atmosphere, oceans, land, and biosphere. Fundamentals of hydrologic science and its applications. Covers bases for the characterization of hydrologic processes such as precipitation, evaporation, transpiration by vegetation, infiltration, and storm runoff. Understanding and modeling of groundwater flow, hydraulics of wells, and subsurface transport of pollutants. Probabilistic analysis and risk estimation for hydrologic variables.

Thermodynamics and Kinetics with Thermal-fluid Engineering II (combination)

Equilibrium properties of macroscopic systems. Basic thermodynamics: state of a system, state variables. Work, heat, first law of thermodynamics, thermochemistry. Second and third law of thermodynamics: entropy. Gibbs function, phase equilibrium properties of solutions. Chemical equilibrium of reactions in gas and solution phase. Rates of chemical reactions. Focuses on the application of the principles of thermodynamics, heat transfer, and fluid mechanics to the design and analysis of engineering systems. Laminar and turbulent flow. Heat transfer associated with laminar and turbulent flow of fluids in free and forced convection in channels and over surfaces. Pure substance model. Heat transfer in boiling and condensation. Thermodynamics and fluid mechanics of steady flow components of thermodynamic plants. Heat exchanger design. Power cycles and refrigeration plants. Design of thermodynamic plants. Radiation heat transfer. Multi-mode heat transfer and fluid flow in thermodynamic plants.

Each of the curricula includes two ***core courses***:

Sustainable Energy and one of the following:

Management for Engineers
Applications of Technology in Energy and the Environment
Systems Optimization

Sustainable Energy – 12 units

Assessment of current and potential energy systems, covering extraction, conversion and end-use, with emphasis on meeting regional and global energy needs in the 21^{st} century in a sustainable manner. Examination of energy technologies in each fuel cycle stage for fossil (oil, gas, synthetic), nuclear (fission and fusion) and renewable (solar, biomass, wind, hydro, and geothermal) energy types, along with storage, transmission, and conservation issues. Focus on evaluation and analysis of energy technology systems in the context of political, social, economic, and environmental goals.

Management for Engineers – 12 units

Provides an overview of management issues for graduate engineers. Topics approached in terms of career options as engineering practitioner, manager, and entrepreneur. Specific topics include semantics, finance, starting a company, and people management. Through selected readings from texts and cases, focus is on the development of individual skills and management tools. Requires student participation and discussion, and term paper. Limited to 25 graduate students.

Applications of Technology in Energy and the Environment – 12 units

Introduces advanced undergraduates or graduate students in the Schools of Engineering and Science to the integration of technical, economic, political, and environmental consideration required for the successful implementation of new technology. Case studies are drawn from the energy and environment sectors with some emphasis on analytic techniques that serve as a "tool box" for students. Technologies considered include fossil, nuclear, solar, wind, fuel cell and energy conservation. International aspects, such as weapons proliferation and global climate effects, also discussed.

Systems Optimization – 12 units

Application-oriented introduction to systems optimization focusing on understanding system tradeoffs. Introduces modeling methodology (linear, integer and nonlinear programming) and simulation methods, with applications in production planning and scheduling, inventory planning and supply contracts, logistics network design, facility sizing and capacity expansion, yield management, electronic trading and finance.

The five curricula developed to date follow:

Master of Science in Engineering Systems and Management

System Architecture – 12 units

Covers principles and methods for technical System Architecture. Presents a synthetic view including: the resolution of ambiguity to identify system goals and boundaries; the creative process of mapping form to function; and the analysis of complexity and methods of decomposition and re-integration. Industrial speakers and faculty present examples from various industries. Heuristic and formal methods are presented.

Product Design and Development – 12 units

Covers modern tools and methods for product design and development. The cornerstone is a project in which teams of management, engineering, and industrial design students conceive, design, and prototype a physical product. Class sessions employ cases and hands-on exercises to reinforce the key ideas. Topics include: product planning, identifying customer needs, concept generation, product architecture, industrial design, concept design, and design-for-manufacturing.

System Project Management – 12 units

Subject focuses on management principles, methods, and tools to effectively plan and implement successful system and product development projects. Material is divided into four major sections: project preparation, planning, monitoring, and adaptation. Brief review of classical techniques such as CPM and PERT. Emphasis on new methodologies and tools such as Design Structure Matrix (DSM), probabilistic project simulation, as well as project system dynamics (SD). Topics are covered from strategic, tactical, and operational perspectives. Industrial case studies expose factors that are typical drivers of success and failure in complex projects with both hardware and software content. Term projects analyze and evaluate past and ongoing projects in student's area of interest. Projects used to apply concepts discussed in class.

System Dynamics for Business Policy – 12 units

Introduction to system dynamics modeling applied to strategy, organizational change, and policy design. Uses simulation models, management "flight simulators," and case studies to develop conceptual and modeling skills for the design and management of high-performance organizations in a dynamic world. Case studies of successful applications of system dynamics in growth strategy, management of technology, operations, supply chains, product development, and others. Principles for effective use of modeling in the real world. Prerequisite for further work in the field.

Environmental Policy and Economics – 12 units

Explores the proper role of government in the regulation of the environment. Explore the tools necessary to estimate the costs and benefits of environmental regulations to evaluate a series of current policy questions, including: Should air and water pollution regulations be tightened or loosened? What are the costs of climate change in the US and abroad? Is there a "race to the bottom" in environmental regulation? Students help design and execute a cutting edge research project that tests whether air pollution causes infant mortality. Graduate students are expected to complete additional assignments.

Technology Strategy – 12 units

Outlines tools for formulating and evaluating technology strategy, including an introduction to the economics of technical change, models of technological evolution, and models of organizational dynamics and innovation. Topics covered include: making money from innovation; competition between technologies and the selection of standards; optimal licensing policies; joint ventures; organization of R&D; and theories of diffusion and adoption. Taught using a combination of readings and case studies.

Master of Science in Information Technology

Foundations of Software Engineering – 12 units

Modern software development techniques for engineering and information technology. Design and development of component-based software (using C# and .NET); data structures and algorithms for modeling, analysis, and visualization; basic problem-solving techniques; web services; and the management and maintenance of software. Treatment of topics such as sorting and searching algorithms; and numerical simulation techniques. Foundation for in-depth exploration of image processing, computational geometry, finite element methods, network methods and e-business applications.

Computer Systems Engineering – 12 units

Topics on the engineering of computer software and hardware systems: techniques for controlling complexity; strong modularity using client-server design, operating systems; performance, networks; naming; security and privacy; fault-tolerant systems, atomicity and coordination of concurrent activities, and recovery; impact of computer systems on society. Case studies of working systems and readings from the current literature provide comparisons and contrasts. Two design projects. Students engage in extensive written communication exercises. Enrollment may be limited. 4 Engineering Design Points.

Database, Internet & System Integration Technology – 12 units

Information technology fundamentals: software process, data modeling, UML, relational databases and SQL. Internet technologies: http, xhtml, XML, Web services. Introduction to security. Fundamentals of telecommunications. Students complete project that covers requirements/design, data model, database implementation, website, and system architecture. No prior programming experience required.

Integrating Information Systems: Technical, Strategic, and Organizational Factors – 12 units

Explores critical issues of communications and connectivity of global and internet-based information systems from strategic, technical, and organizational perspectives. Strategic connectivity: globalization and integration of information, competitive forces, interlinked value chains. Physical connectivity: protocols and technologies of local-area and wide-area, and internet communications networks. Logical connectivity: distributed databases, data extraction from web sites, semantic web, semantic reconciliation among heterogeneous sources. Organizational connectivity: loosely coupled organizations, development of standards, motivating strategic alliances.

Data Mining: Finding the Data and Models that Create Value – 12 units

Introducion to a class of methods known as data mining or machine learning that assist managers in recognizing patterns and making intelligent use of massive amounts of electronic data collected via the internet, e-commerce, electronic banking, point-of-sale devices, bar-code readers, and intelligent machines. Topics selected from logistic regression; association rules; tree-structured classification and regression; cluster analysis; discriminant analysis; and neural network methods. Examples of successful applications in areas such as credit ratings, fraud detection, database marketing, customer relationship management, investments, and logistics are covered. Introduction to data-mining software.

Generating Business Value from IT – 12 units

Provides concepts, frameworks, practice and evidence to help managers generate business value from information technology in their enterprises. Takes the strategic perspective of the general manager and studies how leading firms get more value from their IT investments. Focuses on the business value that can be achieved rather than the details of the technology. Topics include business operating models; IT portfolios; IT investment and justification; business strategy and IT alignment; IT infrastructure; IT architecture and IT governance. Draws heavily on research and case studies from MIT Sloan Center for Information Systems Research. Restricted to graduate students.

Master of Science in Materials Science and Engineering

Mathematical Methods for Materials Scientists and Engineers – 12 units

Mathematical techniques necessary for materials science and engineering topics such as energetics, materials structure and symmetry, materials response to applied fields, mechanics and physics of solids and soft materials. Mathematical concepts and materials-related problem solving skills. Symbolic algebraic computational methods, programming, and visualization techniques. Topics include linear algebra, quadratic forms, tensor operations, symmetry operations, calculus of several variables, eigensystems, introduction to complex analysis, systems of ordinary and partial differential equations, phase plane analysis, beam theory, resonance phenomena, special functions, numerical solutions, statistical analysis, Fourier analysis, and random walks.

Thermodynamics and Kinetics of Materials – 12 units

Laws of thermodynamics applied to materials and materials processes. Solution theory. Equilibrium diagrams. Kinetics of processes that occur in materials, including diffusion, phase transformations, and the development of microstructure.

Mechanical Properties of Materials / Electrical, Optical, and Magnetic Properties of Materials – 12 units

Electrical, optical, magnetic, and mechanical properties of metals, semiconductors, ceramics and polymers. Discussion of roles of bonding, structure (crystalline, defect, energy band and microstructure) and composition in influencing and controlling physical properties. Case studies drawn from a variety of applications including semiconductor diodes, optical detectors, sensors, thin films, biomaterials, composites, and cellular materials.

Atomistic Computer Modeling of Materials – 12 units

Theory and application of atomistic computer simulations to model, understand, and predict the properties of real materials. Energy models: from classical potentials to first-principles approaches. Density-functional theory and the total-energy pseudopotential method. Errors and accuracy of quantitative predictions. Thermodynamic ensembles: Monte Carlo sampling and molecular dynamics simulations. Free energies and phase transitions. Fluctuations and transport properties. Coarse-graining approaches and mesoscale models.

Mechanical Behavior of Polymers – 12 units

Influence of processing and structure on mechanical properties of synthetic and natural polymers: Hookean and entropic elastic deformation, linear viscoelasticity, composite materials and laminates, yield and fracture.

Fabrication Technology – 12 units

Discusses a wide variety of technologies including welding, brazing, soldering, casting, forging and non-destructive testing, especially as related to ship building and heavy fabrication. Emphasis on the underlying science of a given process rather than a detailed description of the technique or equipment.

Master of Science in Mechanical Engineering

Advanced Fluid Mechanics – 12 units

Survey of principal concepts and methods of fluid dynamics. Mass conservation, momentum, and energy equations for continua. Navier-Stokes equation for viscous flows. Similarity and dimensional analysis. Lubrication theory. Boundary layers and separation. Circulation and vorticity theorems. Potential flow. Introduction to turbulence. Lift and drag. Surface tension and surface tension driven flows.

General Thermodynamics – 12 units

General foundations of thermodynamics from an entropy point of view, entropy generation and transfer in complex systems. Definitions of work, energy, stable equilibrium, available energy, entropy, thermodynamic potential, and interactions other than work (nonwork, heat, mass transfer). Applications to properties of materials, bulk flow, energy conversion, chemical equilibrium, combustion, and industrial manufacturing.

Advanced Heat and Mass Transfer – 12 units

Advanced treatment of fundamental aspects of heat and mass transport. Topics covered include: diffusion kinetics, conservation laws, laminar and turbulent convection, mass transfer including phase change or heterogeneous reactions, and basic thermal radiation. Problems and examples include theory and applications drawn from a spectrum of engineering design and manufacturing problems.

Fundamentals of Advanced Energy Conversion – 12 units

Fundamentals of thermodynamics, chemistry, flow and transport processes as applied to energy systems. Analysis of energy conversion in thermomechanical, thermochemical and electrochemical processes in existing and future power and transportation systems, with emphasis on efficiency, environmental impact and performance. Systems utilizing fossil fuels, hydrogen, nuclear and renewable resources, over a range of sizes and scales are discussed. Applications include fuel reforming, hydrogen and synthetic fuel production, fuel cells and batteries, combustion, hybrids, catalysis, supercritical and combined cycles, other direct energy conversion processes, photovoltaics, and modes of energy storage and transmission. Optimal source utilization and fuel-life cycle analysis.

Nano-to-Macro Transport Processes – 12 units

Parallel treatments of photons, electrons, phonons, and molecules as energy carriers, aiming at a fundamental understanding of descriptive tools for energy and heat transport processes from nanoscale to macroscale. Topics include the energy levels, the statistical behavior and internal energy, energy transport in the forms of waves and particles, scattering and heat generation processes, Boltzmann equation and derivation of classical laws, deviation from classical laws at nanoscale and their appropriate descriptions, with applications in nanotechnology and microtechnology.

Fundamentals and Applications of Combustion – 12 units

Fundamentals and modeling of reacting gas dynamics and combustion using analytical and numerical methods. Conservation equations of reacting flows. Chemical thermodynamics and kinetics. Non-equilibrium flow. Detonation and boundary layers. Ignition, flammability, and extinction. Premixed and diffusion flames. Combustion instabilities. Supersonic combustion. Turbulent combustion. Fire, safety, and environmental impact.

Master of Science in Water and Environment

Chemicals in the Environment: Fate and Transport – 12 units

For Institute students in all departments interested in the behavior of chemicals in the environment. Emphasis on man-made chemicals, their movement through water, air, soil, and their eventual fate. Physical transport, as well as chemical and biological sources and sinks, are discussed. Linkages to health effects, sources and control, and policy aspects. Core requirement for Environmental MEng program.

Industrial Ecology – 12 units

Quantitative techniques for life cycle analysis of the impacts of materials extraction, processing use, and recycling; and economic analysis of materials processing, products, and markets. Student teams undertake a major case study of automobile manufacturing using the latest methods of analysis and computer-based models of materials process.

Groundwater Hydrology – 12 units

Fundamentals of subsurface flow and transport, emphasizing the role of groundwater in the hydrologic cycle, the relation of groundwater flow to geologic structure, and the management of contaminated groundwater. Topics include: Darcy equation, flow nets, mass conservation, the aquifer flow equation, heterogeneity and anisotropy, storage properties, regional circulation, unsaturated flow, recharge, stream-aquifer interaction, well hydraulics, flow through fractured rock, numerical models, groundwater quality, contaminant transport processes, dispersion, decay, and adsorption. Includes laboratory and computer demonstrations. Core requirement for Environmental and Geoenvironmental MEng program.

Desalination – 12 units

Introduces the fundamental science and technology of desalinating water to overcome water scarcity and ensure sustainable water supplies. Covers basic water chemistry; flash evaporation; reverse osmosis and membrane engineering; electrodialysis; applications of nanotechnology to desalination; solar desalination; energy efficiency of desalination systems; fouling and scaling; environmental impacts; and economics of desalination systems. Open to upper-class undergraduates.

Environmental Policy and Economics – 12 units

Explores the proper role of government in the regulation of the environment. Explore the tools necessary to estimate the costs and benefits of environmental regulations to evaluate a series of current policy questions, including: Should air and water pollution regulations be tightened or loosened? What are the costs of climate change in the US and abroad? Is there a "race to the bottom" in environmental regulation? Students help design and execute a cutting edge research project that tests whether air pollution causes infant mortality. Graduate students are expected to complete additional assignments.

Water Resource Systems – 12 units

Survey of simulation and optimization methods for management of water resources. Linear, nonlinear, and dynamic programming illustrated with case studies. Applications include reservoir and irrigation development, conjunctive use of surface and groundwater, capacity expansion, and sustainable resource development.

OR

Global Climate Change: Economics, Science and Policy – 12 units

Introduces scientific, economic, and ecological issues underlying the threat of global climate change, and the institutions engaged in negotiating an international response. Develops an integrated approach to analysis of climate change processes, and assessment of proposed policy measures, drawing on research and model development within the MIT Joint Program on the Science and Policy of Global Change.

Research initiation

Masdar Institute faculty members spend up to one year at MIT in Cambridge, Massachusetts, USA, working with their MIT counterparts on joint research projects and auditing graduate-level classes that they will teach in Abu Dhabi. By working at MIT, Masdar Institute faculty members are exposed to the culture and entrepreneurial spirit of the MIT community, which will be brought to bear on their Masdar Institute activities.

An initial group of MIST faculty members has spent their first year at MIT, developing courses which will be taught in Abu Dhabi and starting research projects in conjunction with MIT faculty members. Those collaborative research projects will then be transferred to Abu Dhabi when the MIST faculty members move at the end of their MIT periods. Following are the titles of projects undertaken by several of the MIST faculty members:

Power System Planning with Integrated Renewable Energy Sources

Objective: Modeling and analysis of distributed generation and micro-grid operation to assist in breaking down the barriers for widespread integration of renewable energy sources in distribution systems, while assuring safe, reliable, efficient, and cost effective operation of the distribution system.

Hybrid Solar Thermoelectric and Photovoltaic Energy Conversion

Objective: Development of hybrid system technology that combines photovoltaics with thermoelectrics to enhance the conversion of solar light into electric energy.

Semantics-Enabled Technology Forecasting: A Case Study on Alternative Energies

Objective: Investigation of the extraction of patterns and trends from science and technology information sources to support technology forecasting and the formulation of research strategies.

Hydrodynamics of Wave-Power Extraction

Objective: Development and analysis of mathematical models that describe the extraction of mechanical energy from sea waves and the allied problem of motion and safety of wave-energy absorbers.

Low-Energy Future for the Built Environment

Objective: Development of specific simulation tools, low-energy cooling technologies, and analysis methodologies that support the planning, construction, and operation of low-energy/low-carbon emission communities in Abu Dhabi and potentially other regions around the world.

Commercial Aviation in a Carbon-Constrained Future: Effective Technological, Operational, and Policy Responses

Objective: Analysis and modeling of the future for commercial aviation in a carbon-constrained environment via identification of the key leverage points for optimal system response that minimize carbon emissions, while maintaining a high level of service that allows the global economic system to operate.

Toward Very High-Performance Thin-Film Photovoltaic Cells: Designs and Implementation

Objectives: Design and implementation of thin-film photovoltaic (PV) devices, including: (1) high-efficiency thin-film Si solar cells with novel light trapping; (2) Ge-based thin-film thermophotovoltaic (TPV) cells with photon recirculation; and (3) A1GaAs/Si/Ge tandem solar cells for ultra-high-efficiency energy conversion.

Renewable Energy and Fuels from Waste: Thermochemical Pathways

Objective: Development of gasification technology to generate clean, renewable fuel or electricity from a wide variety of feedstock considered mostly as "waste."

A High-Efficiency and Environmentally Friendly Nuclear Reactor for Electricity and Hydrogen

Objective: Development of approaches for evolution of the design of water-cooled nuclear power plants to address future needs of electricity, drinkable water, and hydrogen through a highly efficient and environmentally friendly reactor (HEEFR).

Conclusion

In response to the human capacity building needs of Abu Dhabi and surrounding energy intensive countries, the Masdar Institute of Science and Technology has been established – a graduate level, research intensive institution focused on alternative energy and sustainability. MIST has developed five curricula for its initial master's level programs, to be offered starting on 2009, and has initiated faculty research programs which will form the initial thrust of its basic research initiative.

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Biography

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