CURRICULUM

M. TECH. in Renewable Energy

(August 2020 admissions onwards)

BOARD OF STUDIES (BOS)

MEETING: 17 August 2020

Teaching Scheme of Joint Program

SARDAR SWARAN SINGH NATIONAL INSTITUTE OF BIO-ENERGY, KAPURTHALA

DR. B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY JALANDHAR

Programmed Educational Objectives (PEO) for M. Tech in Renewable Energy

S. No.	Programme Educational Objectives
PEO1	To impart knowledge in the recent developments in Energy Sector with emphasis on Renewable Energy including resource assessment, energy harnessing process for various application including power generation.
PEO2	To prepare Graduates to develop into effective collaborators/innovators in efforts to address social, technical and engineering challenges being faced by RE sector
PEO3	To prepare Graduates for innovative and independent research work in academia/industry to develop and maintain renewable energy systems and processes and to deploy the wisdom.
PEO4	To prepare Graduates to exhibit a high level of professionalism, integrity, environmental and social responsibility, and life-long independent learning ability.

Program Outcomes - M.Tech (Renewable Energy)

The course would enable the students to

(a) Resource assessment and mapping, energy planning and implementation techniques including basics of various renewable energy systems and devices with specialization in one of the areas/subareas of various renewable energy technologies,

(b) Understand the contemporary developments and evolve innovative methods/techniques to address the challenges being faced/anticipated to be faced to bring the research and developments into actual use,

(c) Conduct independent experimental and numerical research, as well as to organize, analyze and present data to produce meaningful conclusions.

(d) Understand professional, legal and ethical issues and responsibilities.

(e) Address the environmental issues arose due to conventional energy based economy and to address them with renewable energy for sustainable development.

(f) Acquire skills to share ideas through technical reports, presentations and journal publications.

(g) Learn the project planning and development, project management techniques including financial and economic analysis

(h) Understand the need for, and an ability to engage in life-long learning and continual updating of professional skills.

(i) Work as a team member with leadership skills.

(j) Understand and take active part understanding, formulation and implementation of Govt policies and suggest modification / upgradation time to time.

Structure of Curriculum for M.Tech Programme in Renewable Energy

Duration	Two years (4 semesters)
Number of Courses	10 (Theory); 1 (Practical)
Dissertation work	02 semesters
Total Credits	65
Core Courses (Theory)	10
Department Electives	3

Credit Distribution for M. Tech in Renewable Energy

Category	Sem - I	Sem - II	Sem - III	Sem - IV	Total No. of Credits to be earned
Core Courses	18	12	-	-	30
Electives	3	6	-	-	9
Lab Courses	-	2	-	-	2
Seminar	-	-	3	-	3
Dissertation	-	-	9	12	21
Total	21	20	12	12	65

Proposed Course Structure and Syllabus for M.TECH (Renewable Energy)

FIRST SEMESTER				
S.No.	**Course no.**	**Subjects**	**L-T-P**	**Credit**
1.	**RE-501**	Introduction to Renewable Energy systems	3-0-0	3
2.	**RE-503**	Fundamentals of Energy and Environment	3-0-0	3
3.	**RE-505**	Solar Photovoltaic Devices and Systems	3-0-0	3
4.	**RE-507**	Bio-Energy and Biofuels	3-0-0	3
5.	**RE-509**	Wind and Small Hydro Energy Systems	3-0-0	3
6.	**RE-511**	Process Modeling & Simulation in Renewable Energy Systems	3-0-0	3
7.	**xx-xxx**	Elective I	3-0-0	3
		Total		**21**

SECOND SEMESTER				
S.No.	**Course no.**	**Subjects**	**L-T-P**	**Credit**
1.	**RE-502**	Solar Thermal Technologies and Applications	3-0-0	3
2.	**RE-504**	Energy Conservation, Management & Audit	3-0-0	3
3.	**RE-506**	Economics and Financing of Renewable Energy Systems	3-0-0	3
4.	**RE-508**	Waste to Energy Conversion processes	3-0-0	3
5.	**xx-xxx**	Elective II	3-0-0	3
6.	**xx-xxx**	Elective III	3-0-0	3
7.	**RE-510**	Renewable Energy Lab	0-0-3	2
		Total		**20**

THIRD SEMESTER				
S.No.	**Course no.**	**Subjects**	**L-T-P**	**Credit**
1.	**RE-600**	M Tech Dissertation (Phase I)	0-0-18	9
2.	**RE-601**	Seminar/Industrial Visit	0-0-6	3
		Total		**12**

FORTH SEMESTER				
S.No.	**Course no.**	**Subjects**	**L-T-P**	**Credit**
1.	**RE-600**	M Tech Dissertation (Phase II)	0-0-24	12
		Total		**12**

Electives

Departmental Electives				
S.No.	**Course Code.**	**Subjects**	**L-T-P**	**Credit**
1	**RE-512**	Electric Vehicle	3-0-0	3
2	**RE-513**	Fuel cell and hydrogen energy	3-0-0	3
3	**RE-514**	Solar refrigeration and Air conditioning	3-0-0	3
4	**RE-515**	Energy storage	3-0-0	3
5	**RE-516**	Developing Energy Efficiency and Renewable Energy Projects	3-0-0	3
6	**RE-517**	Energy, Climate Change and Carbon Trade	3-0-0	3
7	**RE-518**	Energy Efficient Buildings	3-0-0	3
8	**RE-519**	Renewable Energy Grid Integration	3-0-0	3
9	**RE-520**	Energy Conservation by Waste Heat Recovery	3-0-0	3
10	**RE-521**	Biomass characterization and management	3-0-0	3
11	**RE-522**	Fuels & Combustion Technology	3-0-0	3
12	**RE-523**	Advanced Waste Water Treatment	3-0-0	3
13	**RE-524**	Power Generation, Distribution & Transmission	3-0-0	3
14	**RE-525**	Nuclear Energy	3-0-0	3

Interdepartmental Electives relevant to the program				
15	**BT-501**	Bioreactor and Bioprocess Design	3-0-0	3
16	**BT-506**	Environmental Biotechnology	3-0-0	3
17	**CE-531**	Geoenvironmental Engineering	3-0-0	3
18	**CE-533**	Solid and Hazardous Waste Management	3-0-0	3
19	**CE-553**	Environmental Risk Assessment	3-0-0	3
20	**CH-520**	Energy Efficiencies in Thermal Utilities	3-0-0	3
21	**CH-522**	Advanced Heat Transfer and Fluid Dynamics	3-0-0	3
22	**CH-525**	Biomass Conversion Processes	3-0-0	3
23	**CH-529**	Environment Impact Assessment	3-0-0	3

24	**CH-535**	Petroleum Engineering and Technology	3-0-0	3
25	**CH-541**	Biorefinery and Bioproducts Engineering	3-0-0	3
26	**IC-596**	Power System Operation and Control	3-0-0	3
27	**ID-601**	Research Methodology	3-0-0	3
28	**IP-524**	Environment Management Systems	3-0-0	3
29	**IP-536**	Design and Analysis of Experiments	3-0-0	3
30	**IP-539**	Sustainable Manufacturing	3-0-0	3
31	**ME-528**	Materials and Sustainable Development	3-0-0	3
32	**ME-555**	Computational Fluid Dynamics	3-0-0	3
33	**ME-565**	Advanced IC Engines	3-0-0	3
34	**ME-566**	Advanced Power Plant Cycles	3-0-0	3
35	**ME-567**	Advanced Steam Power Plants	3-0-0	3
36	**ME-569**	Alternative Fuels for IC Engines	3-0-0	3
37	**ME-571**	Combustion Generated Pollution and Control	3-0-0	3
38	**ME-573**	Exergy Analysis of Thermal & Energy System	3-0-0	3
39	**ME-581**	Photovoltaic Cell and its Applications	3-0-0	3
40	**ME-584**	Solar Passive Design & Sustainable Buildings	3-0-0	3
41	**ME-587**	Waste Heat Utilization and Polygeneration	3-0-0	3

Course Details

First Semester

Course no.	Subject	L-T-P	Credit
RE-501	Introduction to Renewable Energy systems	3-0-0	3

a. Course Objectives

- To provide knowledge of solar energy concept and applications.
- To impart knowledge of geothermal, ocean and tidal energy and their applications.
- To understand the design of wind mills and applications.
- To understand the turbines and generators for small scale hydroelectric generation.
- To understand the important parts of a biogas plant, design and principle of bio-diesel.

b. Course Outcomes

At the end of the course the student will be able to:

CO1. To explain the basic principles of various renewable energy conversion processes and devices used therein

CO2. To identify various parameters that influences the performance of renewable energy devices/processes.

CO3. To undertake the field projects in the area of solar thermal, solar PV, wind, biomass, ocean energy, geothermal etc.

CO4. To identify suitable renewable source and technology for a given requirement To develop the integrated renewable energy technology for decentralized power sector.

c. Course contents

Need of sources of renewable energy: Introduction to different sources of renewable energy, e.g., Solar Energy, Wind Energy, Bio-mass, Geothermal Energy, Ocean energy, Solar Energy and Applications.

Basic concepts of radiations: Solar radiation, Direct and Indirect radiation, Radiation measuring instrument, applications etc.

Solar Energy: Basics of solar thermal applications both low and high temperature ranges such as water heating, air heating, steam generation, desalination of water, crop drying and power generation, Principle of photovoltaics including introduction to various components of a photovoltaic systems for standalone/hybrid/grid connected systems

Wind Energy: Wind Resource assessment including instrumentation used in resource assessment, basic theory of wind, wind power generators both for decentralized applications and grid connected systems, performance characteristics, Augmentation of wind power, Betz criteria

Bioenergy: Types and availability of biomass resources, various methods of biomass utilisation for energy generation: gasification, briquette, palatization, syn-gas, Anaerobic/Aerobic digestion, ethanol and biodiesel production, types of Bio-gas digesters, Combustion characteristics of bio-gas and its different utilizations,

Geothermal Energy: availability and methods of utilisation of geothermal resource for thermal applications and electricity generation

Hydro Energy: Basic principle of hydroelectric power generation, classification of hydropower projects (pico, micro, mini, small hydro sand large hydro projects), types of hydro turbine, various components of hydropower projects.

Ocean Energy: Principles utilization, thermodynamic cycles, tidal and wave energy, potential and conversion technique, Principle of ocean thermal energy conversion system.

Fuel Cells and Hydrogen Energy: Introduction, principle of fuel cells, thermodynamic analysis of fuel cells, types of fuel cells, fuel cell batteries, applications of fuel cells. Hydrogen as a renewable energy source, sources of hydrogen, fuel for vehicles, hydrogen production- direct electrolysis of water, thermal decomposition of water, biological and biochemical methods of hydrogen production.

d. Suggested texts and reference materials

1. Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes, fourth edition, Wiley.
2. Tiwari, G. N., & Ghosal, M. K. (2007). Fundamentals of renewable energy sources. Alpha Science International Limited.
3. Mukherjee, D., & Chakrabarti, S. (2004). Fundamentals of renewable energy systems. New Age International.
4. Sukhatme, S. P. (2005). Solar Energy Principles of Thermal Collection and storage Tata McGraw Hill Publishing Company Ltd. New Delhi.
5. Kothari, D. P., Singal, K. C., & Ranjan, R. (2011). Renewable energy sources and emerging technologies. PHI Learning Pvt. Ltd.

Course no.	Subject	L-T-P	Credit
RE-503	Fundamentals of Energy and Environment	3-0-0	3

a. Course Objectives

To impart basic knowledge to the students about current energy scenario, energy analysis in transportation, buildings etc. To inculcate among the students systematic knowledge and skill about assessing the environment impact of energy use.

b. Course Outcome

CO1. Students will be able to apply the knowledge of the subject to calculate the efficiency of various thermal utilities.

CO2. Students will be able to design suitable energy monitoring system to analyze and optimize the energy consumption in an organization.

CO3. Students will be able to improve the thermal efficiency by designing suitable systems for heat recovery and cogeneration.

CO4. Students will be able to carry out environmental impact of various energy systems.

CO5. Students will be able to guide the employees of the organization about the need and the methods of energy conservation

c. Course contents

Introduction to Global Energy Scenario : Global Energy Requirements , Depletion of Conventional Energy Resources, Need & Availability of Renewable Energy resources, Fallouts of Energy Usage, Application of Carbon Credit. Renewable Energy systems.

Energy Analysis and Thermodynamics : Fundamentals of Thermodynamics (Relationship Between Heat and work) The First Law, The Second Law, Carnot Cycle, Rankine Cycle, Energy Balance (Heat Balance for Steam Process), Energy Balance of Steam Generator.

Energy Analysis of 'Real' Industrial Systems Factories: Process System Optimization, Electrical System Optimization, Cogeneration, Heating Ventilation and Air Conditioning Systems, Principles of Heat Transfer.

Energy Analysis of Real Industrial Systems Transportation Systems: Energy Conservation in Transportation (Pattern of Energy Consumption, Emission Targets for Transportation), New Technologies, Progress in Clean Diesel Technology (Areas of Improvement, Fuel, Engine, Exhaust Systems, Cleaning the Tail Pipe).

Energy Analysis of Real Industrial Systems- Buildings: Energy Consumption in Buildings, Construction Cost Vs Life Cycle Cost, Building Design- Walls and Roof, Heating Ventilation and Air Conditioning (HVAC) Systems, Water Supply Systems, Lighting Systems, Building

Data Loggers and advanced Controls, The Energy Conservation Act 2001, National Building Code of India 2005.

Environmental Impacts of energy use: Sources of pollution: primary and secondary pollutants; Consequence of pollution growth: Air, water, soil, thermal, noise pollution- cause and effect; Air Pollution - SOx, NOx, CO, particulates Solid and Water Pollution Causes of global, regional and local climate change; Pollution control methods; Formation of pollutants, measurement and controls; sources of emissions; Environmental laws on pollution control Global warming: Green House Gas emissions, impacts, mitigation, effect of operating and design parameters on emission, control methods, Exhaust emission test, procedures, standards and legislation; Emission factors and inventories Global Warming, CO2 Emissions, Impacts, Mitigation Sustainability, Externalities, Future Energy Systems, Euro-IV and Euro-VI emission norms.

d. Suggested texts and reference materials

1. Fay, J. A., & Golomb, D. S. (2002) Energy and the Environment. Oxford University Press, New York
2. Mori, Y. H., & Ohnishi, K. (Eds.). (2012). Energy and Environment: Technological Challenges for the Future. Springer Science & Business Media.
3. Allenby, B. (2013). Reconstructing earth: Technology and environment in the age of humans. Island Press. Washington, D.C
4. Jeong, H. W. (2006). Globalization and the Physical Environment. Chelsea House Publishers. Philadelphia
5. Snedden, R. (2007). Science and Society. Gareth Stevens Publishing LLLP. Heinemann Library, Chicago, IL
6. Goldemberg, J. (Ed.). (2009). Interactions: Energy/Environment. Eolss Publishers Company Limited.
7. Wilson, R. F. (2012). Energy, ecology, and the environment. Elsevier.
8. Kaushika, N. D., & Kaushik, K. (2004). Energy, Ecology and Environment: A Technological Approach. Capital Publishing Comapny.

Course no.	Subject	L-T-P	Credit
RE-505	Solar Photovoltaic Devices and Systems	3-0-0	3

a. Course Objectives

This course designed for a detail discussion on the topics related to principle of solar photovoltaic technology to system design. It includes the understanding of physical theories and phenomena of solar cell with inclusion of semiconductor physics. The course also discusses different aspects of solar photovoltaic technologies for applications in building integrated PV, standalone system and power plant system.

b. Course Outcome

CO1. To understand the physical principles of the photovoltaic (PV) solar cell and what are its sources of losses

CO2. To know the electrical (current-voltage and power-voltage) characteristics of solar cell, panel or generator and how the environment parameters influence it

CO3. To know the most important characteristics of the elements within a PV system, battery and charge controller, DC/DC converter, DC/AC converter (inverter) and loads

CO4. To understand the role of solar energy in the context of regional and global energy system, its economic, social and environmental implications, and the impact of technology on a local and global context

CO5. To know the main lines of research in the field of photovoltaic technology and solar energy.

c. Course contents

Solar Radiation: Introduction, Measurement of Solar Radiation on Earth‟s Surface, Sun–Earth Angles, Solar Radiation on a Horizontal Surface, Solar Radiation on an Inclined Surface, Solar Cell Materials and Their Characteristics, Introduction, Doping, Fermi Level, p-n Junction, p-n Junction Characteristics, Photovoltaic Effect, Photovoltaic Material, Basic Parameters of Solar Cells, Effect of Cell Temperature on Cell Efficiency, Current Research on Materials and Devices, Silicon Processing.

PV Array Analysis: Introduction, Solar cell 10 parameters, production of silicon, fabrication of solar cells, design of solar cells, optimization of process parameters, measurements of solar cell parameters; short circuit current, open circuit voltage, fill factor, efficiency, Photovoltaic (PV) Module and Array, Theory and Construction, Series and Parallel Combinations, Balance of PV Array, Partial Shading of Solar Cell and Module, Maximum Power Point Tracker (MPPT), Balance of PV system (BOS), Issues and Challenges of PV system operation and maintenance; Factor affecting the PV system performance;

Role of Batteries and Their Uses: Introduction, Fundamental Principles, Electro-chemical Action, Physical Construction, Discharge Characteristics, Charging Characteristics, Selection of

PV Battery, Batteries Commonly Used for PV, Applications, Battery Installation, Operation and Maintenance, Battery Protection and Regulating Circuits Battery Simulation and Sizing, Battery Lifetime in a PV System, Charging State of PV-powered Storage Batteries, General Terms.

Thermal Modelling of Hybrid Photovoltaic/Thermal (PV/T) Systems: Introduction, PV/T Air Collectors, Hybrid Air Collector, Double-pass PV/T Solar Air Collector, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Tedlar Type PV Module, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Glass Type PV Module, Testing of the Solar Air Collector, PV/T Solar Water Heater, PV/T Solar Distillation System, Active PV/T Distillation System, PV/T Solar Dryers

Energy and Exergy Analysis: Energy Analysis, Energy Matrices, Embodied Energy, Embodied Energy of PV Module (Glass-to- Glass) Balance of System (BOS), Analysis of Embodied Energy and EPBT of PV/T Solar Systems, Energy Pay-back Periods of Roof-mounted Photovoltaic Cells, Exergy Analysis, Importance of Exergy, Exergy of a Process, Exergetic Analysis of Flat-plate Collector, Exergetic Analysis of PV/T Systems.

Economic Analysis: Introduction, Cost Analysis, Cash Flow, Cost Comparisons with Equal Duration, Cost Comparisons with Unequal Duration, Analytical Expression for Payout Time, Net Present Value, Benefit-Cost Analysis, Internal Rate of Return, Effect of Depreciation, Cost Comparisons of Solar Dryers with Duration.

Case Studies of PV Systems: Introduction, Different types of case study, Centralized and decentralized PV systems; Stand alone, hybrid and grid connected system; Grid-connected, Building Integrated, Photovoltaic System (BIPV), Rooftop PV systems, Net and Feed-inTariff mechanism, PV-integrated Water-pumping Application, Simulation of an Existing BIPV System for Indian Climatic Conditions, PV market analysis and economics; National Solar Energy Mission etc.

d. Suggested texts and reference materials

1. Archer, M. D., & Green, M. A. (Eds.). (2001). Clean electricity from photovoltaics. London: Imperial College Press.
2. Solanki, C. S. (2015). Solar photovoltaics: fundamentals, technologies and applications. PHI Learning Pvt. Ltd..
3. Mukerjee, A. K., & Thakur, N. (2011). Photovoltaic Systems: Analysis and Design. PHI Learning Pvt. Ltd.
4. Mohanty, P., Muneer, T., & Kolhe, M. (Eds.). (2015). Solar photovoltaic system applications: a guidebook for off-grid electrification. Springer.
5. Mertens, K. (2018). Photovoltaics: fundamentals, technology, and practice. John Wiley & Sons.
6. Fahrenbruch, A., & Bube, R. (2012). Fundamentals of solar cells: photovoltaic solar energy conversion. Elsevier.

7. Fraas, L. M., & Partain, L. D. (2010). Solar cells and their applications (Vol. 236). John Wiley & Sons.
8. Frank, K., & Kreider, J. F. (1978). Principles of solar engineering. McGraw-Hill Book.

Course no.	Subject	L-T-P	Credit
RE-507	Bio-Energy and Biofuels	3-0-0	3

a. Course Objectives

This course is aimed at dissemination of important information of bioenergy to enable students to acquire knowledge on cutting-edge technologies for conversion of various biomass feedstock to bioenergy / biofuel production and their utilization in combustion engines / devices and fuel cells. On successful completion of the course, the students would be able to contribute towards providing biomass based sustainable energy solutions.

b. Course Outcome

CO1. To characterize different biomass feedstocks based on its constituents and properties

CO2. To understand and evaluate various biomass pretreatment and processing techniques in terms of their applicability for different biomass type for biomass conversion processes

CO3. To understand the process of combustion, pyrolysis, gasification and liquefaction for production of value added bio-products, biogas, bio-CNG generation etc.

CO4. To understand basics of biofuels, their production technologies and applications in various energy utility routes

c. Course contents

Biomass resource assessment: Introduction, Classification and properties of biomass, Biomass characterization, different energy conversion methods, Bio Energy Resources, World Bio Energy Potential, India's Bio Energy Potential, Biomass Resources and classification, Physio-chemical characteristics. Biomass Combustion, Loose biomass densification, Biomass based power generation and utilization for domestic cooking, Improved biomass cookstoves.

Biogas Systems: Technology of Biogas production, Biogas Plants, Digester types, Digester design, Chemical kinetics and mathematical modeling of bio methanation process, Dung, Vegetable Waste and Municipal Waste based Biogas plants, Biogas as fuel for transportation, Lighting, Running Dual Fuel Engines, Electricity generation, Biogas Bottling Plant Technology, Application of Biogas slurry in agriculture, Design of Biogas for cold climates. Case studies and numerical.

Biomass Gasifiers: History , Principle , Design of Bio mass Gasifiers , updraft gasifier, down draft gasifier, zero carbon biomass gasification plants, Gasification of plastic-rich waste, applications for cooking, electricity generation, Gasifier Engines, Operation of spark ignition and compression ignition engine with wood gas, methanol, ethanol and biogas, Biomass integrated gasification/combined cycles systems, gasification, pyrolysis, liquification, biomass pre-treatment and processing, Case studies, biodiesel, improved biomass cookstove, biohydrogen generation, electricity generation from biomass gasifier, engine systems, bio-gasoline, bio-diesel and duel fuel engine, case studies.

Biofuel: Bioethanol production from lignocelluloses, waste material, including crop residue, sugar and starch; biodiesel production from vegetable oil and animal fat, algae; biofuel derived from; economics of biofuel production; environmental impacts of biofuels; biofuel blends; green diesel from vegetable oil; biodiesel production process, by-product utilization**.** Production of butanol and propanol; Production of biohydrogen; production of hydrogen by fermentative bacteria.

Bio-refinery concept: Bio-refinery concept: definition; different types of bio-refinery; challenge and opportunities; Fuel and chemical production from saccharides, lingocellulosic biomass, protein; vegetable oil; algal biorefinery.

d. Suggested texts and reference materials

1. Mutha, V. K. (2010). Handbook of bioenergy and biofuel SBS Publishers, Delhi
2. Clark, J. H., & Deswarte, F. (Eds.). (2014). Introduction to chemicals from biomass. John Wiley & Sons.
3. Klass, D. L. (1998). Biomass for renewable energy, fuels, and chemicals. Elsevier.
4. Mukunda, H. S. (2011). Understanding clean energy and fuels from biomass. Wiley India.
5. Higman C. and Burgt M v d (2003); Gasification, Elsevier Science
6. Speight, J. (2008). Synthetic fuels handbook: properties, process and performance. McGraw-Hill
7. Dahiya, A. (Ed.). (2014). Bioenergy: Biomass to biofuels. Academic Press.
8. Hall, D. O., & Overend, R. P. (1987). Biomass: regenerable energy.
9. San Pietro, A. (Ed.). (2012). Biochemical and photosynthetic aspects of energy production. Elsevier. New York

Course no.	Subject	L-T-P	Credit
RE-509	Wind and Small Hydro Energy Systems	3-0-0	3

a. Course Objectives

This course deals with wind and hydro energy sources and systems in details. The course aimed to teach the students on various aspects of wind and hydro energy resource assessment, conversion process, applications and economics of energy generation.

b. Course Outcome

CO1. To understand wind and hydro energy resource assessment techniques.
CO2. To understand the principles of conversion to useful form of energy from these resources.
CO3. To understand the working principles of the conversion devices, limitations, cost of energy generation and environmental issues

c. Course contents

Basics of Wind Energy: Atmospheric circulations, classification, factors influencing wind, wind shear, turbulence, wind speed monitoring, Wind resource assessment, Weibull distribution, Betz limit, Aerodynamic theories, Axial momentum, Blade element and combine theory, Rotor characteristics, Maximum power coefficient, Tip loss correction

Wind energy conversion systems: Classification, applications, power, torque and speed characteristics Aerodynamic design principles etc, wind turbine design considerations: methodology, theoretical simulation of wind turbine characteristics.

Principle of WEG: Stand alone, grid connected; Hybrid applications of WECS; Wind pumps, performance analysis of wind pumps, design concept and testing, economics of Wind energy utilization, Wind energy Program in India.

Hydrology: Resource assessment, Potential of hydropower in India, Classification of Hydropower Plants, Small Hydropower Systems, Overview of micro, mini and small hydro systems, Status of Hydropower Worldwide and India

Hydraulic Turbines: types and operational aspects, classification of turbines, elements of turbine, selection and design criteria, geometric similarity operating characteristic curves; Speed and voltage regulation Selection of site for hydroelectric plant, Essential elements of hydroelectric power plant

Economics: cost structure, Initial and operation cost, environmental issues related to large hydro projects, Potential of hydro power in North East India

d. Suggested texts and reference materials

1. Johnson G. L. (2006). Wind Energy Systems (Electronic Edition), Prentice Hall
2. Wagner H. and Mathur J. (2011). Introduction to Hydro Energy Systems: Basics, Technology and Operation, Springer Reference Books
3. Hau E. (2000). Wind Turbines: Fundamentals, Technologies, Application and Economics, Springer
4. Mathew S. (2006). Wind Energy: Fundamentals, Resource Analysis and Economics, Springer
5. Burton T. Sharpe D. Jenkins N. and Bossanyi E. (2001). Wind Energy Handbook, John Wiley
6. Nag P. K. (2008). Power Plant Engineering, Third Edition, Tata McGraw Hill
7. Jiandong T. (et al.) (1997). Mini Hydropower, John Wiley

Course no.	Subject	L-T-P	Credit
RE-511	Process Modeling & Simulation in Renewable Energy Systems	3-0-0	3

a. Course Objectives

This course is intended to impart basic skill of model development and optimization in the field of energy. The learners will be familiarized to variety of energy related field problems associated mostly with economy and environment. The main Objectives are to enable learners to develop basic skill of development of energy system model and to enable learners to use system modeling as tool for optimization vis-à-vis decision making on energy related field problems

b. Course Outcome

CO1. To understand modeling, its types and principles

CO2. The learner will understand how to develop a model, and how to apply varies strategies for different parametric model.

CO3. To optimize the energy systems and to understand the working principles econometric modeling

c. Course contents

Introduction to modeling: types and classification, uses, limitations, advantages of modeling; Review of computational tools/techniques used for mathematical modeling including solutions for non-linear equations, system of simultaneous equations, Conservation principles, thermodynamic principles.

Introduction to Development Based on first principles: Steady state and dynamic, Lumped and distributed parameter models, Block diagrams and computer simulation. Modeling of Process elements consisting of Mechanical (translational and rotational), Electrical, Electro-mechanical, Fluid flow, Thermal and Chemical reaction system elements.

Development of Models: Grey box models, Empirical model building, Statistical model calibration and validation. Population balance models, examples of energy system modeling, static and dynamic modeling; Modeling errors, accuracy and methods of model validation

Solution strategies for Lumped parameter models: Solution methods for initial value and boundary value problems, Euler's method, R-K method, Shooting method, Finite difference methods. Finite element and Finite volume methods. Solving the problems using MATLAB / SCILAB.

Optimization: Problem formulation with practical examples from energy system, constrained optimization and unconstrained problems: necessary and sufficiency conditions. Uses of Linear Programming technique for solution of problems related to Energy systems/ case studies. Constrained Optimization, Lagrange multipliers, constrained variations, Kuhn-Tucker conditions, Case studies of optimization in Energy systems problems, Dealing with uncertainty-probabilistic techniques.

Energy systems simulation Optimization: Objectives/constraints, problem formulation. Unconstrained problems, Necessary & Sufficiency conditions.

Econometric modeling: Input Output models considering energy budgeting, Sensitivity analysis, importance of parametric analysis and tools for sensitivity analysis

d. Suggested texts and reference materials

1. Rao S. S. (2004). Engineering Optimization: Theory and Practice, Third Edition, New Age International
2. Kennedy P. (2008). A Guide to Econometrics, Sixth Edition, Wiley-Blackwell
3. Meier P. (1984). Energy Systems Analysis for Developing Countries, Springer Verlag
4. Ravindran A. Ragsdell K. M. and Reklaitis G. V. (2006). Engineering Optimization: methods and applications, Second Edition, Wiley
5. Neufville R. De. (1990). Applied Systems Analysis: Engineering Planning and Technology Management, McGraw Hill
6. Hangos, K., & Cameron, I. (2001). Process modelling and model analysis. Academic Press
7. James, J. C. (1989). Process modeling, simulation and control for chemical engineers. McGraw-Hill.
8. Close, C. M., & Frederick, D. K. (2002). Modeling and analysis of dynamic systems. John Wiley & Sons.

Course Details

Second Semester

Course no.	Subject	L-T-P	Credit
RE-502	Solar Thermal Technologies and Applications	3-0-0	3

a. Course Objectives

This course discusses in details the theory and design aspects of various types of solar thermal collectors. Details of thermal performance of different thermal collector configurations are included. Emphasis has been given to the concentrating collector for power generation and the application of solar energy for industrial process heat. Solar thermal energy storage through different mechanics and processes and also discussed. The course is designed with objectives to make the students capable to analyze the performance of solar thermal systems.

b. Course Outcome

CO1. To understand different aspects and parameters of solar energy to enable learners to design solar thermal system
CO2. The learner will understand different issues and challenges of various solar thermal collectors
CO3. To understand the power generation aspects from solar thermal systems

c. Course contents

Basics for solar thermal system: Different design and components; Radiation transmission and absorption through glazing; Selective surfaces: Ideal coating characteristics, Anti reflection coating;
Flat plate collector: Theory and basic design aspects; Thermal analysis and effective heat loss; Performance analysis methods; Thermal analysis and effective energy loss of evacuated tube collector; Flat plate solar dryer: Issues and challenges.
Concentrating collector: Classification of concentrating collector; concentrating collector configurations; concentration ratio: optical, geometrical; Thermal performance of concentrating collector; Optical and thermal performance of different concentrating collector designs; Parabolic trough concentrators; Compound parabolic concentrator; Concentrators with point focus.
Solar thermal power plant: Central receiver systems; Heliostats; Comparison of various designs: Parabolic trough systems, Rankine cycle, Parabolic Dish - Stirling System, Combined cycle

Solar industrial process heat: Integration of solar thermal system with industrial processes; Mechanical design considerations; Economics of industrial process heat

Solar thermal energy storage: Sensible storage; Latent heat storage; Thermo-chemical storage; High temperature storage; Designing thermal storage systems

d. Suggested texts and reference materials

1. Duffie J. A. and Beckman W. A. (2013), Solar Engineering of Thermal Processes, John Wiley
2. Garg H. P. and Prakash S. (2000), Solar Energy: Fundamental and Application, Tata McGraw Hill
3. Goswami D. Y. (2015), Principles of Solar Engineering, Taylor and Francis
4. Tiwari G. N. (2002), Solar Energy: Fundamentals, Design, Modeling and Applications, Narosa
5. Nayak J. K. and Sukhatme S. P. (2006), Solar Energy: Principles of Thermal Collection and Storage, Tata McGraw Hill
6. Serrano, M. I. R. (2017). Concentrating solar thermal technologies. In Concentrating Solar Thermal Technologies (pp. 11-24). Springer, Cham.
7. Tyagi, H., Chakraborty, P. R., Powar, S., & Agarwal, A. K. (Eds.). (2019). Solar Energy: Systems, Challenges, and Opportunities. Springer Nature.

Course no.	Subject	L-T-P	Credit
RE-504	Energy Conservation, Management & Audit	3-0-0	3

a. Course Objectives

The course discusses about the energy scenario, energy conservation and its importance, energy strategy for the future, energy conservation act-2001 and its features, Kyoto protocol and global warming. The students would learn about the concepts of energy management & audit.

b. Course Outcome

CO1. Students will be able to understand the current energy scenario along with energy management and strategies

CO2. Students will be able to take action on energy conservation techniques.

CO3. Students will acquire the knowledge of financial management

CO4. Students will be able to analyze the data for energy monitoring and targeting.

c. Course contents

Energy Scenario: Commercial and Non-Commercial Energy, Primary Energy Resources, Commercial Energy Production, Energy Needs of Growing Economy, Long Term Energy Scenario, Energy Pricing, Energy Sector Reforms, Energy and Environment: Air Pollution, Climate Change, Energy Security, Energy Conservation and its Importance, Energy Strategy for the Future, Energy Conservation Act-2001 and its Features, Kyoto Protocol, Global warming.

Energy Conservation: Introduction, Energy and heat balances, Methods for preparing process flow chart, material and energy balance in different processes, Sankey diagram, Energy conservation in boilers, Energy conservation in steam systems, Heat exchanger networking, concept of pinch, lighting systems energy efficiency study, Energy conservation opportunities; conservation in buildings, opportunities in compressed air systems, Refrigeration plants etc.

Principles And Objectives of Energy Management: Introduction, Energy Planning, Energy Staffing, Energy Organization, Energy Requirement, Energy Costing, Energy Budgeting, Energy Monitoring, Energy Consciousness Energy Conversions, Energy Efficient Equipment, Energy Management Professionals, Environment Pollution due to Energy Use, Evaluation of alternative Energy Sources

Energy Management & Audit: Definition, Types of energy audit, Energy management (audit) approach-understanding energy costs, Ventilation Audit, Measuring and Detection Instruments for Energy Survey, Scope of Energy audit, Bench marking, Energy performance, Matching energy use to requirement, Maximizing system efficiencies, Optimizing the input energy requirements, Fuel and energy substitution, Energy audit instruments.

Energy Action Planning: Key elements, Force field analysis, Energy policy purpose, perspective, Contents, Formulation, Ratification, Design of Energy Management Programmes, Saving Energy and Implementation of Energy Conservation, location of energy management, Top management support, Managerial function, Roles and responsibilities of energy manager, Accountability. Motivating-motivation of employees: Information system designing barriers, Strategies; Marketing and communicating-training and planning.

Financial Management: Investment-need, Appraisal and criteria, Financial analysis techniques, Simple payback period, Return on investment, Net present value, Internal rate of return, Cash flows, Risk and sensitivity analysis; Financing options, Energy performance contracts and role of ESCOs.

Project Management: Definition and scope of project, Technical design, Financing, Contracting, Implementation and performance monitoring. Implementation plan for top management, Planning Budget, Procurement Procedures, Construction, Measurement & Verification.

Energy Monitoring and Targeting: Defining monitoring & targeting, Elements of monitoring & targeting, Data and information-analysis, Techniques, energy consumption, Production, Cumulative sum of differences (CUSUM).

d. Suggested texts and reference materials

1. Capehart, B. L., Turner, W. C., & Kennedy, W. J. (2006). Guide to energy management. The Fairmont Press, Inc. Atlanta, GA
2. Kumar, Anil, Om Prakash, Prashant Singh Chauhan, and Samsher Gautam. Energy Management: Conservation and Audits. CRC Press, 2020.
3. Thumann, A., & Mehta, D. P. (2001). Handbook of energy engineering. CRC Press.
4. Loftness, Robert L. “Energy Handbook.” 2d ed. New York: Van Nostrand Reinhold Co., 1984.
5. Turner, W. C., & Doty, S. (2013). Energy management handbook (Vol. 2). Lulu Press, Inc.
6. Kenney, W. F. Energy conservation in the process industries. Academic Press, 2012.
7. Kreith, F., & Goswami, D. Y. (Eds.). (2007). Energy management and conservation handbook. CRC Press.
8. Rao, P. S., & Rao, P. R. P. (2000). Environment Management and Audit. Deep and Deep Publications.

Course no.	Subject	L-T-P	Credit
RE-506	Economics and Financing of Renewable Energy Systems	3-0-0	3

a. Course Objectives

Economics of energy and its financing is a broad scientific area which includes topics related to economic aspects of supply and use of energy in society in general and the nation as a whole for its growth and development needs. Hence, it is very important for the students to understand the basics of economic principles that govern the supply and demand of energy in the context of modern civilization. This course aims at bridging the technological aspects of energy resources to that of its economic principles.

b. Course Outcome

CO1. To impart knowledge on fundamentals of economic principles and their applications in the broad field of supply and demand of energy
CO2. To make students inquisitive about the problems of energy economics and arousing their interest on practical problem solving skills.

c. Course contents

Energy economics: Basic concepts, energy data, energy cost, energy balance. Relevance of economic and financial viability evaluation of renewable energy technologies, Basics of engineering economics

Energy accounting framework: Economic theory of demand, production and cost market structure; National energy map of India, Energy subsidy – National and international perspectives

Concepts of economic attributes: Calculation of unit cost of power generation from different sources with examples, different models and methods, Social cost – benefit analysis of renewable energy technologies. Financial feasibility evaluation of renewable energy technologies, Technology dissemination models, Volume and learning effects on costs of renewable energy systems, Dynamics of fuel substitution by renewable energy systems and quantification of benefits

Application of econometrics: input and output optimization; energy planning and forecasting - different methods, Economic approach to environmental protection and management,

Financial incentives: Fiscal, financial and other incentives for promotion of renewable energy systems and their effect on financial and economic viability, electricity tariff types. Financing of renewable energy systems, Carbon finance potential of renewable energy technologies and impact of other incentives. Software for financial evaluation of renewable energy systems. Case studies on financial and economic feasibility evaluation of renewable energy projects.

d. Suggested texts and reference materials

1. Campbell, H. F., & Brown, R. P. (2003). Benefit-cost analysis: financial and economic appraisal using spreadsheets. Cambridge University Press.
2. Kandpal, T. C., & Garg, H. P. (2003). Financial evaluation of renewable energy technologies. MacMillam India Limited.
3. Park, C. S. (2002). Contemporary engineering economics (Vol. 4). Upper Saddle River, NJ: Prentice Hall.
4. Kroemer, K. H., Kroemer, H. B., & Kroemer-Elbert, K. E. (2001). Ergonomics: how to design for ease and efficiency. Pearson College Division.
5. Dorsman, A. B., Ediger, V. Ş., & Karan, M. B. (Eds.). (2018). Energy Economy, Finance and Geostrategy. Springer.
6. Banks, F. E. (2012). Energy economics: a modern introduction. Springer Science & Business Media.
7. Thuesen G. J. and Fabrycky W. J. (2001); Engineering Economy, Ninth Edition, Prentice Hall India
8. Ayyub, B. M. (2014). Risk analysis in engineering and economics. CRC Press.

Course no.	Subject	L-T-P	Credit
RE-508	Waste to Energy Conversion processes	3-0-0	3

a. Course Objectives

- To enable students to understand of the concept of waste to energy.
- To learn about the best available technologies for waste to energy.
- To link legal, technical & management principles for production of energy from waste.

b. Course Outcomes

CO1. To apply the knowledge about the operation of waste to energy plants.
CO2: Analyze the various aspects of waste to energy plant.
CO3: Apply the knowledge in planning & operation of waste to energy plants

c. Course contents

Introduction to energy from waste: characterization and classification of waste as fuel; agro-based, forest residues, industrial waste, Municipal solid waste
Solid Waste Sources: Solid Waste Sources, types compositions and Properties, Municipal Solid Waste, Physical, chemical and biological properties, Waste Collection and transfer stations, Waste minimization and recycling of municipal waste, Segregation of waste, Size Reduction, Managing Waste, Status of technologies for generation of Energy from Waste.
Waste Treatment and Disposal: Aerobic composting, Furnace types and designs, Medical waste /Pharmaceutical waste treatment Technologies, concept of Bioremediation, Incineration, Environmental impacts, Measures to mitigate environmental effects due to incineration
Land Fill method of Solid waste disposal: Land fill classifications, Types, methods and Siting consideration, Layout and preliminary design of landfills: Composition, characteristics, generation, movement and control of landfill leachate and gases, Environmental monitoring system for land fill gases.
Waste to energy options: Biochemical and Thermochemical routes; Biochemical Options – Anaerobic Digestion, Fermentation; Thermochemical Options – Pyrolysis, Gasification and Incineration; Other options – Biodiesel synthesis, Briquetting and Torrefaction, Hazardous waste management;
Energy Generation from Waste (Biochemical Conversion): Sources of energy generation, Anaerobic digestion of sewage and municipal wastes, Direct combustion of MSW-refuse derived solid fuel, Industrial waste, Agro residues, Anaerobic Digestion: Biogas production, Land fill gas generation and utilization, Thermochemical conversion: Sources of energy generation, Gasification of waste using gasifiers, Briquetting, Utilization and advantages of briquetting, Case studies of Commercial Waste to Energy Plants , Present status (National and International) of

Technologies for Conversion of Waste into Energy, Design of Waste to Energy Plants for Cities, small townships and villages.

Properties of fuels derived from waste to energy: Producer gas, Biogas, Ethanol and Briquettes, Comparison of properties with conventional fuels; Landfills: Gas generation and collection in landfills, Introduction to transfer stations

Environmental Impact: Benefits of Biochemical and Thermochemical conversions

d. Suggested texts and reference materials

1. Energy from Waste - An Evaluation of Conversion Technologies by C Parker and T Roberts (Ed),
2. Parker, C., & Roberts, T. (1985). Energy from waste: an evaluation of conversion technologies. Elsevier Applied Science, London.
3. Shah, K. L. (2000). Basics of solid and hazardous waste management technology, Prentice Hall.
4. Christensen, T. H., Cossu, R., & Stegmann, R. (Eds.). (2005). Landfilling of waste: leachate. CRC Press.
5. White, P., Dranke, M., & Hindle, P. (2012). Integrated solid waste management: a lifecycle inventory. Springer Science & Business Media.
6. Klinghoffer, Naomi B., and Marco J. Castaldi, eds. Waste to energy conversion technology. Elsevier, 2013.
7. Kalogirou, E. N. (2017). Waste-to-Energy technologies and global applications. CRC Press.

Course no.	Subject	L-T-P	Credit
RE-510	Renewable Energy Lab	0-0-3	2

a. Course Objectives

The main focus of this laboratory is to provide exposure and hands-on-skills practice to the students on various aspects of renewable energy sources and technology. The students would be able to get detailed insights into the design and operational aspects of renewable energy devices and systems.

b. Course Outcome

CO1. To impart knowledge on fundamentals of economic principles and their applications in the broad field of supply and demand of energy
CO2. To make students inquisitive about the problems of energy economics and arousing their interest on practical problem solving skills.

c. Course contents

Preparation for Laboratory Experiments and report writing Basic concepts: Terminology used in experimental methods i.e. sensitivity, accuracy, uncertainty, calibration and standards; experimental system design and arrangement. Analysis of experimental data, Analysis of causes and types of experimental errors, uncertainty and statistical analysis of experimental data; Error analysis, Technical Communication: Report preparation of experimental work, use of graphs, figures, tables, software and hardware aids for technical communication

Experiments

Solar: Experimental study on thermal performance of solar water heater, solar dryers, solar cooker; solar thermal; solar PV module characterization with different configuration

Biomass: Experimental study on thermal performance and efficiency of biomass downdraft gasifier and sampling and analysis of air and flue gas from biomass energy systems i.e. gasifier, combustor and cook stoves using gas chromatography technique; Liquid bio-fuel production and characterization; Biogas production by anaerobic digestion and analysis.

Wind: Experimental study on Wind Energy Training System, Wind Turbine Emulator etc for power generation and energy assessment due to wind

Fuel: Density, Viscosity, Flash-point, Fire-point Pour-point, ASTM distillation of liquid fuels; Proximate and Ultimate analysis, calorific value of solid fuels

Engine performance analysis: CI engine performance using Diesel fuel, Engine performance analysis using synthesis gas

Instrumentation and control: Use of microprocessor kit, microcontroller, data acquisition and display experiments, performance evaluation of renewable energy systems (solar thermal, solar PV, Wind turbine, biomass gasifier) using microprocessor/microcontroller based data acquisition systems

Energy system Simulation: Photovoltaic system performance analysis using simulation tool; Hybrid energy systems using simulation tool; Building design and thermal performance analysis using simulation tool

d. Suggested texts and reference materials

Necessary laboratory instruction related to lab experiment and brochure will be provided by the lab instructor.

Course Details

Electives

Course Code.	Subject	L-T-P	Credit
RE-512	Electric Vehicle	3-0-0	3

a. Course Objectives

The objective of this course is to provide an advanced level understanding on electric vehicles and batteries that are used in such vehicles. The course will impart knowledge on the fundamental electrochemistry of battery systems, design of electric vehicle, business model, policy, impact etc.

b. Course Outcomes

CO1. To get the knowledge of electric vehicles and batteries systems

CO2. To get the knowledge of design of electric vehicle, business model, policy, impact etc.

c. Course contents

Review of Conventional Vehicle: Introduction to Hybrid Electric Vehicles: Types of EVs, Hybrid Electric Drive-train, Tractive effort in normal driving, Energy consumption Concept of Hybrid Electric Drive Trains

Architecture of Hybrid Electric: Drive Trains, Series Hybrid Electric Drive Trains, Parallel hybrid electric drive trains, Electric Propulsion unit, Configuration and control of DC Motor drives, Induction Motor drives, Permanent Magnet Motor drives, switched reluctance motor

Sizing the drive system: Design of Hybrid Electric Vehicle and Plug-in Electric Vehicle, Energy Management Strategies, Automotive networking and communication, EV and EV charging standards, V2G, G2V, V2B, V2H.

Energy Storage Requirements:- Battery based energy storage and its analysis, Fuel Cell based energy storage and its analysis, Hybridization of different energy storage devices.

Fundamental of Rechargeable batteries: Electrochemistry, Lithium batteries, Nickel metal hydride battery, Lead-acid battery, High temperature batteries for back-up applications, Flow batteries for load leveling and large scale grid application, Battery applications for stationary and secondary use, Battery chargers and battery testing procedures, Battery management, Regulations and safety aspects of high voltage batteries, Super capacitors.

Business: E-mobility business, electrification challenges, Business- E-mobility business, electrification challenges, Connected Mobility and Autonomous Mobility- case study E-mobility Indian Roadmap Perspective.

Policy: EVs in infrastructure system, integration of EVs in smart grid, social dimensions of EVs. Simulations and case studies in above mentioned areas.

d. Suggested texts and reference materials

1. Emadi, A. (Ed.). (2014). Advanced electric drive vehicles. CRC Press.
2. Larminie, J., & Lowry, J. (2012). Electric vehicle technology explained. John Wiley & Sons.
3. Fenton, J., & Hodkinson, R. (2001). Lightweight electric/hybrid vehicle design. Elsevier.
4. Dincer, I., Hamut, H. S., & Javani, N. (2016). Thermal management of electric vehicle battery systems. John Wiley & Sons.
5. Williamson, S. S. (2013). Energy management strategies for electric and plug-in hybrid electric vehicles. New York, NY: Springer.
6. Pistoia, G., & Liaw, B. (Eds.). (2018). Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety, and Cost. Springer.
7. Reddy, T. B. (2011). Linden's handbook of batteries (Vol. 4). New York: Mcgraw-hill.
8. Larminie, J., & Lowry, J. (2012). Electric vehicle technology explained. John Wiley & Sons.

Course Code.	Subject	L-T-P	Credit
RE-513	Fuel cell and hydrogen energy	3-0-0	3

a. Course Objectives

Fuel cell is an electrochemical device that converts chemical energy to electrical energy. The basics of fuel cell and the fundamental principle associated with it are presented in this course. However, the primary focus of the course is on the fundamental principles and processes in proton exchange membrane fuel cells, direct methanol fuel cells, and solid oxide fuel cells. Special topics in the cutting-edge technologies including the future direction of fuel cell and hydrogen technology are also covered. This course also imparts comprehensive and logical knowledge of hydrogen production, storage and utilization.

b. Course Outcomes

CO1. To understand the fundamentals of various types of fuel cell system, its components and characterization

CO2. To understand comprehensive background in fuel cell base systems and hydrogen technologies

CO3. To understand hydrogen generation techniques, storage and hydrogen economy.

c. Course contents

Fuel cells: Introduction and overview, operating principle, polarization curves, components, types of fuel cell, low and high temperature fuel cells, fuel cell stacks.

Thermodynamics and Electrochemistry of fuel cell: application of the first and second law to fuel cells, significance of the Gibbs free energy, concept of electrochemical potential and emf, halfcell potentials and the electrochemical series, Faraday's law, Nernst equation, Butler–Volmer theory thermodynamic efficiencies of fuel cell in comparison to Carnot efficiencies, thermodynamic advantage of electrochemical energy conversion

Fuel cell technology: Types of Fuel Cells, Fuel Cell systems and sub-systems, system and subsystem integration; Power management, Thermal management; Pinch analysis

Fuel cell characterization: In-situ and Ex-situ; System and components' characterization modeling a Fuel Cell

Hydrogen Production: Properties of hydrogen as fuel, General introduction to infrastructure requirement for hydrogen production, Thermal-steam reformation, Thermo-chemical water splitting, Gasification-pyrolysis, Storage, Dispensing and utilization, Hydrogen Storage, Metal hydrides, chemical hydrides, carbon nano-tubes; sea as the source of Deuterium, methane hydrate, etc.

Hydrogen Economy: Hydrogen as an alternative fuel in IC engines; Suitability of Hydrogen as a fuel, and techno-economic aspects of fuel cell as energy conversion device; Hydrogen fuel for transport

Bio-Hydrogen: Production of bio hydrogen; production of hydrogen by fermentative bacteria, Hydrogen, Methane and Other Energy Fuels Energy from Algae: Algae Cultivation, Photo-bioreactors,

Hydrogen Storage, Utilization and Safety: Physical and chemical properties, General storage methods, Compressed storage-composite cylinders, Glass micro sphere storage, Zeolites, Metal hydride storage, Chemical hydride storage, Cryogenic storage, Carbon based materials for hydrogen storage, Overview of hydrogen utilization, Hydrogen burners, Power plant, Marine applications, Hydrogen dual fuel engines, Hydrogen safety aspects, Backfire, Pre-ignition, Hydrogen emission, NOx control techniques and strategies, Hydrogen powered vehicles

d. Suggested texts and reference materials

1. O'Hayre R. P., Cha S. W., Colella W., and Prinz F. B., (2008). Fuel cell fundamentals, John Wiley
2. Larminie J., Dicks A. and McDonald M. S. (2003). Fuel cell systems explained. Vol. 2, Wiley
3. Zhang J. (2008), PEM Fuel Cell Electrocatalysts and Catalyst Layers: Fundamentals and Applications, Springer
4. Spiegel C. (2011), PEM Fuel Cell Modeling and Simulation Using Matlab, Elsevier Science.
5. Vielstich W., Lamm A., and Gasteiger H. A. (2003), Handbook of Fuel Cells: Fundamentals, Technology, Applications, Vol (1-4), Wiley
6. Gupta R. B. (2008), Hydrogen Fuel: Production, Transport and Storage, CRC Press
7. Sørensen, B., & Spazzafumo, G. (2018). Hydrogen and fuel cells: emerging technologies and applications. Academic Press.
8. Hordeski, M. F. (2009). Hydrogen & fuel cells: advances in transportation and power. The Fairmont Press, Inc..
9. Gupta, R. B. (Ed.). (2008). Hydrogen fuel: production, transport, and storage. Crc Press.
10. Töpler, J., & Lehmann, J. (2016). Hydrogen and Fuel Cell. Springer: Berlin/Heidelberg, Germany.

Course Code.	Subject	L-T-P	Credit
RE-514	Solar refrigeration and Air conditioning	3-0-0	3

a. Course Objectives

The course main objectives are:

- To provide understanding of fundamental concepts of solar operated refrigeration and air conditions.
- To provide fundamental knowledge desiccant material and desiccant air conditioning systems.
- To provide understanding of fundamental concepts the solar adsorption refrigeration system.
- To understand the design of solar powered absorption refrigeration system and its applications.

b. Course Outcomes

CO1. To get the knowledge of solar vapor compression and vapor absorption system.
CO2. To get the knowledge of design of adsorption refrigeration and absorption refrigeration system.

c. Course contents

Introduction: Basics of refrigeration and air conditioning, comfort zones, potential and scope of solar cooling and heating, fundamentals of conventional vapour compression system and vapour absorption system**.** Solar cooling technology: solar electrical cooling, solar thermal cooling:- open cycles (liquid and solid desiccant system), closed cycle (absorption cycle, adsorption cycle, solar radiation cooling), thermo mechanical systems, steam ejector cycle, solar combined power/cooling.

Desiccant Air Conditioning: Desiccant materials, classification of desiccant material, fundamentals of desiccant material: adsorption process, regeneration process, adsorption rate, regeneration rate, factor affecting adsorption and regeneration of desiccant material, heating/humidification, cooling/dehumidification, desiccant dehumidifiers: desiccant bed, desiccant wheel, desiccant coated heat exchanger, solar powered desiccant air conditioning system**.**

Adsorption Refrigeration System: Introduction, principle of adsorption, thermodynamics of adsorption cycles: - basic adsorption cycle, heat recovery adsorption refrigeration cycle, mass recovery adsorption refrigeration cycle, thermal wave cycle, convective thermal wave cycle, intermittent adsorption systems: silica-gel/water and silica-gel methanol systems, zeolite–water systems, activated carbon–methanol systems, activated carbon–ammonia systems.

Absorption Refrigeration System: Absorption cycle of operation, maximum, COP, properties of solution, aqua-ammonia solution, simple absorption system, h-x diagram, ammonia enrichment process and water -lithium bromide refrigeration system, single-effect solar absorption cycle, half-effect solar absorption cooling system, double-effect solar-assisted absorption cooling systems, diffusion absorption solar cooling system, hybrid solar absorption cooling systems.

Potential and scope of solar cooling: Types of solar cooling systems, solar collectors and storage systems for solar refrigeration and airconditioning, Solar operation of vapour absorption and compression refrigeration cycles and their assessment, Solar dessicant cooling system. Open cycle absorption/desorption solar cooling alternatives, advanced solar cooling systems, refrigerant storage for solar absorption cooling systems, solar thermoelectric refrigeration and air conditioning. Economics of solar cooling

d. Suggested texts and reference materials

1. Mugnier, D., Neyer, D., & White, S. D. (Eds.). (2017). The solar cooling design guide: case studies of successful solar air conditioning design. John Wiley & Sons.
2. McVeigh, J. C., & Sayigh, A. A. M. (Eds.). (2012). Solar air conditioning and refrigeration. Newnes. Pergamon.
3. Prasad, M. (2011). Refrigeration and air conditioning. New Age International.
4. Wang, R., & Ge, T. (Eds.). (2016). Advances in solar heating and cooling. Woodhead Publishing.
5. Garg, H. P. (1987). Solar Refrigeration and Air-Conditioning. In Advances in Solar Energy Technology (pp. 342-442). Springer, Dordrecht.
6. Althouse, A. D., Turnquist, C. H., Bracciano, A. F., Bracciano, D. C., & Bracciano, G. M. (2004). Modern refrigeration and air conditioning. Goodheart-Willcox.

Course Code.	Subject	L-T-P	Credit
RE-515	Energy storage	3-0-0	3

a. Course Objectives

This course covers all types of currently-available energy storage systems, which are, or can be, used in the electricity, heat and transport sectors. The various technologies discussed may be categorized as mechanical/kinetic, thermodynamic, electrical, chemical, electrochemical or thermal processes.

b. Course Outcomes

CO1. To understand the theory and applications of different energy storage devices

CO2. Learners will identify the optimal (appropriateness, cost and sustainability) solutions to any potential energy storage application.

c. Course contents

Energy availability: Demand and storage, Need for energy storage, Different types of energy storage; Mechanical, Chemical, Electrical, Electrochemical, Biological, Magnetic, Electromagnetic, Thermal; Comparison of energy storage technologies.

Thermal energy storage: principles and applications, Sensible and Latent heat, Phase change materials; Energy and exergy analysis of thermal energy storage, solar energy and thermal energy storage, case studies.

Mechanical Energy storage: Flywheel and compressed air storage; Pumped hydro storage; Hydrogen energy storage, Capacitor and super capacitor, Electrochemical Double Layer Capacitor: Principles, performance and applications

Electrochemical energy storage: Battery – fundamentals and technologies, characteristics and performance comparison: Lead-acid, Nickel-Metal hydride, Lithium Ion; Battery system model, emerging trends in batteries.

Hydrogen as energy carrier and storage: Hydrogen resources and production; Basic principle of direct energy conversion using fuel cells; Thermodynamics of fuel cells

Fuel cell types: AFC, PEMFC, MCFC, SOFC, Microbial Fuel cell, Fuel cell performance, characterization and modeling; Fuel cell system design and technology, applications for power and transportation.

Application of Energy Storage: Food preservation, Waste heat recovery, Solar energy storage: Greenhouse heating; Drying and heating for process industries.

d. Suggested texts and reference materials

1. Dincer I., and Rosen M. A. (2011); Thermal Energy Storage: Systems and Applications, Wiley

2. Huggins R. A. (2015). Energy Storage: Fundamentals, Materials and Applications. Springer
3. O'Hayre R., Cha S., Colella W., and Prinz F. B. (2009). Fuel Cell Fundamentals, Second Edition, Wiley
4. Narayan R. and Viswanathan B. (1998). Chemical and Electrochemical Energy System, Universities Press
5. Rahn C. D. and Wang C. (2013). Battery Systems Engineering, First Edition, Wiley
6. Moseley P. T., and Garche J. (2014). Electrochemical Energy Storage for Renewable Sources and Grid Balancing, Elsevier Science.
7. Miller F. P., Vandome A. F., and John M. B. (2010). Compressed Air Energy Storage, VDM Publishing

Course Code.	Subject	L-T-P	Credit
RE-516	Developing Energy Efficiency and Renewable Energy Projects	3-0-0	3

a. Course Objectives

To introduce all relevant steps as well as the issues and challenges involved in developing projects on energy efficiency and renewable energy utilization. The course also aims at discussion on policy, regulatory and other support measures that can promote such projects

b. Course Outcomes

CO1. To understand the fundamentals of various types of fuel cell system, its components and characterization

CO2. To understand comprehensive background in fuel cell base systems and hydrogen technologies

CO3. To understand hydrogen generation techniques and hydrogen economy.

c. Course contents

Relevance of developing energy efficiency: Renewable energy projects, Key project development concepts,

Project motivation: Key drivers-pre development, gauging market characteristics that provide motivation for the project and assessment of market readiness, Project development framework, Essential elements, project development environment including existing policy environment-relevant codes (such as ECBC),

Pre-investment phase: assessing potential sites, identifying partners, Assessment of commercially available energy technologies for improving energy efficiency and harnessing renewable energy, preparation of business plan (that includes feasibility study, engineering design, Financial closure, permitting activities and related documentation and agreements), consensus with project stakeholders

Implementation phase: Procurement, land acquisition, site preparation, construction, installation, commissioning of the project, operation of the facility, Actual implementation of the business plan, Monitoring and evaluation of the business and the project performance, Issues in implementation of energy efficiency and renewable energy projects, Essential areas for strong project development in renewable energy - site, resource, permits, technology, team and capital, Size and diversity of potential project sponsors and also of projects in the field of renewable energy and energy efficiency,

Risks Factor: Risk in energy efficiency and renewable energy projects and appropriate de-risking/ mitigation measures and approaches, dispute resolution,

Role of policies: Policy and support measures in promoting energy efficiency and renewable energy, Developing community driven projects, Developing projects for improving energy access, socially inclusive projects,

Issue and Challenges: Issues in using public lands for developing renewable energy projects, Various considerations in selecting local versus imported technologies, Challenges in implementing energy efficiency in public sector within government financial and other regulations, Environmental impact and sustainability assessment of energy efficiency and renewable energy projects and projects while addressing environmental issues, Utility scale versus local projects,

Examples and Case Studies: developing PV/wind power projects, projects for enhanced LED use in domestic, commercial, institutional and industrial sectors, environmental management projects.

d. Suggested texts and reference materials

1. Lokey, E. (2012). Renewable energy project development under the clean development mechanism: a guide for Latin America. Routledge.
2. Springer, R. (2013). Framework for Project Development in the Renewable Energy Sector (No. NREL/TP-7A40-57963). National Renewable Energy Lab.(NREL), Golden, CO (United States).
3. Ontario Sustainable Energy Association. (2010). Guide to developing a community renewable energy project in North America. Montreal, Canada
4. PVPS, I. (2003). 16 Case Studies on the Deployment of Photovoltaic Technologies in Developing Countries. International Energy Agency IEA-PVPS.T9-07
5. Trieb, F. (2006). Concentrating solar power now. DLR, Berlin, Germany.
6. Guide, L. S. R. E. (2003) Developing Renewable Energy Projects Larger Than 10 MWs at Federal Facilities. Report DOE/GO-102013-3915, US Department of Energy
7. Thomsen, K. (2014). Offshore wind: a comprehensive guide to successful offshore wind farm installation. Academic Press.
8. Winebrake, J. J. (Ed.). (2004). Alternate energy: Assessment and implementation reference book. The Fairmont Press, Inc..
9. Chuck, C. (Ed.). (2016). Biofuels for aviation: feedstocks, technology and implementation. Academic Press.

Course Code.	Subject	L-T-P	Credit
RE-517	Energy, Climate Change and Carbon Trade	3-0-0	3

a. Course Objectives

The role of energy is increasingly important with growing environmental constraints, international pressure on climate change compliance and increasing trend in energy consumption. This course deals with science of climate change, factors causes' climate to change across different time scales and possible consequences of climate change. Carbon trading is a market mechanism designed to put a price on carbon in order to reduce carbon dioxide emissions and helps to reduce the emission. Carbon trading forms a part of the wider sustainability issue and it is helpful for students to understand the concept and implications of carbon trading.

b. Course Outcomes

CO1. The course makes the students inquisitive about the current problems of climate change, international pressure on climate change compliance and competition for energy and global initiative to address the issue

CO2. To understand the concept and implications of carbon trading to reduce the emission.

c. Course contents

Energy and Climate Change: Global Consensus, GHGs emission and energy activities; Montreal protocol, evidence and predictions and impacts, Clean energy technologies, Energy economy, Risk and opportunities; Measures to reduce GHGs; Role of renewable energy, Evidence of economic impacts of climate change and economics of stabilizing greenhouse gases.

Climate Change Act: Kyoto Protocol and CDM, Governments policies for mitigation and adaptation, National Action Plan on Climate change, Nationally Appropriate Mitigation Actions (NAMA), Intended Nationally Determined Contributions (INDCs).

New Industrial Emissions Directive: Categorization of Scope 3 Emissions for Streamlined Enterprise Carbon Foot printing, Calculating Scope 3 Emissions

Emissions: Carbon dioxide (CO_2) emissions due to energy conversion; combustion physics; case studies and comparison of (i) different technologies and (ii) different resources used for energy conversion; Role of technology up-gradation and alternative resources on reduction of CO2 emission; Methodology for CO2 assessment; UNFCCC baseline methodologies for different conversion process, estimation of emission from fossil fuel combustion; Case studies

Carbon credit: concept and examples; Commerce of Carbon Market, Environmental transformation fund; Technology perspective: Strategies for technology innovation and transformation; future prospect/limitation of carbon trading mechanism

d. Suggested texts and reference materials

1. Mathez E. A. (2009). Climate Change: The Science of Global Warming and Our Energy Future, First edition, Columbia University Press
2. Dessler A. (2011). Introduction to Modern Climate Change, Cambridge University Press
3. Stern N. (2007). The Economics of Climate Change. The Stern Review. Cambridge University Press
4. IPCC (Intergovernmental for Climate Change), Climate Change (2007). Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press
5. Yamin F. (ed) (2005). Climate Change and Carbon Markets: A Handbook of Emissions Reduction Mechanisms, Earthscan
6. Franchetti M. J. and Apul D. S. (2013). Carbon Footprint Analysis: concepts, methods, implementation and case studies, CRC Press

Course Code.	Subject	L-T-P	Credit
RE-518	Energy Efficient Buildings	3-0-0	3

a. Course Objectives

Buildings consume energy both in construction and operations. However, energy consumption in operation of buildings is approximately more than 80% of total energy consumption. Principles of building physics that are required for understanding the thermal performance of buildings will have specific focus for the design of the energy efficient buildings. This course includes an overview of the main design features of different types of buildings, advantages and disadvantages and their applicability to different building types and climatic regions. This course aims to provide an understanding on the concept of reduction in energy consumption through energy efficient building design.

b. Course Outcomes

CO1. To understand the principles of energy auditing, energy flow diagram, economics of energy conservation opportunities in buildings
CO2. To understand thermal performance study, building performance simulation and thermal comfort
CO3. To understand the energy conservation buildings codes, rating systems and case studies on energy efficient buildings in India.

c. Course contents

Energy management concept in building: Energy auditing in buildings, Bioclimatic classification of India; Climate Analysis for Nat-Vent Buildings, Mixed Mode Buildings and Conditioned building; Passive design concepts for various climatic zones; Case studies on typical design of selected buildings in various climatic zones
Vernacular architecture: Vernacular architecture in Indian Context, Factors which shape the architecture, building material and construction techniques; Case studies on vernacular architecture of Rajasthan, North-East India; Low cost buildings, climate responsive buildings, energy efficient buildings, green buildings, intelligent buildings, Building Integrated Photovoltaics (BIPV), Green Buildings in India; Case studies
Building codes and Rating systems: LEED, GRIHA, ECBC, Thermal properties and energy content of building materials; Building energy simulation, Simulation tool like TRANSYS, eQuest; Building management systems/automation, Artificial and daylighting in buildings
Thermal performance studies: concept of comfort and neutral temperatures, Thermal comfort, PMV-PPD models, Thermal comfort models, Adaptive thermal comfort models, case studies

Heat flow calculations in buildings: Unsteady heat flows through walls, roof, windows etc. Concept of sol-air temperature and its significance; heat gain through building envelope; building orientation; shading and overhangs; Ventilation and Air-conditioning systems

Passive heating concepts: Passive and low energy concepts and applications, Direct heat gain, indirect heat gain, isolated gain and sunspaces; 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

d. Suggested texts and reference materials

1. Sodha M. S. Bansal N. K. Bansal P. K. Kumar A. and Malik M. A. S. (1986). Solar Passive Building, Science and Design, Pergamon Press
2. Gallo C. Sala M. and Sayigh A. A. M. (1988). Architecture: Comfort and Energy, Elsevier Science
3. Nayak J. K. and Prajapati J. A. (2006). Handbook on Energy Conscious Buildings; Solar Energy Centre, New Delhi
4. Underwood C. P. and Yik F. W. H. (2004). Modelling Methods for Energy in Buildings, Blackwell Publishing
5. Parsons K. C. (2003). Human Thermal Environments, Second edition, Taylor and Francis
6. Majumder M. (2009). Energy Efficient Buildings, TERI, New Delhi
7. Nicol F. (2007). Comfort and Energy Use in Buildings- Getting Them Right, Elsevier

Course Code.	Subject	L-T-P	Credit
RE-519	Renewable Energy Grid Integration	3-0-0	3

a. Course Objectives

The generation of electricity from renewable energy sources includes technologies such as hydropower, wind power, solar power, tidal and wave power, geothermal power, and power from renewable biomass. These sources are termed as distributed power generators and they need to be integrated among themselves and with the conventional power grid for storage and uninterrupted power flow. Grid integration is an important aspect of renewable energy engineering and needs to be formally studied.

b. Course Outcomes

CO1. To understand the distributed generation systems, to identify emerging issues with it, and thus understand the requirements for the correct integration of renewable energies into the power grid.
CO2. To understand power electronic components necessary for integration to include inverters and their control, island detection systems, and maximum power point tracking.

c. Course contents

Power system operation: Introduction on electric grid, Supply guarantees, power quality and Stability, Introduction to renewable energy grid integration, concept of mini/micro grids and smart grids; Wind, Solar, Biomass power generation profiles, generation electric features, Load scheduling
Power electronic systems: Introduction to basic analysis and operation techniques on power electronic systems; Functional analysis of power converters, Power conversion schemes between electric machines and the grid, Power systems control using power converters; Electronic conversion systems application to renewable energy generation systems, Basic schemes and functional advantages; Wind Power and Photovoltaic Power applications
Power control and management systems: Grid integration, island detection systems, synchronizing with the grid; Issues in integration of converter based sources; Network voltage management; Power quality management and Frequency management; Influence of PV/WECS on system transient response
Simulation: tools, Simulation of grid connected/off grid renewable energy system (PV/WECS); Design of grid-interactive photovoltaic systems for house hold applications.

d. Suggested texts and reference materials

1. Kersting W. H. (2004). Distribution System Modeling and Analysis, Second Edition, CRC Press
2. Vittal V. and Ayyanar R. (2012). Grid Integration and Dynamic Impact of Wind Energy, Springer
3. Bollen M. H. and Hassan F. (2011). Integration of Distributed Generation in the Power System, Wiley-IEEE Press
4. Keyhani A. (2011). Design of Smart Power Grid Renewable Energy Systems, Wiley–IEEE Press
5. Muhannad H. R. (2004). Power Electronics: Circuits, Devices and Applications, Pearson Prentice Hall
6. Gellings C. W. (2009). The Smart Grid: Enabling Energy Efficiency and Demand Response, First Edition, CRC Press
7. Teodorescu R. Liserre M. Rodriguez P. (2011). Grid Converters for Photovoltaic and Wind Power Systems, First Edition, Wiley-IEEE Press

Course Code.	Subject	L-T-P	Credit
RE-520	Energy Conservation by Waste Heat Recovery	3-0-0	3

a. Course Objectives

The industrial sector accounts for about 40 percent of the total energy consumed in India and are responsible for around one fourth of the total greenhouse gas emissions. This share is more than half of the total GHG emissions, if energy industries are considered together. It is estimated that somewhere between 30 to 50% of industrial energy input is lost as waste heat in the form of exhaust gases, cooling water, and heat lost from equipment surfaces and heated products. As the industrial sector continues efforts to improve its energy efficiency, recovering waste heat losses provides an attractive opportunity for an emission free and less costly energy resource

b. Course Outcomes

CO1. To understand the on basic principles and available technologies for waste heat recovery.
CO2. To understand industrial waste heat recovery systems

c. Course contents

Introduction: heat losses, its quality and quantity, potential for energy conservation. Waste heat sources: steam, compressed air, refrigeration, flue gases, furnace/air stream exhaust, high grade heat, low grade heat
Optimal utilization of fossil fuels: Total energy approach; Coupled cycles and combined plants; Cogeneration systems
Exergy analysis: Utilization of industrial waste heat; Properties of exhaust gas; Gas-to- gas, gas-to-liquid heat recovery systems; Recuperators and regenerators; Shell and tube heat exchangers; Spiral tube and plate heat exchangers
Waste heat boilers: various types and design aspects. Heat pipes: theory and applications in waste heat recovery.
Prime movers: sources and uses of waste heat; Fluidized bed heat recovery systems; Utilization of waste heat in refrigeration, heating, ventilation and air conditioning systems; Thermoelectric system to recover waste heat; Heat pump for energy recovery; Heat recovery from incineration plants
Waste Heat Recovery calculations: Quantifying available heat (kWh), Pinch analysis, typical energy costs/construction costs, pay back analysis, thermo-economic viability.
Need for energy storage: Thermal, electrical, magnetic and chemical storage systems.

d. Suggested texts and reference materials

1. Hewitt, G. F., Shires, G. L., and Bott, T. R. (1993). Process Heat Transfer, CRC Press, Florida.
2. Flynn, A. M., Akashige, T., & Theodore, L. (2019). Kern's Process Heat Transfer. John Wiley & Sons.
3. Goswami, D. Y., and Kreith, F. (2007). Energy Conversion, CRC Press.
4. Serth, R. W., & Lestina, T. (2014). Process heat transfer: Principles, applications and rules of thumb. Academic press.
5. Beith, R. (Ed.). (2011). Small and micro combined heat and power (CHP) systems: advanced design, performance, materials and applications. Elsevier.
6. Khanna, S., & Mohan, K. (Eds.). (1996). Wealth from waste. Tata Energy Research Institute.
7. Eriksen, V. L. (Ed.). (2017). Heat Recovery Steam Generator Technology. Woodhead Publishing.

Course Code.	Subject	L-T-P	Credit
RE-521	Biomass characterization and management	3-0-0	3

a. Course Objectives

There is an immense prospect in the biomass feedstocks to address the growing energy demands. However biomass recalcitrant that is not easy to break into simple sugars and varied physio-chemical attributes of biomass that is biomass growing at different regions, seasons and field conditions showing varied physio-chemical properties impede the biomass energy conversion process largely. Overall, this course provides overall information on concepts, tools and techniques for converting the different biomass into various energy forms for starting the biomass based energy production and its management.

b. Course Outcomes

CO1. To understand the on basics of biomass resources and it composition
CO2. To understand biomass sample preparation, methods of pre-treatments and characterization
CO3. To understand and analyze the biochemical and ultimate properties of biomass
CO4. To understand supply chain methods of biomass management.

c. Course contents

Introduction: properties of biomass, different energy conversion methods combustion, Bio Energy Resources, World Bio Energy Potential, India's Bio Energy Potential, Biomass Resources and classification, Physio - chemical characteristics

Biomass Cookstoves: Energy Systems Energy Efficient Wood Stoves**,** Traditional Stoves, Energy Efficient Cooking and Space heating Stoves, Metal Stoves Improved Gasifier Stoves , Current Research Status, Pollution due to smoke emissions, Improved Cookstoves, National Policy on cookstove

Characterization of biomass feedstock: physico-chemical properties, ultimate, proximate, compositional, calorific value, thermogravimetric, differential thermal and ash fusion temperature analyses; classification of biomass feedstock

Application of biomass fuel: Biomass based incineration plant for heat generation; co-firing of biomass for heat generation for industrial processes; Biomass fuelled combustion devices for cooking and heating applications; Utilization of biomass in external combustion engines including steam turbine power plant and Stirling engines; Case studies for setting up biomass based small power plant (~ 1MW) capacity for rural electrification; analysis of carbon neutral and carbon credit.

Biomass Management: Introduction to biomass management, biomass resource assessment management techniques/supply chains, Processing of paddy straw, densification-Extrusion process, pellets, mills and cubers, Bailing-classification, uses; residue management for surface mulch and soil incorporation, Paddy Straw choppers and spreaders as an attachment to combine Harvester, Mulch seeder, Paddy Straw Chopper-cum-Loader, Balar for collection of straw; Processing of straw/ fodder for animal use; Agricultural and horticultural use, Cushioning material for fruits and vegetables, Mulching and Composting, Paper and cardboard manufacturing, Straw as a fuel.

Biomass resource assessment management techniques/supply chains: Elements of an Assessment or Feasibility Study , Objectives of biomass resource assessment, Biomass resource from agricultural and residues, Biomass resource from forestry, Biomass resource from live stock (animals), Technologies available for the conversion of biomass, Techno-economic feasibility of suitable renewable energy generation system

d. Suggested texts and reference materials

1. Cheng, J. (Ed.). (2017). Biomass to renewable energy processes. CRC press.
2. Strezov, V., & Anawar, H. M. (Eds.). (2018). Renewable Energy Systems from Biomass: Efficiency, Innovation and Sustainability. Crc Press.
3. Holm-Nielsen, J., & Ehimen, E. A. (Eds.). (2016). Biomass supply chains for bioenergy and biorefining. Woodhead Publishing.
4. Jeguirim, M., & Limousy, L. (Eds.). (2019). Char and Carbon Materials Derived from Biomass: Production, Characterization and Applications. Elsevier.
5. Mukunda, H. S. (2011). Understanding clean energy and fuels from biomass. Wiley India.
6. Tumuluru, J. S. (Ed.). (2018). Biomass preprocessing and pretreatments for production of biofuels: mechanical, chemical and thermal methods. CRC Press.
7. Dayton, D. C., & Foust, T. D. (2019). Analytical Methods for Biomass Characterization and Conversion. Elsevier.

Course Code.	Subject	L-T-P	Credit
RE-522	Fuels & Combustion Technology	3-0-0	3

a. Course Objectives

- To impart knowledge on fossil fuel and their combustion characteristics.
- To make students inquisitive about the problems of combustion.

b. Course Outcomes

CO1: To understand the fuel combustion process.
CO2: Apply fundamental aspects of combustion related problem and an understanding on the combustion appliances

c. Course contents

Basics of fuels: Modern concepts of fuel, Solid, liquid and gaseous fuels, composition, basic understanding of various properties of solid fuels - heating value, ultimate analysis, proximate analysis, ash deformation points; liquid fuels - heating value, density, specific gravity, viscosity, flash point, ignition point (self, forced), pour point, ash composition and gaseous fuels.
Coal as a source of energy: Coal reserves – World and India, Coal liquefaction process, various types of coal and their properties, Origin of coal, composition of coal, analysis and properties of coal, Action of heat on coal, caking and coking properties of coal; Processing of coal: Coal preparations, briquetting, carbonization, gasification and liquefaction of coal, Coal derived chemicals.
Petroleum as a source of energy: Origin, composition, classification of petroleum, grading of petroleum; Processing of petroleum: Distillation of crude petroleum, petroleum products, purification of petroleum products – thermal processes, catalytic processes, specifications and characteristics of petroleum products.
Natural gas and its derivatives: Classification of gaseous fuels – natural gas and synthetic gases, Natural gas reserves - World and India, properties of natural gas – heating value, composition and density
Principles of combustion: Chemistry and Stoichiometric calculation, thermodynamic analysis and concept of adiabatic flame temperature; Combustion appliances for solid, liquid and gaseous fuels: working, design principles and performance analysis.
Emissions from fuel combustion systems: Pollutants and their generation, allowed emissions, strategies for emission reduction, Euro and BIS norms for emission, recent protocols

d. Suggested texts and reference materials

1. Raghavan, V. (2016). Combustion technology: essentials of flames and burners. John Wiley & Sons.
2. Sharma, S. P., & Mohan, C. (1984). Fuels and combustion. Tata McGraw Hill
3. Sarkar, S. (1974). Fuels and combustion. Universities Press. Orient Longman
4. Sharma, B. K. (1998). Fuels and Petroleum Processing. Krishna Prakashan Media.
5. Hsu, C. S., & Robinson, P. R. (Eds.). (2017). Springer handbook of petroleum technology. Springer.
6. Zheng, C., & Liu, Z. (Eds.). (2017). Oxy-fuel Combustion: Fundamentals, Theory and Practice. Academic Press.
7. Maurya, R. K., Maurya, R. K., & Luby. (2018). Characteristics and control of low temperature combustion engines. Springer.

Course Code.	Subject	L-T-P	Credit
RE-523	Advanced Waste Water Treatment	3-0-0	3

a. Course Objectives

Satisfying the stringent standards for disposal of treated effluents in various sinks and reusing/ recycling of treated effluents for different uses requires that the wastewater be given more exhaustive and advanced treatment. Hence this subject aims to give knowledge to the students regarding advanced wastewater treatment technologies

b. Course Outcomes

CO1. To apply advanced technologies in Wastewater treatment.

CO2. To select the most appropriates types of membrane processes for tertiary treatment of wastewater.

CO3. To apply advanced oxidation processes to treat concentrated non biodegradable wastewater.

CO4. To apply tertiary treatment processes like adsorption, ion exchange for optimum removal of pollutants.

c. Course contents

Overview of Advanced Waste Water Treatment: Introduction, Need of Advanced Waste Water Treatment, Purpose of Advanced Waste Water Treatment

Waste water collection: sewerage systems and sewage pumping, natural drainage system and waste water disposal; Typical sewage quality, its composition and health hazards of handling and disposal

Waste Removal: Nitrogen & Phosphorus Nitrogen Removal, Nitrification, Denitrification Phosphorus removal by Biological Precipitation, Bioremediation, Microorganisms involved in the process, Process configurations, screening, grit removal, flow equalisation, sedimentation; aerobic, anaerobic, attached and suspended growth processes.

Processes: Fundamentals of adsorption, Type of adsorbents, Development of adsorption isotherms, Membrane Process Terminology, Microfiltration, Ultrafiltration, Nano filtration, Reverse Osmosis, Electrodialysis Membrane Configurations, Plate-and-frame module , Spiral-wound module, Tubular module, Hollow-fiber module Membrane Fouling, Modes of membrane fouling , Control of membrane fouling Application of membrane processes: Microfiltration , Ultrafiltration, Nanofiltration, Reverse Osmosis

Membrane Bio Reactor: Introduction MBR Process, Description, Membrane Bioreactor with Membrane Module Submerged in the Bioreactor, Membrane Bioreactor with Membrane Module Situated Outside the Bioreactor MBR System Features Membrane Module Design Considerations Process Applications : Industrial Wastewater Treatment, Municipal Wastewater

Ion Exchange: Fundamentals of Ion Exchange Types of Ion Exchange Resins Theory of Ion Exchange Applications, Removal and recovery of heavy metals , Removal of nitrogen , Removal of phosphorus , Organic chemical removal

Electrochemical Wastewater Treatment Processes: Introduction Electro-coagulation: Factors affecting Electrocoagulation, Electrode materials , Reactor configurations Electro-floatation : Factors affecting electro floatation Comparison with other technology, Reactor configurations Electro-oxidation : Electro oxidation process, Reactor configurations

Advanced Oxidation Processes: Theory of advanced oxidation, Types of oxidizing agents, ozone based and non ozone based processes Fenton and photo-Fenton Oxidation Solar Photo Catalytic Treatment Systems

Operation and maintenance of waste water treatment plants: polishing of treated waste water, disinfection, natural treatment systems; Treatment of sludge, disposal of treated effluent and sludge; Resource generation by way of biogas generation, sale of treated water and sludge, tertiary treatment, reuse of treated water in agriculture/horticulture/construction work, CDM of conservation facilities like STPs, toilets, crematoria to generate additional revenues;

d. Suggested texts and reference materials

1. Davis, M. L., & Cornwell, D. A. (2008). Introduction to environmental engineering. McGraw-Hill.
2. Metcalf, L., Eddy, H. P., & Tchobanoglous, G. (1979). Wastewater engineering: treatment, disposal, and reuse (Vol. 4). New York: McGraw-Hill.
3. Davis, M. L. (2010). Water and wastewater engineering: design principles and practice. McGraw-Hill.
4. Judd, S. (2010). The MBR book: principles and applications of membrane bioreactors for water and wastewater treatment. Elsevier.
5. Aziz, H. A., & Mojiri, A. (Eds.). (2014). Wastewater engineering: Advanced wastewater treatment systems. IJSR Publications.
6. Henze, M., van Loosdrecht, M. C., Ekama, G. A., & Brdjanovic, D. (Eds.). (2008). Biological wastewater treatment. IWA publishing.
7. Nath, K. (2017). Membrane separation processes. PHI Learning Pvt. Ltd.

Course Code.	Subject	L-T-P	Credit
RE-524	Power Generation, Distribution & Transmission	3-0-0	3

a. Course Objectives

The subject will enhance the understanding of the students on power system dynamic stability, generation control, AC and DC transmission, and reactive power control, distribution systems along with conventional and intelligent controls.

b. Course Outcomes

CO1. To understand the on basic principles of power Generation, Distribution & Transmission

CO2. To understand techniques to optimize transmission losses.

c. Course contents

Generation: Synchronous generator operation, Power angle characteristics and the infinite bus concept, dynamic analysis and modeling of synchronous machines, Excitations systems, Primemover governing systems, Automatic generation control;
Auxiliaries: Power system stabilizer, Artificial intelligent controls, Power quality;
AC Transmission: Overhead and cables, Transmission line equations, Regulation and transmission line losses, Reactive power compensation, Flexible AC transmission;
HVDC transmission: HVDC converters, advantages and economic considerations, converter control characteristics, analysis of HVDC link performance, Multi-terminal DC system, HVDC and FACTS;
Distribution: Distribution systems, conductor size, Kelvin's law, performance calculations and analysis, Distribution inside and commercial buildings entrance terminology, Substation and feeder circuit design considerations, distribution automation, Futuristic power generation.

d. Suggested texts and reference materials

1. Kim, C. K., Sood, V. K., Jang, G. S., Lim, S. J., & Lee, S. J. (2009). HVDC transmission: power conversion applications in power systems. John Wiley & Sons.
2. Gonen, T. (2011). Electrical power transmission system engineering: Analysis and design. CRC press.
3. Wood, A. J., Wollenberg, B. F., & Sheblé, G. B. (2013). Power generation, operation, and control. John Wiley & Sons.
4. Anderson, P. M., & Fouad, A. A. (2008). Power system control and stability. John Wiley & Sons.
5. Kundur, P., Balu, N. J., & Lauby, M. G. (1994). Power system stability and control (Vol. 7). New York: McGraw-hill.
6. Elgerd, O. I. (1982). Electric energy systems theory: an introduction, Tata McGraw-Hill.

Course Code.	Subject	L-T-P	Credit
RE-525	Nuclear Energy	3-0-0	3

a. Course Objectives

Nuclear energy renaissance as an energy source to combat the climate change related issues. This course provides an introduction to nuclear reactor technology with particular emphasis of power generation. It introduces the students to the key disciplines of reactor physics and thermal hydraulics as applied in the design of nuclear reactor system, nuclear fuel cycle. This course describes the development of new-generation reactors and key safety issues associated with nuclear power generation.

b. Course Outcomes

CO1. To understand the principle of power generation from nuclear reactor

CO2: To understand the working of various types of reactors and materials properties that are used in it.

CO3: To understand the optimization of nuclear waste.

c. Course contents

Review of Nuclear Energy: Nuclear Fission, Types of nuclear fission reactors, nuclear fusion and its prospects, Radio topic generation and its applications, Nuclear power generation, Operation efficiency of steam cycles for nuclear power plants. The world-wide nuclear renaissance; comparison with other energy sources; public perception; non-proliferation and nuclear safeguards; financial costing; Nuclear energy programme in India

Reactor Physics: Mechanism of Nuclear Fission and Fusion, Nuclides, Radioactivity, Decay chains, Neutron reactions (scattering, absorption, fission), Fission process and product distribution; neutron energy distribution; moderation; delayed neutrons; neutron cycle reactor types, Fast Breeding, Design and construction of nuclear reactors, Heat transfer techniques in nuclear reactors; Reactor shielding, boiling water reactors (BWR) Light water and heavy water pressurized water reactors (PWR) Light water heavy water, Gas cooled reactors, liquid cooled reactors.

Nuclear Fuel Cycle: Characteristics of nuclear fuels and various cycles, mining; conversion; enrichment; refueling; transport; reprocessing; waste handling; storage; geological disposal

Thermal-hydraulics and Fuel Design: Radial and axial flux profiles; general thermodynamic considerations; heat transfer processes from fuel to coolant; primary coolant system: fluid flow; frictional losses in pipes; pumped flow; heat exchanger types; steam generation; coolant/moderator selection; coolant circuit considerations

Reactor material properties and requirements: Fast breeder (FBR), Fissile and fertile materials, Breeding process, Gas cooled (He or CO_2) FBR, Liquid metal cooled FBR (LMEBR), scope of FBR in power generation. Nuclear engineering design, Materials selection, Availability and cost, Computer programming for material election and reactor design.

Nuclear Waste Management: Scientific and engineering aspects of the management of spent fuel, Reprocessed high-level waste, Low-level wastes, Decommissioning wastes, Characteristics of nuclear wastes, Classification of nuclear wastes and waste forms, Discussion on performance assessment.

d. Suggested texts and reference materials

1. Raymond M and Keith E. H. (2014); Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes, Seventh Edition, Butterworth-Heinemann
2. Bodansky D. (2008). Nuclear Energy: Principles, Practices and Prospects, Second Edition, Springer
3. John K. S. and Richard E. F. (2007). Fundamentals of Nuclear Science and Engineering, Second Edition, CRC Press
4. Lamarsh J. R. and Baratta A. J. (2001). Introduction to Nuclear Engineering, Third Edition, Pearson
5. Oka Y. and Kiguchi T. (2014). Nuclear Reactor Design, Fourth Edition, Springer
6. Bayliss C. and Langley K. (2003). Nuclear Decommissioning, Waste Management, and Environmental Site Remediation, First Edition, Butterworth-Heinemann
7. Brookes L. G. (2013). The Economics of Nuclear Energy, Springer