M Sc
RENEWABLE ENERGY PROGRAMME

FACULTY OF SCIENCE
UNIVERSITY OF LUCKNOW (NEW CAMPUS)
LUCKNOW – 226 021

SYLLABUS (OLD)

SYLLABUS

Choice-Based Credit System

M Sc (RENEWABLE ENERGY)
FACULTY OF SCIENCE
UNIVERSITY OF LUCKNOW, LUCKNOW

YEAR – 1

SEMESTER – I

CORE SUBJECT	CREDIT				ELECTIVE SUBJECT	CREDIT			
	L	T	P	C		L	T	P	C
Module REC-101 : Combustion, Heat and Mass Transfer	4	-	-	4	**Module REE-101 :** Energy Sources, Scenario and Environment	3	-	-	3
Module REC-102 : Electrical Power Technology	4	-	-	4					
Module REC-103 : Solar Thermal Energy Conversion	4	-	-	4					
Module REC-104 : Solar Photovoltaic Energy Conversion	4	-	-	4					
Module REC-105 : Energy Laboratory I	-	-	4	4					
Total Credits – 23									

SEMESTER – II

CORE SUBJECT	CREDIT				ELECTIVE SUBJECT	CREDIT			
	L	T	P	C		L	T	P	C
Module REC-201 : Numerical Methods and Computational Techniques	4	-	-	4	**Module REE-201 :** Energy Economics Policy and Planning	3	-	-	3
Module REC-202 : Wind Energy Conversion Systems	4	-	-	4					
Module REC-203 : Bio-energy and Waste to Energy Conversion Systems	4	-	-	4					
Module REC-204 : Energy Management	4	-	-	4					
Module REC-205 : Energy Laboratory II	-	-	4	4					
Total Credits – 23									

YEAR – II									
SEMESTER – III									
CORE SUBJECT	**CREDIT**				**ELECTIVE SUBJECT**	**CREDIT**			
	L	**T**	**P**	**C**		**L**	**T**	**P**	**C**
Module REC-301 : Small Hydropower Conversion and other Renewable Energy Systems	4	-	-	4	**Module REE-301 :** Solar Photovoltaic Power Plants	3	-	-	3
Module REC-302 : Energy in Buildings	4	-	-	4					
Module REC-303 : Distributed Generation and Integration of Renewable Energy with Grid	4	-	-	4					
Module REC-304 : Energy Storage Systems	4	-	-	4					
Module REC-305 : Industrial Training and Field Visits	-	-	4	4					
Total Credits – 23									
SEMESTER – IV									
CORE SUBJECT	**CREDIT**				**ELECTIVE SUBJECT**	**CREDIT**			
	L	**T**	**P**	**C**		**L**	**T**	**P**	**C**
Module REC-401 : Hydrogen Energy and Fuel Cells	4	-	-	4	**Module REE-401 :** Carbon Foot Prints and Clean Development Mechanism	3	-	-	3
Module REC-402 : Energy Auditing and Conservation	4	-	-	4					
Module REC-403 : Energy Modeling and Project Management	4	-	-	4					
Module REC-404 : Energy Project (including Seminar and Viva)	4	-	-	4					
Module REC-405 : Energy Project Laboratory	-	-	4	4					
Total Credits –23									

***L –** Lecture, ***T –** Tutorial, ***P –** Practical, ***C –**Credit

M Sc (Renewable Energy) Semester I

REC-101

COMBUSTION, HEAT AND MASS TRANSFER (4 Credits)

UNIT I (12 Lectures)

Material balance involving chemical reaction, limiting component, excess reactant, conversion, selectivity and yield, energy in thermo chemistry, energy balance **(04 Lectures).**
Fuels, calorific values, combustion, Stoichiometry **(04 Lectures).**
Air requirement and flue gases, combustion calculation, Fluidized bed combustion process **(04 Lectures).**

UNIT II (13 Lectures)

Gas Power cycles: Carnot, Stirling, Brayton, Otto, Diesel and Duel cycles **(05 Lectures).**
Vapour power cycles: Rankine cycle and improvements **(03 Lectures).**
Refrigeration, dehumidification, Psychrometry **(03 Lectures).**
Role of thermodynamics in Energy conversion **(02 Lectures).**

UNIT III (13 Lectures)

Conduction, Fourier's law, General Equation of Heat Conduction; 1-D and 2-D steady conduction and unsteady conduction– analytical approach **(05 Lectures).**
Convection; Equations for mass, momentum and energy conservations; Natural convection; Internal and external laminar forced convection; Effect of turbulence on convective heat transfer **(04 Lectures).**
Basic principles and design of Heat Exchangers and heat pumps, Numerical approach to conduction and convection problems **(04 Lectures).**

UNIT IV (13 Lectures)

Introduction to Radiation, Black body radiation; Spectral and directional nature of surface radiation; Kirchhoff's law and gray surface approximation, Wein's displacement law **(03 Lectures).**
Solar spectrum high temperature measurement, radiation pyrometry, View factor; Radiation exchange between black and diffuse gray surfaces in an enclosure **(05 Lectures).**
Interaction of radiation with medium; Boiling and Condensation; Mass Transfer; Conservation of species equations **(05 Lectures).**

Books:

1. Nag P K, *Engineering Thermodynamics*, Tata Mc-Graw Hill, New Delhi.
2. Callen H B, *Thermodynamics and an Introduction to Thermostatistics*, John Wiley, Toronto.
3. Bejan, *Advanced Engineering thermodynamics*, John Wiley, Toronto.
4. Ghoshdastidar P S, *Heat Transfer*, Oxford.
5. Sukhatme S P, *A Text Book on Heat Transfer*, University Press.
6. Incropera F P, Dewitt D P, *Fundamentals of Heat and Mass Transfer*, John Wiley and Sons.

7. Sharma S P, Chander Mohan, *Fuels and Combustion*, Tata McGraw Hill Publishing Co. Ltd.
8. Sarkar Samir, *Fuels and Combustion*, Orient Longman.
9. Sharma B K, *Fuels and Petroleum Processing,* Goel Publishing, Meerut.
10. Goswami D Y, Kreith Frank, Kreider J F, *Principles of Solar Engineering*, Taylor and Francis, USA.
11. Tiwari, G N, *Solar Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.
12. Duffie J A, Beckman W A, *Solar Engineering of Thermal Processes*, John Wiley and Sons.
13. Garg H P et al, *Solar Thermal Energy Storage,* D Reidel Publishing Co. Alexiades,
14. Solomon A D, *Mathematical Modeling of Melting and Freezing Process*, Hemisphere Publishing Corporation, Washington.
15. Zemansky M W, *Heat and Thermodynamics,* McGraw Hill.
16. Gupta V, *Elements of Heat and Mass Transfer*, New Age International Publishers, New Delhi.
17. Holman J P, *Heat Transfer*, Mc Graw-Hill, London.
18. Bhatt ,Vora, *Stoichiometry*, Tata Mcgraw Hill.
19. Khartchenko Nikolai V Ed, *Advanced Energy Systems*, Taylor Francis Washington D.C.

REC-102

ELECTRICAL POWER TECHNOLOGY (4 Credits)

UNIT I (12 Lectures)

AC fundamentals: sinusoidal-average and effective values, form and peak factor, concept of phasors, phasor representation of sinusoidally varying voltage and current **(06 Lectures).**
Analysis of series, parallel, series-parallel RLC circuit, resonance in series and parallel circuits, bandwidth and quality factor, apparent, active and reactive powers, power factors, problems of low power factor, concept of power factor improvements **(06 Lectures).**

UNIT II (13 Lectures)

Three phase system–necessity and advantages, star and delta connections **(04 Lectures).**
Balance supply and balance load, line and phase voltage/current relation, three phase power and its measurements **(04 Lectures)**.
Single phase transformers: principle of operation, construction, EMF equation, equivalent circuit, power losses, efficiency **(05 Lectures).**

UNIT III (13 Lectures)

DC machines: types, EMF equation of generator and torque equation of the motor, characteristics and applications of DC motors **(04 Lectures).**
Three Phase Induction Motor: types, principle of operation, slip-torque characteristic, applications **(03 Lectures).**
Single Phase Induction Motor: principle of operation and introduction to methods of starting, applications **(03 Lectures).**
Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications **(03 Lectures).**

UNIT IV (13 Lectures)

Introduction to Power System: Transmission and Distribution **(03 Lectures).**
Power crisis in India, future trends, economic considerations, significance of load factor and diversity factor, selection of units, tariff, types of tariff, classification of cost **(05 Lectures).**
Classification sources of power, economic in generation, hydro-electric power plant, steam power plants **(03 Lectures).**
Basic concept of grid and smart grid **(02 Lecture).**

Books:

1. Toro V Del, *Principles of Electrical Engineering*, Prentice Hall International
2. Kothari D P, Nagarath I J, *Principles Electrical Engineering*, Tata McGraw Hill
3. Singh S N, *Basic Electrical Engineering*, Prentice Hall International
4. Sahay Kuldeep, *Basic Electrical Engineering*, New Age International Publishers
5. Khartchenko Nikolai V Ed, *Advanced Energy Systems*, Taylor Francis Washington D.C.
6. Hughes Edward, *Electrical and Electronics Technology,* Pearson
7. Hayt W H & Kimerly J E, *Engineering Circuit Analysis*, McGraw Hill
8. Wadhwa C L, *Basic Electrical Engineering*, New Age International
9. Nagsarkar T K, Shukhija M S, *Basic Electrical Engineering*, Oxford University Press

REC-103

SOLAR THERMAL ENERGY CONVERSION (4 Credits)

UNIT I (12 Lectures)

Solar radiation, its measurement and prediction **(03 Lectures).**
Solar angles, day length, angle of incidence on tilted surface; Sun-path diagrams **(03 Lectures).**
Shadow determination; Extraterrestrial characteristics; Effect of earth atmosphere **(03 Lectures).**
Measurement and estimation on horizontal and tilted surfaces; Analysis of Indian solar radiation data and applications **(03 Lectures).**

UNIT II (13 Lectures)

Effective energy losses; Thermal analysis; Heat capacity effect; Testing methods; **(03 Lectures).**
Evacuated tubular collectors; Air flat-plate collectors: types; Thermal analysis; Thermal drying **(03 Lectures).**
Ideal coating characteristics; Types and applications; Anti-reflective coating; Preparation and characterization **(03 Lectures).**

ASHRAE code; Modeling of solar thermal system components and simulation; Design and sizing of solar heating systems: f – chart method and utilizability methods of solar thermal system evaluation; Development of computer package for solar heating and cooling applications **(04 Lectures).**

UNIT III (14 Lectures)

Classification of solar concentrators; Collector configuration; Concentration ratio and thermodynamics limit of concentration **(02 Lectures).**
Solar concentrator mounting; Solar incident angle for different concentrator mounting; Thermal analysis of cylindrical parabolic collector; Compound parabolic collector and Central power receiver systems; **(03 Lectures).**
Materials for solar concentrator; Optical performance of concentrating collectors; Optical characteristics of non imaging concentrator; incident angle modifier and energy balance **(03 Lectures).**
Layout, design and performance study of Scheffler dishes, Solar furnaces, Designing of concentrating power plant, Experience on solar thermal power plants **(03 Lectures).**
Volumetric receiver, Direct absorption receiver, Receiver loss calculations **(03 Lectures).**

UNIT IV (14 Lectures)

Solar energy for industrial process heat, Temperature requirements of industrial process heat **(03 Lectures).**
Consumption pattern of heat in different industries industrial processes and scope of using solar energy for such processes, Case studies **(03 Lectures).**
Economic evaluation of industrial process heat, solar thermal systems standard testing protocols **(02 Lectures).**
Fundamentals, design, modeling and applications of Solar still; Solar cooker; Solar drier; Solar pondand other solar thermal systems **(03 Lectures).**

Techno economic evaluation of solar thermal power plants, market considerations **(03 Lectures).**

Books:

1. Sukhatme S P, *Solar Energy: principles of Thermal Collection and Storage*, TataMcGraw-Hill.
2. Duffie J A, Beckman W A, *Solar Engineering of Thermal Processes,* Johnn Wiley.
3. Goswami D Y, Frank Kreith and Kreider J F, *Principles of Solar Engineering*, Taylor and Francis, USA.
4. Garg H P, Prakash S, *Solar Energy: Fundamental and Application,* Tata McGrow-Hill, New Delhi.
5. Kreith F, Kreider J F, *Principles of Solar Engineering*, McGraw-Hill.
6. Kreider J F, Kreith F, *Solar Energy Handbook,* McGraw-Hill.
7. Bent Sorensen, *Renewable Energy*, Academic press, New York.
8. Tiwari, G N, *Solar Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.

REC-104

SOLAR PHOTOVOLTAIC ENERGY CONVERSION (4 Credits)

UNIT I (12 Lectures)

Intrinsic, extrinsic and compound semiconductor; Energy levels; Electrical conductivity; Determination of Fermi energy level; Probability of occupation of allowed states; Dynamics of energy density of allowed states; Density of electrons and holes **(06 Lectures).**
Carrier transport: Drift, diffusion, continuity equations **(03 Lectures).**
Absorption of light; Recombination process; Basic equations of semiconductor devices physics **(03 Lectures).**

UNIT II (15 Lectures)

Principle of photovoltaic conversion of solar energy **(01 Lecture).**
p-n junction: homo- and hetro-junctions, Metal-semiconductor interface; Dark and illumination characteristics; Figure of merits of solar cell; Efficiency limits; Variation of efficiency with band-gap and temperature; Efficiency measurements; High efficiency cells, Spectral response of solar cell, Tandem structure **(05 Lectures).**
Preparation of metallurgical, electronic and solar grade Silicon; Production of single crystal Silicon: Czokralski (CZ) and Float Zone (FZ) method: Procedure of masking, photolithography and etching; Design of a complete silicon **(04 Lectures).**
GaAs, InP solar cell; High efficiency III-V, II-VI multi-junction solar cell; a-Si-H based solar cells; Quantum well solar cell, Thermo-photovoltaics **(03 Lectures).**
LEDs: principles and operation **(02 Lectures).**

UNIT III (12 Lectures)

Solar cell array system analysis and performance prediction; Shadow analysis: Reliability **(03 Lectures).**
Solar cell array design concepts; PV system design; Design process and optimization; Detailed array design; Storage autonomy; Voltage regulation; Maximum tracking **(05 Lectures).**
Use of computers in array design; MPPT and its algorithm, Quick sizing method; Array protection and trouble shooting **(04 Lectures).**

UNIT IV (12 Lectures)

Centralized and decentralized SPV systems; Stand alone, hybrid and, grid connected system, Battery charger **(04 Lectures).**
Domestic lighting; Street lighting; Water pumping; System testing, installation, operation and maintenances; Field experience **(05 Lectures).**
LEDs lighting systems, integration of photovoltaic generation with LED systems **(03 Lectures).**

Books:

1. Green M A, *Third Generation Photovoltics: Advanced Solar Energy*, Springer.
2. Tiwari G N, *Solar Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.

3. Goswami D Yogi, Frank Kreith, Kreider Jan F, *Principles of Solar Engineering*, Taylor and Francis, USA.
4. Kreith F, Kreider J F, *Principles of Solar Engineering*, McGraw-Hill.
5. Kreider J F, Kreith F, *Solar Energy Handbook*, McGraw-Hill.
6. Garg HP, Prakash J, *Solar Energy: Fundamentals and Applications*, Tata McGraw-Hill, New Delhi.
7. Alan L Fahrenbruch, Richard H Bube, *Fundamentals of Solar Cells: PV Solar Energy Conversion*, Academic Press, New York.
8. Larry D Partain Ed, *Solar Cells and Their Applications,* John Wiley and Sons, Inc, New York.
9. Richard H Bube, *Photovoltaic Materials*, Imperial College Press.
10. Rauschenbach H S, Van Nostrand, *Solar Cell Array Design Handbook*, Reinfold Company, New York.

REC-105

ENERGY LABORATORY – I (4 Credits)

Exp. 1 To measure the total solar energy for a day or for a specified period with different inclination:
(a) at horizontal
(b) at latitude for Lucknow, 26° 50' N
(c) at 45° inclination

and also calculate the tilt factor at 12.00 hours and measure sunshine hours.

Exp. 2 To determine of the Horizontal Shadow Angle (Δ) and Vertical Shadow Angle (E) at a given site.

Exp.3 To determine the reflectivity of a booster (reflector) in a Box-Type Solar Cooker.

Exp. 4 To study the thermal performance of a Box-Type Solar Cooker
(a) with air and
(b) with water.

Exp. 5 To conduct the Heating and Cooling Tests on a Parabolid Concentrator Solar Cooker to determine its Optical Efficiency Factor and Heat Loss Factor and stagnation test.

Exp. 6 To draw the I-V characteristics of a Mono-Crystalline Silicon Photovoltaic Module and calculate the Fill-Factor and Efficiency at two Global Radiation (insolation) values. Also to find the variation of current (I) and voltage (V) in different loads.

Exp. 7 To draw the I-V characteristics of a Poly-Crystalline Silicon Photovoltaic Module and calculate the Fill-Factor and Efficiency at two Global Radiation (insolation) values.

Exp. 8 To study the variation of Voltage with Power in a Poly-Crystalline Silicon Photovoltaic Module.

Exp. 9 To determine of the Energy Band Gap of Germanium by using Point Contact Diode.

Exp. 10 To study of Inner Photoelectric Effect in case of Photovoltaic Cell by using a Light Source of Continuous Spectrum and determine the Value of Planck's Constant (h).

REE-101

ENERGY SOURCES, SCENARIO AND ENVIRONMENT (3 Credits)

UNIT I (12 Lectures)

Definition and units of energy and power; Forms of energy; Classification of energy sources (coal, oil, natural gas, nuclear power and hydroelectricity); Origin of fossil fuels, Time scale of fossil fuels (formation of coal, petroleum, biomass); Earth's energy flow; calorific values of fuels;

UNIT II (11 Lectures)

Energy Scenario: commercial & non-commercial forms of energy; energy resources available in India; Role of energy in economic development; socio economical impacts; environmental & ethical concerns; energy crises; energy conservation and efficiency.

UNIT III (11 Lectures)

Energy Scenario: Energy consumption in various sectors; urban and rural energy consumptions; projected energy consumptions for the next century; impact of rise in energy consumption on global economic; energy sector reforms; electricity acts; energy pricing; factor affecting energy cost; final energy consumption.

UNIT IV (12 Lectures)

Environmental effects of energy extraction, conversion and use **(02 Lectures).**
Sources of pollution; primary and secondary pollutants, Consequences- cause and effect of pollution- air, water, soil, thermal, noise pollution; Pollution control methods, Environmental laws on pollution & its control; biological damage due to environmental degradation; Pollution due to thermal power station; nuclear power generation; hydro electric power station on ecology and environment

Books:

1. Banerjee Bani P, *Energy and the Environment in India*, Oxford University Press, New Delhi.
2. Rai G D, *Non- conventional Sources of Energy*, Khanna Publishers, Delhi.
3. Kumar Gopal, *Energy Independence Vision of a Hybrid, Unbound Future*, Deep and Deep Publications Pvt. Ltd., New Delhi.
4. Asthana D K, Asthana Meera, *Environment Problems and Solutions*, S Chand and Company Ltd., New Delhi.
5. Mubeen Abdul, Khan M Emran, Hasan M Muzaffarul, *Energy and Environment*, Anamaya Publishers, New Delhi.
6. Pandel Upender, Poonia M P, *Energy Technologies for Sustainable Development*, Prime Publishing, Ghaziabad (UP).
7. Ristinen R A, Kraushaar J J, *Energy and the Environment,* John Willey and Sons.
8. Dass M C, *Fundamentals of Ecology*, Tata McGraw Hill.
9. Kaushik N D, Kaushik K, *Energy, Ecology and Environment*, Capital Publishing.

M Sc (Renewable Energy) Semester II

REC-201

NUMERICAL METHODS AND COMPUTATIONAL TECHNIQUES (4 Credits)

UNIT I (13 Lectures)

Interpolation, finite difference method, forward difference method, backward difference method, central difference method **(04 Lectures).**
Differentiation using forward, backward and central difference formulae **(03 Lectures).**
Integration using trapezoidal, Simpson's one-third and Simpson's three-eighth rule **(03 Lectures).**
Empirical laws and curve-fitting **(03 Lectures).**

UNIT II (13 Lectures)

Solution of Laplace's equation, Poisson's equation **(04 Lectures).**
Solution of one-dimensional heat equation using Schmidt and Crank-Nicholson method; Solution of two-dimensional heat equation **(05 Lectures).**
Solution of wave equation **(04 Lectures).**

UNIT III (12 Lectures)

Introduction to Optimization Techniques **(03 Lectures).**
Linear programming methods: Simplex method, Artificial variables and dual phase method **(05 Lectures).**
Introduction to genetic, simulated annealing and global optimization algorithms **(04 Lectures).**

UNIT IV (13 Lectures)

Introduction to MATLAB, variables and workspace, Arrays, vectors and matrix **(02 Lectures).**
Operators, expressions and statements, output, loops (for, each), decisions (if, else, elseif, while etc.) **(02 Lectures).**
Program design and algorithm development, MATLAB functions and data import export utilities, logical vectors **(04 Lectures).**
Introduction to graphics: basic 2D graphics, 3D plots, function M-files, graphical user interface, introduction to simulation **(05 Lectures).**

Books:

1. Balagurusamy E, *Numerical Methods*, Tata Mc Graw Hill, New Delhi.
2. Jain M K, Iyengar S R K, Jain R K, *Numerical Methods for Scientific and Engineering Computation*, New Age International (P) Ltd. New Delhi.
3. Rajsekaran S, *Numerical Methods in Science and Engineering*, Wheeler, Allahabad.

4. Hilderbrand F B, *Introduction to Numerical Analysis*, Tata McGraw Hill, New Delhi.
5. Harman T L, Dabney J B, Richert N J, *Advanced Engineering Mathematics with MATLAB.*
6. Brain D Hahn, Daniel T Valentine*, Essential MATLAB for Engineers and Scientists,* Elsevier.
7. Redfern Darren, Colin Campbell, *The MATLAB5 Handbook*, Springer, New York.
8. Mathews John H, Numerical *Methods for Mathematics, Science and Engineering*, Prentice Hall of India Pvt. Ltd., New Delhi.
9. Sastry S S, *Introductory Methods of Numerical Analysis*, Prentice Hall of India Pvt. Ltd., New Delhi.
10. Deb Kalyanmoy, *Optimization for Engineering DesignAlgorithms and Examples,* Prentice Hall of India Pvt. Ltd., New Delhi.
11. William H, Teuklosky S A, Vellerling W T, Flannery B P, N*umerical Recipes in C The Art of Scientific Computing*, Cambridge University Press.

REC-202

WIND ENERGY CONVERSION SYSTEMS (4 Credits)

UNIT I (13 Lectures)

Introduction to wind energy, Atmospheric circulations, Factors influencing wind: variation with height and time **(03 Lectures).**
Classification, Wind shear, Turbulence, Wind speed monitoring and maps **(03 Lectures).**
Wind energy conversion principles; Types and classification of wind energy conversion systems (WECS), Power, Torque and speed characteristics, Betz limit **(07 Lectures).**

UNIT II (12 Lectures)

Aerodynamic design principles; Aerodynamic theories; Axial momentum, blade element and combine theory **(05 Lectures).**
Rotor characteristics: Solidity, Tip speed ratio, Tip loss correction, Maximum power coefficient; Dynamic matching, Extension of linear momentum theory, Power extraction by a turbine **(07 Lectures).**

UNIT III (14 Lectures)

Wind electric generators: Aerogenerator classification, tower, rotor, gearbox, power regulation, safety mechanisms **(05 Lectures).**
Wind turbine design considerations; methodology **(02 Lectures).**
Theoretical simulation of wind turbine characteristics; test methods **(07 Lectures).**

UNIT IV (15 Lectures)

Wind pumps: Performance analysis, Design concept and standard testing conditions **(03 Lectures).**
Principle of wind energy electricity generation; Stand alone, grid connected and hybrid applications of WECS **(04 Lectures).**
Wind energy in India; Case studies **(02 Lectures).**
Matching supply and demand, Control option, Environmental benefits and problems of wind energy **(03 Lectures).**
Economics of wind energy: Factors influencing the cost of energy generation, Life cycle cost analysis **(03 Lectures).**

Books:

1. Johnson G L, *Wind Energy Systems*, Prentice Hall Inc, New Jersey, USA.
2. Spera David A Ed, *Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering,* American Society of Mechanical Engineers.
3. Paul Gipe, Karen Perez, *Wind Energy Basics: A Guide to Small and Micro Wind Systems*, Chelsea Green Publishing Company.
4. Kruger P, *Alternative Energy Resources: The Quest for Sustainable Energy*, Wiley Publications.
5. Rosa Aldo V, *Fundamentals of Renewable Energy Processes*, Second Edition, Academic Press.
6. Boyle G, *Renewable Energy: Power for a Sustainable Future*, Second Edition, Oxford University Press.

7. Mukund R Patel, *Wind and Solar Power Systems*, CRC Press.
8. John F Walker, Nicholas Jenkins, *Wind Energy Technology*, John Wiley and Sons.
9. Hau Erich, *Wind Turbines: Fundamentals, Technologies, Application and Economics,* Springer Verlag.
10. Manwell J F, McGowan J G, Rogers A L, *Wind Energy Explained*, John Wiley and Sons.
11. Burton Tony, Sharpe David, Jenkins Nick, Bossanyi Ervin, *Wind Energy Handbook*,John Wiley and Sons.
12. Freris L L, *Wind Energy Conversion Systems*, Prentice Hall.
13. Sorensen Bent, *Renewable Energy*, Academic press, New York.
14. Johansson Thomas B Ed, *Renewable Energy: Sources for Fuels and Electricity*, Earthscan Publishers, London.

M Sc (Renewable Energy) Semester II
Centre of Excellence in Renewable Energy Education and Research
University of Lucknow

REC-203
BIO-ENERGY AND WASTE TO ENERGY CONVERSION SYSTEMS

(4 Credits)

UNIT I (13 Lectures)

Formation of biomass; Biomass Resources: Classification and characteristics; Techniques for biomass assessment; Application of remote sensing in forest assessment; Biomass estimation **(04 Lectures).**
Different processes of thermo-chemical conversion; Direct combustion, Incineration, Pyrolysis, Gasification and Liquefaction **(04 Lectures).**
Chemical Conversion, Hydrolysis and hydrogenation; Solvent extraction of hydrocarbons; Solvolysis of wood; Bio-crude and bio-diesel; Chemicals from biomass **(05 Lectures).**

UNIT II (12 Lectures)

Biological Conversion, Biodegradation and biodegradability of substrate **(03 Lectures).**
Biochemistry and process parameters of bio-methanation; Anaerobic digestion; Biogas digester types; Digester design and biogas utilization; Chemical kinetics and mathematical modeling of bio-methanation process; Environmental and social impacts of biogas plants **(05 Lectures).**
Bioconversion of substrates into alcohol: Methanol and ethanol production, Organic acids, Solvents, Amino acids, Antibiotics, etc. **(04 Lectures).**

UNIT III (14 Lectures)

Power Generation: Industrial waste, Agro residues; Briquetting; Utilization and advantages of briquetting **(04 Lectures).**
Industrial applications of gasifiers, Utilization of gasifier for electricity generation; Operation of spark ignition and compression ignition engine with wood gas, methanol, ethanol and biogas **(04 Lectures).**
Biomass integrated gasification/combined cycles systems **(02 Lectures).**
Sustainable co-firing of biomass with coal **(02 Lectures).**
Biomass productivity: Energy plantation and power programme **(02 Lectures).**

UNIT IV (13 Lectures)

Solid Waste: Definitions, Sources, Types and Compositions; Properties of solid waste; Municipal solid waste: Physical, Chemical and Biological property **(04 Lectures).**
Waste minimization and recycling of municipal waste. Waste Treatment and Disposal: Size reduction, Aerobic composting, Furnace type and design; Medical/Pharmaceutical waste incineration **(04 Lectures).**
Environmental impacts; Measures to mitigate environmental effects due to incineration; Land fill method of solid waste disposal; Land fill classification; Types, Methods and Siting consideration; Layout and preliminary design of landfills **(05 Lectures).**

Books:

1. Sorensen Bent, *Renewable Energy*, Academic Press, New York.
2. Johansson Thomas B, *Renewable Energy: Sources for Fuels and Electricity*, Earthscan Publishers, London.
3. Rai G D, *Non-Conventional Energy Sources,* Khanna Publishers, New Delhi.
4. Ravindranath N H and D O Hall, *Biomass, Energy, and Environment: A Developing Country Perspective from India*, Oxford University Press.
5. Boyles David, *Bio-Energy Technology Thermodynamics and Costs*, Ellis Hoknood, Chichester.
6. El-Halwagi M M, *Biogas Technology: Transfer and Diffusio*n, Elsevier Applied SC, London.
7. Ralph Sims, *Brilliance of Bio-energy*, James and James Publication.
8. Wyman Charles, Taylor, Francis, *Handbook on Bio-ethanol: Production and Utilization*, Applied Energy Technology Series.
9. Reed Tom, Bryant Becky, *Densified Biomass: A New Form of Solid Fuel*, Biomass Energy Foundation.
10. Milne T, Abatzoglou N, Evans R J, *Biomass Gasifier "tars"*: *their Nature*, *Formation, and Conversion,* NREL, USA.
11. Higman, Burgt, *Gasification*, Elsevier.
12. Muzumdar B, *A Text Book of Energy Technology: Both Conventional and Renewable Source of Energy*.
13. Reed T, Das A, *Biomass Downdraft Gasifier Engine Systems Handbook* by Biomass Energy Foundation.
14. Estill Lyle, *Biodiesel Power: The Passion, the People and the Politics of the Next Renewable Fuel*, New Society Publishers.
15. Anthony San Pietro, *Biochemical and Photosynthetic Aspects of Energy Production*, Academic Press, New York.
16. E R Berman, *Geothermal Energy*, Noyes Data Corporation, New Jersey.
17. Parker, Colin, Roberts, *Energy from Waste-An Evaluation of Conversion Technologies*, Elsevier Applied Science London.
18. Boyle Godfrey Ed, *Renewable Energy: Power for a Sustainable Future*, Oxford, OUP.
19. Ralph E.H. Sims, *Bioenergy Options for Cleaner Environment*, World Renewable Energy Network.
20. Ravindranath N H, Hall D O, *Biomass, Energy and Environment, A Developing Country Perspective from India*, Oxford University Press.
21. Brown Robert C, *Bio-renewable Resources: Engineering New Products from Agriculture*, Iowa State University Press,USA.
22. Khandelwal K C, Mahdi S S, *Biogas Technology - A Practical Handbook*, Tat Mcgraw Hill.
23. Rosillo-Calle Frank, Francisco Rosillo, *The Biomass Assessment Handbook: Bioenergy for a Sustainable Environment*, Published Earthscan.
24. Mittal K M, *Biogas Systems: Principles and Applications*, New Age International.
25. Maheswari R C, *Bio-Energy for Rural Energisation*, Concepts Publication.

REC-204

ENERGY MANAGEMENT (4 Credits)

UNIT I (13 Lectures)

Concept of energy management; Energy demand and supply **(03 Lectures).**
Basic concepts of Energy Conservation, Energy conservation in household, Transportation, Agricultural, Service and Industrial sectors, Lighting, HVAC systems **(05 Lectures).**
Material and Energy Balance: Facility as an energy system; Methods for preparing process flow; Material and energy balance diagrams **(05 Lectures).**

UNIT II (14 Lectures)

Energy Audit: Definition, Need and Types of energy audit **(03 Lectures).**
Energy Audit Approach: Understanding energy costs, Bench marking, Energy performance, Matching energy use to requirement, Maximizing system efficiencies, Optimizing the input energy requirements; Fuel and energy substitution **(05 Lectures).**
Energy audit instruments **(02 Lectures).**
Energy Conservation Act **(02 Lectures).**
Duties and responsibilities of energy managers and auditors **(02 Lectures).**

UNIT III (15 Lectures)

Energy Action Planning: Key elements; Force field analysis; Energy policy purpose, perspective, contents, formulation, ratification; Organizing the Management: Location of energy management, Top management support, Managerial function, Roles of energy manager, Accountability; Motivation of employees: Information system-designing barriers, strategies **(05 Lectures).**
Marketing and communicating: Training and planning **(02 Lectures).**
Monitoring and Targeting: Defining monitoring and targeting; Elements of monitoring and targeting; Data and information-analysis **(03 Lectures).**
Techniques: Energy consumption, Production, Cumulative sum of differences (CUSUM) **(03 Lectures).**
Energy Service Companies; Energy management information systems; SCADA systems **(02 Lectures).**

UNIT IV (14 Lectures)

Electrical Energy Management: Supply side: Methods to minimize supply-demand gap, Renovation and modernization of power plants, Reactive power management, High-voltage direct current (HVDC) and Flexible alternating current transmission system **(**FACTS**) (05 Lectures).**
Demand side: Conservation in motors, Pumps and Fan systems; Energy efficient motors **(03 Lectures).**
Thermal Energy Management: Energy conservation in boilers, Steam turbines and industrial heating systems; Application of fluidized bed combustion (FBC); Cogeneration and waste heat recovery; Thermal insulation; Heat exchangers and heat pumps **(05 Lectures).**
Building energy management **(01 Lecture).**

Books:

1. Smith C B, *Energy Management Principles*, Pergamon Press, New York.
2. Hamies, *Energy Auditing and Conservation; Methods, Measurements, Management and Case study*, Hemisphere, Washington.
3. Krieder J, Rabi A, *Heating and Cooling of Buildings: Design for Efficiency,* McGraw-Hill.
4. Archie, Culp W, *Principles of Energy Conservation*, McGraw Hill.
5. Gellings C W, J H Chamberlin, *Demand-Side Management Planning*, Fairmont Press.
6. Murphy, W R, Mckay G, *Energy Management*, Elsevier.
7. Witte, Larry C, *Industrial Energy Management and Utilization*, Hemisphere Publishers, Washington.
8. Callaghan P O, *Energy Management*, McGraw - Hill Book Company.
9. Bureau of Energy Efficiency, *Study Material for Energy Managers and Auditors Examination: Paper I to IV*.

REC-205

ENERGY LABORATORY – II (4 Credits)

Exp. 11 Determination of First and Second Figures of Merit of a Box-Type Solar Cooker.

Exp. 12 Thermal Performance of a Hybrid Solar Cooker with Top and Bottom Heating.

Exp. 13 Performance Evaluation of a Single Basin Solar Still.

Exp. 14 Evaluation of U_L, F_R, η of Solar Thermal Flat Plate Collector in Thermosyphonic Mode of Flow at different Radiation Levels.

Exp. 15 Study of the Performance of a Rectangular Dish Type Solar Cooker with Water Heater Through Stagnation Temperature Test and Solar Water Heating Test.

Exp. 16 Determine the Performance (U_L, F_R, η) of the Parabolic Trough Collector with Fixed Parameters with (I) Water and (II) Oil as Working Fluid.

Exp. 17 Study of the I-V and P-V Characteristics of Series and Parallel Combination of PV Modules.

Exp. 18 Working out Power Flow Calculations of Standalone PV System of DC and AC Load with Battery.

Exp.19 Grid Synchronization of Solar PV Inverter and it Performance Analysis.

Exp. 20 Determination of Efficiency of Improved Chulha through Water Boiling Test Procedure.

REE-201

ENERGY ECONOMICS POLICY AND PLANNING (3 Credits)

UNIT I (12 Lectures)

Economics and Planning of Energy Systems: Relevance of financial and economic feasibility, Evaluation of energy technologies and systems **(04 Lectures).**
Basics of engineering economics, financial evaluation of energy technologies **(04 Lectures).**
Social cost benefit analysis, Case studies on techno-economics of energy conservation and renewable energy technologies **(04 Lectures).**

UNIT II (12 Lectures)

Energy demand analysis and forecasting, Energy supply assessment and evaluation, energy demand – supply balancing **(04 Lectures).**
Energy models, software for energy planning, energy – economy interaction, energy investment planning and project formulation **(03 Lectures).**
Energy pricing, Policy and planning implications of energy – environment interaction, clean development mechanism, technology transfer and its financing, carbon credits and trading opportunities, Financing of energy systems **(05 Lectures).**

UNIT III (13 Lectures)

Energy (and power) policies in the country, Tariffs and subsidies, Energy utility interface, Private sector participation in power generation, State role and fiscal policy **(05 Lectures).**
Energy policy related acts and regulations **(02 Lectures).**
Energy and development, National energy plan, Role of modeling in energy policy analysis, Energy data base, Energy balances, Flow diagrams, Reference energy system, Energy demand analysis, Trend analysis, Econometric models, Elasticities approach, Input-output models, Simulation/process models, Energy supply analysis **(06 Lectures).**

UNIT IV (11 Lectures)

Costs of exploration and economics of utilization of depletable and renewable resources, Scarcity rent, International energy supply, Energy demand supply balancing **(06 Lectures).**
Energy-economy interaction, Energy investment planning, Energy environment interaction, Energy Pricing **(05 Lectures).**

Books:

1. Ferdinand Banks E, *Energy Economics: A Modern Introduction,* Kluwer, London.
2. Kandpal T C, Garg H P, *Financial Evaluation of Renewable Energy Technology*, Macmilan India Ltd. New Delhi.
3. Munasinghe M, Meier P, *Energy Policy Analysis and Modeling*, Cambridge University Press.
4. Samuelson P A, William Nordhaus D, *Economics,* McGraw-Hill, New York.
5. Donnelly W A, *The Econometrics of Energy Demand: A Survey of Applications*, Praeger, New York.
6. Dixon, et al, *Economic Analysis of Environmental Impacts*, Earthscan Publications Ltd., London.

7. Hackett Steven C, Sharpe M E, *Environmental and Natural Resources Economics*, New York.
8. Thuesen G J Fabrycky W J, *Engineering Economy,* Prentice-Hall of India Pvt. Ltd.
9. White J A, et. al., *Principles of Engineering of Economic Analysis*, John Wiley and Sons.
10. Dasgupta Ajit K, Pearce D W, *Cost Benefit Analysis, Theory and Practice*, Macmilan.
11. United Nations Ed, *Energy Issues and options for Developing Countries*, Taylor and Francis.
12. Hohmeyer O, Ottinger R L Ed, *Social costs of energy: Present Status and Future Trends,* Springer Verlag.
13. Kaplan, Seymour, *Energy Economics: Quantitative Methods for Energy and Environmental Decisions*, McGraw Hill.
14. Meyers Robert A Ed, *Handbook of Energy Technology and Economics*, John Wiley and Sons.
15. Robert L Pirog, Stephen Stamos C, *Energy Economics: Theory and Policy*, Prentice-Hall New Jersey.

M Sc (Renewable Energy) Semester III

REC-301

SMALL HYDROPOWER CONVERSION AND OTHER RENEWABLE ENERGY SYSTEMS (4 Credits)

UNIT I (12 Lectures)

Hydropower, Overview of micro, mini and small-hydro systems; Hydrology **(02 Lectures).**
Elements of pumps and turbine; Selection and design criteria of pumps and turbines; Site selection and civil works **(04 Lectures).**
Speed and voltage regulation; Investment issues load management and tariff collection, payback period **(03 Lectures).**
Distribution and marketing issues; Case studies; Potential of small hydro power in India **(03 Lectures).**

UNIT II (12 Lectures)

Introduction to OTEC, Methods of ocean thermal electric power generation: Merits and demerits of OTEC, Bio-fouling, Site selection, Prospects of ocean thermal energy conversion systems in India **(04 Lectures).**
Introduction to tides, Basic principles of tidal power, Components of tidal power plants, Operation methods of utilization of tidal energy, estimate of energy and power, site requirements, storage, advantages and limitation of tidal power generation and prospect of tidal energy in India **(05 Lectures).**
Introduction to ocean waves, advantages and disadvantages of wave energy, Energy and power from waves, Wave-energy conversation devices **(03 Lectures).**

UNIT III (12 Lectures)

Estimate of Geothermal power, Nature of geothermal fields, Geothermal sources, Hydrothermal, Geo-pressurized, Hot dry rock, Magma resources, comparison of flashed steam and total flow concept, Prime movers for geothermal energy conversion **(07 Lectures).**
Advantages and disadvantages of geothermal energy, Application of geothermal energy, Geothermal energy in India **(05 Lectures).**

UNIT IV (12 Lectures)

Nuclear fusion: Nuclear fusion reaction, requirement of nuclear fusion, plasma confinement, Magnetic-confinement, intertial-confinement fusion, characteristics of D-T reaction, advantages of nuclear fusion, fusion hybrid, cold fusion (current status) **(07 Lectures).**
Magneto-hydro-dynamic (MHD) power generation, MHD systems, Advantages of MHD systems, International status of MHD power generation and its future prospects **(05 Lectures).**

Books:

1. Central Electricity Authority, New Delhi, *Small Hydro Power Potential in India*.

2. Tong Jiandong (et al.), *Mini Hydropower* John Wiley and Sons.
3. Kruger P, *Alternative Energy Resources: The Quest for Sustainable Energy*, Wiley Publication.
4. Rosa Aldo V, *Fundamentals of Renewable Energy Processes,* Second Edition, Academic Press.
5. Boyle G, *Renewable Energy: Power for a Sustainable Future*, Second Edition, Oxford University Press.
6. Harvey A, Brown A, *Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes*, Practical Action Publication.
7. Freris L L, *Wind Energy Conversion Systems*, Prentice Hall.
8. Davis S, *Microhydro: Clean Power from Water*, New Society Publishers.
9. Sorensen Bent, *Renewable Energy*, Academic Press, New York.
10. Johansson Thomas B Ed, *Renewable Energy: Sources for Fuels and Electricity*, Earthscan Publishers, London.
11. Harvey A, Brown A, *Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes*, Practical Action publication.

REC-302

ENERGY IN BUILDINGS (4 Credits)

UNIT I (12 Lectures)

Introduction to architecture; Architecture as the art of science of designing buildings ; Building science and its significance; Energy management concept in building **(02 Lectures).**
Thermal comfort; Criteria and various parameters; Psychometric chart; Thermal indices **(03 Lectures).**
Climate and comfort zones; Introduction to design of shading devices; Overhangs **(03 Lectures).**
Factors that effects energy use in buildings; ventilation and its significance; air-conditioning systems; energy conservation techniques in air-conditioning systems **(04 Lectures).**

UNIT II (12 Lectures)

Passive heating concepts: direct heat gain, indirect heat gain, isolated gain and sunspaces **(05 Lectures).**
Passive cooling concepts: evaporative cooling, radiative cooling; application of wind, water and earth for cooling; shading, paints and cavity walls for cooling; roof radiation traps; earth air-tunnel **(07 Lectures).**

UNIT III (13 Lectures)

Heat transmission in buildings: surface co-efficient: air cavity, Internal and external surfaces **(03 Lectures).**
Overall thermal transmittance, Wall and windows; Heat transfer due to ventilation/infiltration, Internal heat transfer; Decrement factor; Phase lag; Design of day-lighting, Concept of sol-air temperature and its significance; **(07 Lectures)**
Estimation of building loads: Steady state method, Network method, Numerical method, Correlations; Computer packages for carrying out thermal design of buildings and predicting performance **(03 Lectures).**

UNIT IV (13 Lectures)

Bioclimatic classification of India; Passive concepts appropriate for the various climatic zones in India; Typical design of selected buildings in various climatic zones; Thumb rules for design of buildings and building codes **(06 Lectures).**
Energy Efficient Landscape Design: Modification of microclimatic through landscape element for energy conservation **(03 Lectures).**
Energy conservation through site selection, Planning and design; Siting and orientation **(02 Lectures).**
Green buildings, Zero emission buildings **(02 Lectures).**

Books:

1. Tiwari G N, Goyal R K, *Greenhouse Technology: Fundamentals, Design Modeling and Application,* Narosa Publishing House.

2. Krieder J, Rabi A, *Heating and Cooling of Buildings: Design for Efficiency*, McGraw-Hill.
3. Archie, Culp W, *Principles of Energy Conservation*, McGraw Hill.
4. Callaghan P O, *Energy Management*, McGraw - Hill Book Company.
5. Williams J R, *Passive Solar Heating*, Ann Arbar Science.
6. Majumder Milli, *Energy Efficient Buildings*, TERI, New Delhi.
7. David A Bainbridge, Ken Haggard, *Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows*, Chelsea Green Publishing Co., UK.
8. Bureau of Energy Efficiency, *Energy Conservation Building Code,* Ministry of Power, Government of India, New Delhi.
9. ASHRAE, *Hand Book: Fundamentals,* Inch-Pound Edition, New York, USA.

REC-303

DISTRIBUTED GENERATION AND INTEGRATION OF RENEWABLE ENERGYWITH GRID (4 Credits)

UNIT I (12 Lectures)

Distributed Generation Systems: Decentralized versus central station generation, Traditional power systems, Load curves and load curve analysis. Coincidence behavior and load curves, measuring load curve data accurately **(04 Lectures).**
Planning and Planning Process: Planning finding the best alternative, short and long range planning, different decision making philosophies **(04 Lectures).**
Cost and Economic Evaluation of Distributed Generation: Costs, time value of money, decision bases and cost effectiveness evaluation **(04 Lectures).**

UNIT II (12 Lectures)

Basic gas turbine generator concepts; Utility system turbine generators; Mini and micro gas turbine generators **(04 Lectures).**
Solar thermal power generations, Utility Scale Photovoltaic (USPV) generation; Wind-powered generation; Biomass based generation **(04 Lectures).**
DG Evaluation: Cost from past, present, and future, basic DG cost analysis, cost evaluation and schedule of demand **(04 Lectures).**

UNIT III (12 Lectures)

Grid Interconnection Issues and Need for Integration of Renewable Energy: The power grid, pro & cons of DG-interconnection, type of DG grid interconnection, DG-Grid interconnection issues **(04 Lectures).**
Case Study; Planning, constraints and economics. Standard engineering economics evaluation, business and financial factors, recommendation for effective DG evaluation **(05 Lectures).**
Effects on the grid by RE systems integration; Interfacing techniques; Innovations required in technology and policy **(03 Lectures).**

UNIT IV (12 Lectures)

Economics: Grid-connected energy storage schemes: response requirement, capacity assessment, cost considerations **(05 Lectures).**
Hybrid Energy Systems: Principles and applications; Comparison of schemes; System design concepts; Techno-economic performance; Energy storage schemes and estimation **(07 Lectures).**

Books:

1. Willis H Lee, *Distributed power generation: planning and evaluation,* Marcel Dekker, Inc.
2. Willis H. Lee, *Power Distribution planning reference book,* Marcel Dekker, Inc.
3. Johansson Thomas BEd, *Renewable energy: sources for fuels and electricity*, Earthscan.

4. Johnson G L, *Wind Energy Systems*, Prentice Hall Inc, New Jersy, USA.
5. Kandpal T C, Garg H P, *Financial Evaluation of Renewable Energy Technology*, Macmilan India Ltd. New Delhi.
6. Kaushika N D, Kaushik Kshitij, *Energy Ecology and Environment: A Technological Approach*. New Delhi, Capital Publishing Company.
7. Ali Keyhani, Mohammad N Marwali, Min Dai, *Integration of Green and Renewable Energy in Electric Power Systems*, Wiley.

REC-304

ENERGY STORAGE SYSTEMS (4 Credits)

UNIT I (14 Lectures)

Need of energy storage; Different modes of Energy Storage **(02 Lectures).**
Potential energy: Pumped hydro storage **(02 Lectures).**
Kinetic energy and Compressed gas system: Flywheel storage, Compressed air energy storage **(02 Lectures).**
Electrical and magnetic energy storage: Capacitors, Electromagnets and Battery storage systems such as primary, secondary, Lithium, Solid-state and Molten solvent batteries **(04 Lectures).**
Role of carbon Nano-tubes in electrodes; Chemical Energy storage: Thermo-chemical, Photo-chemical, Bio-chemical, Electro-chemical, Fossil fuels and Synthetic fuels and Hydrogen storage **(04 Lectures).**

UNIT II (12 Lectures)

Sensible heat storage **(**SHS) mediums; Stratified storage systems; Rock-bed storage systems; Thermal storage in buildings; Earth storage; Energy storage in aquifers. Design, working and case studies of SHS system for industries **(05 Lectures).**
Phase change materials (PCMs); Selection criteria of PCMs; Stefan problem; Solar thermal LHTES systems; Energy conservation through LHTES systems; LHTES systems in refrigeration and Air-conditioning systems; Enthalpy formulation; Numerical heat transfer in melting and freezing process. Design, working and case studies of PCM system for industries **(07 Lectures).**

UNIT III (12 Lectures)

Some areas of application of energy storage: Food preservation; Waste heat recovery **(04 Lectures).**
Solar energy storage; Green house heating **(03 Lectures).**
Power plant applications; Drying and heating for process industries **(05 Lectures).**

UNIT IV (12 Lectures)

Magnetic and Electric Energy Storage Systems: Superconducting magnet energy storage (SMES) systems; Capacitor and batteries: Comparison and application **(05 Lectures).**
Super capacitor: Electrochemical double layer capacitor (EDLC), Principle of working, Structure, Performance and application **(05 Lectures).**
Role of activated carbon and carbon nano-tube **(02 Lectures).**

Books:

1. Narayan R, Viswanathan B, *Chemical and Electrochemical Energy Systems*, University Press (India) Ltd.
2. Sarangpani, S J A Kosek, La Conti A B, *Handbook of Solid State Batteries and Capacitors*, World Scientific Publications, N J, USA.
3. Newman J, *Electro-chemical Systems*, Prentice Hall, Engelwood Cliffs, NJ, USA.

4. Gileadi E, *Electrode Kinetics for Chemists, Chemical Engineers and Material Scientist*, VCH Publications, NY, USA.
5. Harris Peter J F, *Carbon Nanotubes and Related Structures-New Materials for the Twenty-first Century*, Cambridge University Press, UK.
6. Reich, Stefan, C Thomsen, Maultzsch J, *Carbon Nanotubes – Basic Concepts and Physical Properties*, John Wiley and Sons, Canada.

REC-305

INDUSTRIAL TRAINING AND FIELD VISITS (4 Credits)

The students a required to take industrial training in industrial setups or institutes devoted to renewable energy research, development and training activities after their M Sc (Renewable Energy) Semester II examination.

The students are also required to undertake field visits to renewable energy industries and institutions during M Sc (Renewable Energy) Semester III.

The students are also required to undertake studies on some topics/problems/ systems related to renewable energy and prepare detailed reports.

The students are required to prepare reports of industrial training, assigned topics/problems/systems and field visits separately for evaluation. The students are also required to make PPT presentation in the examination.

REE-301

SOLAR PHOTOVOLTAIC POWER PLANTS (3 Credits)

UNIT I (12 Lectures)

Introduction to solar cell array systems, solar cell array analysis and performance prediction; Shadow analysis: Reliability; Solar cell array design concepts; PV system design; Design process and optimization **(05 Lectures).**
Detailed array design; Storage autonomy; Voltage regulation; Maximum tracking **(03 Lectures).**
Use of computers in array design; Quick sizing method; Array protection and trouble shooting **(04 Lectures).**

UNIT II (11 Lectures)

Design of structures and installation, Power conditioning and control: converters, inverters, cabling: size, losses, etc., other components of balance of system including PV mounting system and foundation as per IEC62548 and matching of different components **(07 Lectures).**
Storage batteries, Battery charge controllers **(04 Lectures).**

UNIT III (12 Lectures)

Centralized and decentralized SPV systems; Stand alone, hybrid and grid connected systems, domestic lighting; street etc. System installation, operation and maintenances; Field experience **(06 Lectures).**
Site assessment, planning, design, installation and monitoring with or without storage system of solar photovoltaic power plants including system protection, losses and system yield calculation **(06 Lectures).**

UNIT IV (12 Lectures)

PV market analysis, economics of solar photovoltaic power plant, Case studies **(05 Lectures).**
JNNSM policies and initiatives, feasibility studies and DPR preparation for roof-top and MW scale solar plants, best practices in PV system installation and commissioning **(07 Lectures).**

Books:

1. Sukhatme S P, *Solar Energy*: *Principles of Thermal Collection and Storage*, Tata McGraw-Hill.
2. Duffie J A, Beckman W A, *Solar Engineering of Thermal Processes*, John Wiley and Sons.
3. Green M A, *Third Generation Photovoltics: Advanced Solar Energy*, Springer.
4. Tiwari, G N, Solar *Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.
1. Goswami, D Yogi, Frank Kreith, Kreider Jan F, *Principles of Solar Engineering*, Taylor and Francis, USA.

M Sc (Renewable Energy) Semester IV

REC-401

HYDROGEN ENERGY AND FUEL CELLS (4 Credits)

UNIT I (12 Lectures)

New Energy Systems: Need of new energy systems and materials **(05 Lectures).**
Application to supplement and expedite energy conservation efforts and to address environmental concerns **(07 Lectures).**

UNIT II (13 Lectures)

Hydrogen: Its merit as a fuel and in terms of economic **(03 Lectures).**
Production: from fossil fuels, Electrolysis, Thermal decomposition, Photo-chemical, Photo-catalytic, Hybrid; Storage: Metal hydrides, Metallic alloy hydrides **(07 Lectures).**
Carbon nano-tubes **(01 Lecture).**
Transportation; Sea as the source of Deuterium **(02 Lectures).**

UNIT III (12 Lectures)

Fuel Cell:Principle of working, Basic thermodynamics and electrochemical principles **(05 Lectures).**
Classification, Electrolytes, Fuel types, Fuel-cell electrodes and carbon nano-tubes **(04 Lectures).**
Applications for power and transportation **(03 Lectures).**

UNIT IV (12 Lectures)

Solar Photo-catalytic Detoxification: Mechanism; Advantages; Kinetic model; Nano-particle Catalyst: Physical properties, Sensitization; System design methodology; Performance parameters **(07 Lectures).**
Application for liquid and gas phase organic pollutant mitigation and disinfection **(05 Lectures).**

Books:

1. Wolf, Edmond, *Nano-particles and Nanotechnology: An Introduction to Modern Concepts of Nano-science*, John Wiley and Sons, Canada.
2. O'Hayre R, Cha S, Colella W, Prinz F B, *Fuel Cell Fundamentals*, John Wiley and Sons, New York.
3. Sorensen, B, *Hydrogen and Fuel Cells*, Elsevier Academic Press, USA.
4. Yurum, Yuda Ed, *Hydrogen Energy Systems*, NATO ASI Series, London.
5. Baker BS, *Hydrocarbon Fuel Cell Technology,*Academic Press, New York

REC-402

ENERGY AUDITING AND CONSERVATION (4 Credits)

UNIT I (13 Lectures)

Thermal Energy Auditing: HVAC systems; Waste heat recovery and cogeneration schemes; Pinch analysis – methods, application and case studies **(03 Lectures).**
Boiler performance: Methodology of upgrading boiler performance; Boiler blow down, control, excess air control; Pressure reducing stations **(03 Lectures).**

Energy conservation in steam systems: Importance of correct pressure, Temperature, and quality; Condensate recovery; Pumping; Thermo-compressors; Recovery of flash steam; Air removal and venting; Moisture removal **(03 Lectures).**
Steam Traps: Types, function, necessity, selection and application **(02 Lectures).**
Co-generation: In-plant power generation systems; Co-generation schemes and configuration; Design considerations; Heat rate improvement; Case studies **(02 Lectures).**

UNIT II (13 Lectures)

Energy Conservation in Plant Service Systems: Centrifugal pumps: Energy consumption and saving potentials; Design consideration minimizing over design; Case studies **(03 Lectures).**
Fans and Blowers: Specification, safety margin, choice of fans-controls, design considerations **(02 Lectures).**
Air Compressor and Compressed Air Systems: Selection of compressed air layout, Encon aspects, Design consideration **(03 Lectures).**
Refrigeration and Air-conditioning: Heat load estimation, methods of minimizing heat loads, optimum selections of equipments; Case studies **(03 Lectures).**
Cooling Tower: Energy conservation in cooling towers and spray ponds; Case studies **(02 Lectures).**

UNIT III (13 Lectures)

Electrical Energy Auditing: Electrical energy conservation in various industries; Conservation methods; Energy management opportunities in electrical heating, Lighting system; Cable selection **(05 Lectures).**
Energy efficient motors: Factors involved in determination of motor efficiency; Adjustable AC drives; Application and its use – Variable speed drives/belt drives **(04 Lectures).**
Energy efficiency in electrical systems: High tension (HT) power distribution; Control system in HT/LT side, Harmonics; Case studies **(04 Lectures).**

UNIT IV (12 Lectures)

Load Forecasting: Application and techniques **(03 Lectures).**
Economic load dispatch; High power electronic devices and their applications in electric power systems **(04 Lectures).**
VAR compensation and FACTS devices **(03 Lectures).**
HVDC transmission **(02 Lectures).**

Books:

1. Smith C B, *Energy Management Principles*, Pergamon Press, NewYork.
2. Hamies, *Energy Auditing and Conservation; Methods, Measurements, Management and Case study*, Hemisphere, Washington.
3. Krieder J, Rabi A, *Heating and Cooling of Buildings: Design for Efficiency,* McGraw-Hill.
4. Archie, Culp W, *Principles of Energy Conservation*, McGraw Hill.
5. Gellings C W, Chamberlin J H, *Demand-Side Management Planning*, Fairmont Press.
6. Murphy WR, Mckay G, *Energy Management,* Elsevier.
7. WitteLarry C, *Industrial Energy Management and Utilization*, Hemisphere Publishers, Washington.
8. Callaghan P O, *Energy Management*, McGraw - Hill Book Company
9. Bureau of Energy Efficiency, *Study Material for Energy Managers and Auditors Examination: Paper I to IV.*

REC-403

ENERGY MODELING AND PROJECT MANAGEMENT (4 Credits)

UNIT I (13 Lectures)

Basic concept of econometrics and statistical analysis **(03 Lectures).**
The 2-variable regression model; The multiple regression model; Tests of regression coefficients and regression equation **(04 Lectures).**
Econometric techniques used for energy analysis and forecasting with case studies from India **(04 Lectures).**
Operation of computer package **(02 Lectures).**

UNIT II (12 Lectures)

Basic concept of input-output analysis **(03 Lectures).**
Concept of energy multiplier and implication of energy multiplier for analysis of regional and national energy policy **(05 Lectures).**
Energy and environmental Input - Output analyses using I-O model **(04 Lectures).**

UNIT III (12 Lectures)

Energy Modeling: Interdependence of energy-economy-environment; Modelling concept, and application, Methodology of energy demand analysis; Methodology for energy forecasting **(05 Lectures).**
Sectoral energy demand forecasting; Inter-fuel substitution models; SIMA model, and I-O model for energy policy analysis **(04 Lectures).**
Simulation and forecasting of future energy demand consistent with macroeconomic parameters in India **(03 Lectures).**

UNIT IV (12 Lectures)

Project Evaluation and Management: Financial analysis: Project cash flows, time value of money, Life cycle approach and analysis, Conception, Definition, Planning, Feasibility and Analysis; Project appraisal criteria; Risk analysis; Project planning matrix; Aims oriented project planning; Social cost benefit analysis **(06 Lectures).**
Network analysis for project management; Time estimation; Critical path determination; PERT, CPM and CERT; Fuzzy logic analysis; Stochastic based formulations; Project evaluation techniques; Funds planning; Project material management, Evaluation and analysis; Implementation and monitoring; Performance indices; Case studies **(06 Lectures).**

Books:

1. Polak P, *Systematic Errors in Engineering Experiments*, Macmillan Press Ltd.
2. Holman Jack P, *Experimental Methods for Engineers*, McGraw-Hill Book Company.
3. Doebelin Ernest O, *Engineering Experimentation – Planning, Execution*, Reporting, McGraw-Hill.

4. David Cleland, Roland Gareis, *Global* Project Management *Handbook*: *Planning, Organizing and Controlling International Projects*, McGraw Hill Professional.
5. Jean Carlo Binder, *Global Project Management: Communication, Collaboration and Management Across Borders*, Gower Publishing, Ltd. Hampshire, UK.
6. Garth Ward, *The Project Manager's Guide to Purchasing: Contracting for Goods and Services,* Gower Publishing, Ltd. Hampshire, UK.
7. Denise Bower, *Management of Procurement*, Thomas Telford, London, UK.

REC-404

ENERGY PROJECT (INCLUDING SEMINAR AND VIVA) (4 Credits)

M Sc (Renewable Energy) students during Semester IV are required to undertake an energy project on some innovative idea. The project should be a working model related to renewable energy and other applied aspects.

The students are required to give a seminar on their projects and submit a detailed report on the project which should also include the design and construction of the project.

The evaluation of the energy project will be done on the innovative idea and viva-voce examination including PPT presentation on the project.

REC-405

ENERGY PROJECT LABORATORY (4 Credits)

M Sc (Renewable Energy) students during Semester IV are required to undertake an energy project on some innovative idea. The project should be a working model related to renewable energy and other applied aspects.

The students are required to give a seminar on the performance of the working model and submit a detailed report on the project which should also include laboratory performance of the project.

The evaluation of the energy project will be done on the innovative idea and viva-voce examination including PPT presentation on the laboratory performance of the project.

REE-401

CARBON FOOT PRINTS AND CLEAN DEVELOPMENT MECHANISM (3 Credits)

UNIT I (12 Lectures)

Climate Change Mitigation: Way and means, Concept of Carbon Sequestration. Carbon Sequestration projects, Carbon Sequestration Modalities and Procedures **(06 Lectures).**
Global Carbon Cycle: Stocks and Fluxes of Carbon in terrestrial and marine ecosystems and anthropogenic impact **(06 Lectures).**

UNIT II (10 Lectures)

Policy Perspective: UNFCC, Role and Function of IPCC, Kyoto Protocol and its implication on Developed and developing countries, function of Kyoto Protocol **(06 Lectures).**
Clean Development Mechanism (CDM) and its operation, modalities and procedures for CDM Project **(04 Lectures).**

UNIT III (10 Lectures)

Forestry Perspective: Source or Sink of Carbon, Measuring of Carbon Dioxide **(04 Lectures).**
The Climate Mitigation potential of Forest and its evaluation, Land use, Land use Change and Forestry (LULUCF), Evolution of LULUCF in CDM **(06 Lectures).**

UNIT IV (12 Lectures)

Emissions trading of clean development mechanism (CDM), Difficulties with the CDM **(04 Lectures).**
Financial issues with the CDM, prototype carbon funds (PCF), Carbon Credits and it's trading, carbon finance, and evaluation of Carbon Credit of solar energy systems **(05 Lectures).**
Emissions trading under different article, Carbon foot prints **(03 Lectures).**

Books:

1. Hester R E and Harrison R M, *Carbon Capture: Sequestration and Storage* (Issues in Environmental Science and Technology)
2. Wilson Elizabeth and Gerard David,*Carbon Capture and Sequestration Integrating Technology, Monitoring, Regulation.*
3. Faure Michael, Gupta Joyeeta, Andries and Nentjes, *Climate Change and the Kyoto Protocol: The Role of Institutions and Instruments to Control Global Change*.
4. Bayon Ricardo, Hawn Amanda, Hamilton Katherine,*Voluntary Carbon Markets*.