SYLLABUS FOR M. TECH IN RENEWABLE ENERGY

(*PROPOSED*)

MECHANICAL ENGINEERING
DEPARTMENT NIT SILCHAR

Program Educational Objectives (PEOs)

- To prepare the students for successful career in the energy industry, energy utilities and consultancy agencies, and also in the academic and R&D institutions
- To produce energy professionals, who are sensitive to, and well aware of, the energy issues and concerns, and who can apply their specialized knowledge for the sustainable development of the society.
- To enable the students to acquire knowledge of relevant technologies and multi-disciplinary fields including broad social, ethical and environmental issues.
- To produce professionals equipped with understanding on energy resource technologies, energy management fundamentals,so as to be capable of doing innovations towards the present and potential future energy issues.

Program Objectives (POs)

1. Graduates will demonstrate sound domain knowledge on wider perspective to become successful professionals.
2. Graduates will demonstrate an ability to identify, formulate and solve renewable energy related problems.
3. Graduates will demonstrate an ability to conceptualise designs of renewable energy systems or components and evaluate them to select optimal feasible solution considering safety, environment and other realistic constraints.
4. Graduates will demonstrate skill of good researcher to work on a problem, starting from scratch, to research into literatures, methodologies, techniques, tools, and conduct experiments and interpret data.
5. Graduates will demonstrate research skills to critically analyse complex renewable energy based systems for synthesizing new and existing information for their solutions.
6. Graduates will demonstrate skills to use modern engineering tools, software and equipment to analyze and solve complex renewable energy related problems.
7. Graduates will exhibit the traits of professional integrity and ethics and demonstrate the responsibility to implement the research outcome for sustainable development of the society.
8. Graduates will be able to communicate effectively to comprehend and write effective reports following engineering standards.
9. Graduates will demonstrate skills of presenting their work unequivocally before scientific community, and give and take clear instructions.
10. Graduate will demonstrate traits of manager in handling engineering projects and related finance, and coordinate workforce towards achieving their goals.
11. Graduates will exhibit the traits of good academician and engage in independent and reflective lifelong learning.
12. Graduates will demonstrate an ability to work on laboratory and multidisciplinary tasks.

COURSE STRUCTURE

M.Tech in Renewable Energy
Department of Mechanical Engineering
Semester: I

S.N.	Sub Code	Subject	L	T	P	Credits
1	ME 5501	Foundation for Energy Technology	3	0	0	3
2	ME 5502	Solar Thermal Systems	3	0	0	3
3	ME 5503	Wind Energy Systems	3	0	0	3
4	ME 5xxx	Elective-I	3	0	0	3
5	ME 5xxx	Elective-II	3	0	0	3
6	ME 5504	Renewable Energy Lab-I	0	0	3	2
7	ME 5510	Seminar	0	0	2	1
Total contact hours/credits			**15**	**0**	**5**	**18**

Semester: II

S.N.	Sub Code	Subject	L	T	P	Credits
1	ME 5505	Biomass and Bio energy	3	0	0	3
2	ME 5506	Solar Photovoltaic Systems	3	0	0	3
3	ME 5507	Energy Conservation and Management	3	0	0	3
4	ME 5xxx	Elective-III	3	0	0	3
5	ME 5xxx	Elective-IV	3	0	0	3
6	ME 5508	Renewable Energy Lab-II	0	0	3	2
7	ME 5520	Mini Project	0	0	2	1
	Total contact hours/credits		**15**	**0**	**5**	**18**

Semester: III

S.N.	Sub Code	Subject	L	T	P	Credits
1	ME 6598	Project (Phase-I)	-	-	-	6
Total contact hours/Credits			**-**	**-**	**-**	**6**

Semester: IV

S.N.	Sub Code	Subject	L	T	P	Credits
1	ME 6599	Project (Phase-II)	-	-	-	8
Total contact hours/Credits			**-**	**-**	**-**	**8**

Elective – I

S. N.	Code	Subject
1.	ME 5131	Optimization Technique
2.	ME 5531	Applied Heat Transfer
3.	ME 5532	Solar Collectors and Applications
4.	ME 5533	Energy Storage
5.	EC 5594	Radio Frequency Energy Harvesting for Low Power Applications
6.	PH 5130	Materials Science in Energy Engineering

Elective – II

S. N.	Code	Subject
1.	ME 5401	Advanced Thermodynamics
2.	ME 5435	Alternative Energy Sources
3.	ME 5541	Zero Energy Buildings
4.	ME 5542	Carbon Audit and Management
5.	ME 5543	Energy and Environment

Elective – III

S. N.	Code	Subject
1.	ME 5452	Batteries and Fuel Cells
2.	ME 5551	Solar Passive Concepts
3.	ME 5552	Fuel and Combustion Technology
4.	ME 5553	Hydropower Technologies
5.	ME 5554	Energy Generation from Waste
6.	EE 5256	Energy Market Policies with Renewable Energy Share

Elective – IV

S. N.	Code	Subjects
1.	ME 5246	Theory of Uncertainty
2.	ME 5443	Energy audit and Management
3.	ME 5561	Ocean Renewable Energy
4.	ME 5562	Hydrogen Energy
5.	ME 5563	Zero Emission Vehicles

Syllabus (Proposed)

CORE SUBJECTS

Semester: I

Subject Code: ME 5501
Subject Name: Foundation for Energy Technology

Basics of energy: Different forms of energy, energy conversion process, indirect and direct energy conversion; Different energy sources; Conventional energy systems: engines, power plants, various methods of power generation;Overview of Energy Sector.Laws of thermodynamics and applications, Concepts of internal energy, entropy, enthalpy; Gas laws, Thermodynamic cycles, Irreversible and Reversible processes,

Fluid Mechanics: Properties of fluids, Bernoulli's equation, Navier-Stokes equation, conservation equations for mass, momentum and energy; Uses of non-dimensional numbers to describe flow conditions; Theory and principles of flow measuring devices; Viscous flow in a pipe, Flow through packed and fluidized bed; Introduction to turbulence;

Introduction to Electrical Machines: Working Principle, characteristics and applications of Transformer, motor and generators,DC machines etc.

Energy and environment correlations, Environmental degradation due to energy production and utilization, global warming; Environmental impact assessment, life cycle analysis (LCA) and sustainability issues.

Text and Reference books:

1. Nag P. K. (2014); *Basic and Applied Thermodynamics*, McGraw Hill.
2. Kothari D. P. and Nagrath I. (2009); *Basic Electrical Engineering*, Third Edition, McGrawHill, India
3. Zemansky M. and Dittman R. (2011); *Heat and Thermodynamics*, McGraw Hill, India
4. Wadhwa C. L. (2012); *Generation, Distribution and Utilization of Electrical Energy,* ThirdEdition, New Age International
5. Balachandran P. (2010); *Engineering Fluid Mechanics*, Prentice Hall India
6. Dessler A. (2011); *Introduction to Modern Climate Change,* Cambridge University Press

Course Outcomes:

To provide the students with

- knowledge of various energy resources available, their potential, exploitation, etc.
- basic understanding ofthermodynamics, fluid mechanics and electrical Engineering
- understanding of the overview of energy system instrumentations and control devices
- knowledge of fundamental laws for applying in energy engineering.
- the skill to develop models of real processes and systems and draw conclusions.

Subject Code: ME 5502

Subject Name: Solar Thermal Systems

Introduction: Sun's motion, Earth-Sun relationship, Solar angles and their relationships, Introduction to Solar map.

Solar radiation and its measurements: Terminologies, Types of solar radiation, Absorption of solar radiation by the atmosphere, Spectral distribution of solar radiation, sky models, Intensity of solar radiation falling on flat and inclined surfaces, Solar radiation measuring instruments.

Solar thermal energy: Introduction to solar thermal collectors, Forms of solar thermal energy and their utilization, Solar thermal heating systems, Solar thermal cooling systems. Water heating, process heating, cooling, and space heating applications. Solar Thermal Cooking systems, Solar thermal based co-, tri- and poly-generation, Thermal energy storage

Solar Thermal Power: Introduction, Solar thermal power plants- design configurations, operation and performance; hybrid solar thermal cogeneration/power system- design configurations, operation and performance.

Text and Reference books

1. Soteris.A.Kalogirou., "*Solar Energy Engineering: Processes and systems"*, 2nd edition, Academic press, 2013.
2. K. Sukhatme, SuhasP.Sukhatme., "*Solar energy: Principles of thermal collection and storage",* Tata McGraw Hill publishing Co. Ltd, 8th edition, 2008.
3. S.P. Sukhatme, J.K.Nayak., "*Solar Energy",* Tata McGraw Hill Education Private Limited, New Delhi, 2010.
4. Duffie, J. A. & W. A. Beckman., "*Solar Engineering of Thermal Processes"*, 3rd edition, John Wiley & Sons, Inc., 2006.
5. Chetan Singh Solanki., *Solar Photovoltaic: "Fundamentals, Technologies and Application",* PHI Learning Pvt., Ltd., 2009.
6. Lorenzini G and Biserni C, Solar Thermal and Biomass Energy, WIT Press (2012).

Course Outcomes:

To provide the students with

- fundamental knowledge of solar energy and its application.
- knowledge of utilisation trends of solar energy harvesting.
- understanding of the solar thermal collectors and systems.

Subject Code: ME 5503
Subject Name: Wind Energy Systems

Wind Energy Fundamentals: Wind Energy Basics, Wind energy potential- offshore and onshore wind energy, Terrain, Roughness, Atmospheric Boundary Layer, Turbulence, Wind Speeds and scales, Wind Speed variations, Instruments for wind measurements, Wind data analysis, Wind energy conversion system.

Modern Wind Turbines: Basic classification, Advantages and disadvantages, Conceptual designs, Components and control, Blade designs, Blade motions, Blade material, Wind Turbine noise, Environmental impact, Site selection, Wind farm.

Aerodynamics of Wind Turbines: Actuator disc concepts, Blade element momentum theory, Stream tube models, Vortex theory, CFD analysis, Aerodynamic loading and aero-elasticity of wind turbines.

Wind Turbine Performance: Betz's Limit, Performance curves, Constant rotational speed operation, variable-speed operation, Wind turbine Performance Measurements, Aerodynamic Performance Assessment

Cost Economics: Wind energy market, Fixed and variable costs, Value of wind energy, Life cycle costing and cash flow of wind power projects. Regulations pertaining to Wind Farm integration into existing supply structure, Regulations for energy pricing and its trading.

Text and Reference books:

1. David Wood: Small Wind Turbines- Analysis, Design, and Application. Springer, 2011.
2. James F. Manwell, Jon G. McGowan, Anthony L. Rogers. Wind Energy Explained: Theory, Design and Application. Wiley International, 2nd Edition, 2009.
3. B.H.Khan: Non-Conventional Energy Sources, Tata McGraw Hill, 2006.
4. Perez Arriaga I (Ed): Regulation of Power Sector

Course Outcomes:

To provide the students with

- fundamental knowledge of wind power.
- basic knowledge about factors affecting wind power at different atmospheric and terrain conditions.
- understanding of working principles of different wind driven machines.
- knowledge of analysing different wind driven machines.
- knowledge of techno-economic analysis of wind driven machines.
- understanding the energy market regulations and pricing mechanisms

Subject Code: ME 5504
Subject Name: Renewable Energy Lab-I

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. Further, students will get opportunity to learn applications of computational and simulation experiments on topics under Renewable Energy Systems.

A number of experiments will be conducted in the areas of Renewable Energy Systems in different laboratories, like,

- Experiments on heat transfer laboratory
- Experiments on energy research laboratory
- Experiments on solar RTC laboratory
- Numerical modeling experiments related to Renewable Energy Systems
- Simulation experiments related to Renewable Energy Systems

N.B.: The list of experiments to be conducted will be notified to the students at the start of the semester.

Subject Code: ME 5510
Subject Name: Seminar

Individual students are required to choose a topic or topics of their interest from renewable energy related topics preferably from outside the M.Tech syllabus and give seminar on that/those topic(s) about 30 minutes (each). A committee consisting of at least two/three faculty members shall assess the presentation of the seminar(s) and award marks to the students. Each student shall submit two copies of a write up of his / her seminar topic. One copy shall be returned to the student after duly certifying it by the Chairman of the assessing committee and the other will be kept in the departmental library. Internal continuous assessment marks are awarded based on the relevance of the topic, presentation skill, quality of the report and participation.

Course Outcomes:
To provide the students with

- Presentation Skills
- Discussion Skills
- Listening Skills
- Argumentative Skills and Critical Thinking
- Questioning
- Interdisciplinary Inquiry
- Engaging with Big Questions
- Studying Major Works
- Report Writing Skills

Semester: II

Subject Code: ME 5505
Subject Name: Biomass and Bio energy

Fundamental concepts in understanding biofuels and bioenergy systems, Broad classification, Types of biomass derived fuels and energy, Production of biomass, photosynthesis, Agro and forestry residues utilisation through conversion routes: biological, chemical and thermos-chemical, Biomass pretreatment: Acid/alkali treatment, steam explosion, ammonia fiber expansion, enzymatic, ball milling, other non-conventional techniques, choice of pretreatment based on biomass type.

Thermo-chemical conversion of biomass, conversion to solid, liquid and gaseous fuels, hydrolysis and hydrogenation, torrefaction, choice of thermal process based on biomass type and product requirement, Catalytic processes: Catalytic pyrolysis, catalytic upgradation by hydro-deoxygenation.

Bioalcohol: Production processes of Bioethanol, biobutanol, higher alcohols, valerates, DMF, furanoids, benzenoids; typical reactions, fuel properties, engine applications.

Bio-diesel: History, Availability of Raw materials for bio-diesel-1^{st}, 2^{nd}, 3^{rd} and 4^{th} generation of biodiesels and their sources, Algae as a source for biodiesel, Suitable species for oil extractions, Different processes for extracting oil from algae. Production methods of Bio-diesel: Transesterification process, Supercritical process, Ultrasonic reactor method, Lipase-catalyzed method, Fuel quality, standards and properties, engine applications.

Biogas: biogas production process, composition, bio substrates used for biogas production, types of digesters and feed materials, biogas power generation, biogas filtration techniques and bottling processes. Biogas characterization, Use of biogas in domestic and industrial sectors, Application of biogas in engines.

Biomass gasification: basics of the process, Chemistry of gasification, raw material selection, Different gasification techniques, Operating conditions of gasifiers, Fixed bed reactor, fluidised bed reactors, Tar and ash handling. Characterization of the products and their applications.

Biorefinery: Importance of bio refineries, process of operation of bio refineries, Feedstock selection, Classification of different generations of Bio refineries, their working, advantages and disadvantages; Green bio refinery, sustainability aspects.

Waste to energy: Introduction to Energy from waste-classification of waste as fuel–agro based, forest residue, industrial waste, MSW–conversion devices –incinerators, gasifiers, digesters, Environmental monitoring system for land fill gases, Environmental impacts; Measures to mitigate environmental effects due to incineration.

Text and Reference books:

1. Brown RC and Stevens C, Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, Wiley and Sons (2011).

2. VenkataRamana P and Srinivas S.N., “Biomass Energy Systems”, TERI, 1996.
3. Vaughn C. Nelson, Kenneth L. Starcher, “Introduction to Bioenergy”, CRC Press, 2016.
4. AnjuDahiya. “Bioenergy: Biomass to Biofuels”, Elsevier, 2014.

Course Outcomes:

To provide the students with

- knowledge of biomass energy sources
- understanding on biomass derived fuel systems
- understanding on energy utilization of bio-based fuel.
- knowledge on green chemical technologies and biomaterials.
- understanding on bio-refinery concept for conversion of biomass tomodern biofuels.
- understanding on biofuels, their production technologies and applications invarious energy utility routes.

Subject Code: ME 5506
Subject Name: Solar Photovoltaic Systems

Unit 1: Quantum Mechanics and Basics of Semiconductors
Quantum mechanics, photon energy, crystals structures, atomic bonding, types of semiconductors, energy band diagram, p-type and n-type semiconductors, doping and carrier concentration, diffusion and drift of carriers, continuity equation, P-N junction and its properties, basic equations of P-N junction, junction under illumination.

Unit 2: Solar Cells
Solar cell 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; optical losses; electrical losses, surface recombination velocity, quantum efficiency, I-V curve; Types of solar cells.

Unit 3: Solar Cell Technologies
Thin film solar cell technologies; material properties and processing techniques (crystal growth, diffusion, deposition);fabrication process of crystalline silicon; amorphous Si solar cells, CdTe solar cells, CIGs solar cells, CZTS solar cells, Dye-sensitized solar cells,Perovskite solar cell, tandem and multi-junction solar cells; batteries for PV systems – types of batteries, battery parameters, selection of battery for solar PV systems.

Unit 4: Solar PV Modules
Solar PVmodules, rating and efficiency of PV modules, PV module parameters and their measurements, issues with solar PV modules, connection of PV module in series and parallel, estimation and measurement of PV Module power, selection of PV module.

Unit 5: Solar Photovoltaic Applications
Applications of solar PV systems; electronic circuits in PV; design of solar PV systems; battery sizing,PV panel sizing, inverter sizing, solar lanterns, water pumping application, home & street lightingapplications, off-grid solar PV power plant etc.

Text and Reference books:

1. Antonio Luque, Steven Hegedus, “Handbook of Photovoltaic Science and Engineering,” John Wiley & Sons Ltd, England, 2003.
2. Adrian Kitai, “Principles of Solar Cells, LEDs and Diodes: The role of the PN junction,” John Wiley & Sons, 2011.
3. Chetan Singh Solanki., “Solar Photovoltaic: Fundamentals, Technologies and Application”, PHI Learning Pvt., Ltd., 2009.
4. Chenming Hu, Richard M. White, “Solar Cells: From Basics to Advanced Systems,” McGraw-Hill, 1983.
5. Augustin McEvoy, L. Castaner, Tom Markvart, “Solar Cells: Materials, Manufacture andOperation,”2nd Ed, Newnes, 2012.
6. Arvind Shah, “Thin-Film Silicon Solar Cells”, illustrated edition, EPFL Press, 2010.
7. I. M. Dharmadasa, “Advances in Thin-Film Solar Cells,” Illustrated edition, CRC Press,2012.

Course Outcomes (CO):

To provide the students with:

1. knowledge on principle of quantum mechanics and basics of solar PV technologies.
2. understanding of the physics of semiconductors behind solar cells.
3. knowledge of physics of PN junction to be applied in solar cell design.
4. understanding of various designs of thin film solar cells.
5. Understanding of working principle of solar PV systems.
6. knowledge on emerging solar cells technologies.
7. knowledge on various applications of solar PV systems

Subject Code: ME 5507
Subject Name: Energy Conservation and Management

Introduction: Overview of non-renewable energy resources, and new and renewable energyresources; Overview of energy technologies; Energy crisis and environmental concerns; Principles of energy conservation and management.

Energy conservation and management in thermal systems: Fuels and combustion; Boilers,Internal combustion engines and furnaces; Waste heat recovery systems; Turbines and DG sets; Steam system and condensate systems; Insulation; Heat exchangers; Cooling towers and circulating cooling water systems.

Energy conservation and management in electrical systems: Electrical motors and drives;Pumps, Fans and Blowers; Air compressors and compressed air systems; Buildings and space heating and lighting systems; HVAC systems.

Energy management: Supply side and demand side energy management; Energy monitoringand auditing; Energy management systems.

Text and Reference books:

1. Practical guide to energy conservation – a ready reckoner on energy conservation measures; Petroleum Conservation Research Association (2009).
2. Indian Energy Board-2012; World Energy Council.
3. Reay DA, Industrial energy conservation; Pergamon Press (1979).
4. White LC, Industrial Energy Management and Utilization; Hemisphere Publishers; (1988).
5. Eastop TD and Croft DR, Energy Efficiency for Engineers and Technologists; Longman-Scientific and Technical Series (1988).

Course Outcomes:

To provide the students with

- understanding of the energy management, conservation processes, principles of energy auditing, energy flow diagram, economies of energy conservation opportunities
- understanding of the scope for energy management, information systems, various key features of energy conservation act and ECBC.
- understanding of the scope for energy conservation in electrical and thermal energy utilities
- fundamentals of economic principles and their applications in the broad field of supply and demand of energy
- scientific knowledge for technological innovation towards livelihood improvement by integrating various energy systems.

Subject Code: ME 5508
Subject Name: Renewable Energy Lab-II

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. Further, students will get opportunity to learn applications of computational and simulation experiments on topics under Renewable Energy Systems.

A number of experiments will be conducted in the areas of Renewable Energy Systems in different laboratories, like,

- Experiments on solar PV/T Laboratory
- Experiments on wind energy laboratory
- Experiments on bio-fuel research laboratory
- Numerical modeling experiments related to Renewable Energy Systems
- Simulation experiments related to Renewable Energy Systems

N.B.: The list of experiments to be conducted will be notified to the students at the start of the semester.

Subject Code: ME 5520
Subject Name: Mini Project

The course objective is to develop competency of applying engineering knowledge to real life problems in the field of Renewable Energy.

Mini project may be carried out in one or more form of following:

- Statistical data analysis, survey, etc.
- Design, analysis and/or fabrication,
- Experimentation – practical / simulation / numerical or analytical analysis,
- Product design and development,
- Design and development of laboratory equipments / experiments,
- Software development, integration of software and hardware,
- Industry needs based basic survey or Testing or Analysis etc.

Finally, a project report, comprising introduction, literature review, objective, methodology, background theory, results & discussion, and conclusions along with reference list, following the institute guidelines shall have to be submitted for the evaluation.

Course Outcomes (COs):

At the end of this course students will be able to ,

- Identify an open ended problem in area of Renewable Energy which requires further investigation.
- Identify the methods and materials required for the project work.
- Formulate and implement innovative ideas for social and environmental benefits.
- Analyse the results to come out with concrete solutions.
- Write technical report of the project apart from developing a presentation.

ELECTIVE SUBJECTS

Subject Code: ME 5131
Subject Name: Optimization Technique (Elective-I)

Introduction: Definition of optimization and its importance; Basic terminologies– design variables/vector, cost/objective function, constraints and variable bounds, etc; Different types of optimization problems–based on number of variables, based on nature of variables, based on constraints, based on approaches used, based on number of objectives, etc.

Single variable unconstrained optimization: Global optimum point; Local optimum point; Stationary point; Optimality criteria; Graphical method for optimum point; Direct methods for bracketing the optimum point–exhaustive search method and bounding phase method; Refining the bracketed optimum point through region elimination methods– interval halving method, Fibonacci search method and golden section search method; Gradient based methods–bisection method. Newton-Raphson method and secant method.

Multi-variable unconstrained optimization: Optimality criteria; Unidirectional search; Direct methods–simplex search method, Hooke-Jeeves pattern search method and Powell's conjugate direction method; Gradient based method–Cauchy's steepest descent method, Newton's method, Marquardt's method, conjugate gradient method and variable metric method.

Multi-variable linear and constrained optimization: Definition and formulation of linear programming problem; unrestricted variables; slack variables; artificial variables; feasible design; infeasible design; basic solution; basic feasible solution; Simplex method for less-than-equal type of constraints; Simplex method for equality and greater-than-equal types of constraints.

Multi-variable nonlinear and constrained optimization: Kuhn Tucker conditions; Sensitivity

analysis; Transformation methods–interior penalty function method, exterior penalty function and method of multipliers; Direct methods–variable elimination method, complex search method and random search method; Gradient based methods-cutting plane method, sequential linear programming and feasible direction method.

Integer and mixed optimization: Penalty function method and branch-and-bound method.

Text and Reference Books:

1. Optimization for Engineering Design– Algorithms and Examples. Kalyanmoy Deb, Prentice Hall of India Pvt. Ltd.
2. Introduction to Optimum Design, Jasbir S. Arora, McGraw-Hill International Editions.
3. Ashok D. Belegundu and Tirupathi R. Chandrupatla.Optimization Concepts and Applications in Engineering.Pearson Education.

Course Outcomes:

To provide the students with

- the basic mathematical concepts of optimization.
- basic modelling skills necessary to describe and formulate optimization problems.
- skills necessary to solve and interpret optimization problems in engineering
- enhanced skills related to optimization in Mechanical engineering, open-ended problem solving, critical thinking and life-long learning.

Subject Code: ME 5531
Subject Name: Applied Heat Transfer (Elective-I)

Conduction and radiation heat transfer: One dimensional energy equations and boundary condition - three-dimensional heat conduction equations for extended surface heat transfer - conduction with moving boundaries - radiation in gases and vapour. Gas radiation and radiation heat transfer in enclosures containing absorbing and emitting media – interaction of radiation with conduction and convection.

Turbulent forced convective heat transfer: Momentum and energy equations - turbulent boundary layer heat transfer - mixing length concept - turbulence model – k-ϵ model - analogy between heat and momentum transfer – Reynolds, Colburn, Prandtl turbulent flow in a tube - high speed flows.

Phase change heat transfer and heat exchanger: Condensation with shears edge on bank of tubes - boiling – pool and flow boiling - heat exchanger ϵ-NTU approach and design procedure - compact heat exchangers.

Numerical methods in heat transfer: Finite difference formulation of steady and transient heat conduction problems – discretization schemes – explicit - Crank Nicolson and fully implicit schemes - control volume formulation -steady one-dimensional convection and diffusion problems - calculation of the flow field – SIMPLER Algorithm.

Mass transfer and engine heat transfer correlation: Mass transfer - vaporization of droplets - combined heat and mass transfers - heat transfer correlations in various applications like I.C. engines - compressors and turbines.

Text and Reference books:

1. Yunus A. Cengal, Heat and Mass Transfer – A practical Approach, 3rd edition, Tata McGraw - Hill, 2007.
2. Holman. J.P, Heat Transfer, Tata McGraw Hill, 2002.
3. Ozisik. M.N., Heat Transfer – A Basic Approach, McGraw-Hill Co., 1985.
4. Incropera F.P. and DeWitt. D.P., Fundamentals of Heat & Mass Transfer, John Wiley & Sons, 2002.
5. Nag. P. K, Heat Transfer, Tata McGraw-Hill, 2002.
6. Ghoshdastidar P.S., Heat Transfer, Oxford University Press, 2004 7. Yadav, R., Heat and Mass Transfer, Central Publishing House, 1995.

Course Outcomes:

To provide the students with

- knowledge of scientific and engineering principles to analyze and design thermo-fluid aspects of engineering systems.
- understanding of analytical and computational tools to investigate heat and mass transport phenomena.
- competence and confidence in interpreting results of investigations related to heat transfer, fluid flow, and thermal design;
- understanding of the broad technological context of heat transfer, especially related to energy technology.

Subject Code: ME 5532
Subject Name: Solar Collectors and Applications (Elective-I)

Solar Collectors: Non-concentrating or stationary collectors, Point-focusing and line-focusing concentrating collector, Design and construction of collectors, Sun tracking mechanisms.

Thermal Analysis of collectors: Thermal performance of Flat plate collectors, compound parabolic collectors and evacuated tubular collectors, Optical and thermal performances of concentrating collectors, Second law analysis of collectors.

Performance of Solar Collectors: Collector thermal efficiency, Collector incidence angle modifier, Optimal collector tilt and orientation, Collector time constant, Concentrating collector acceptance angle, modeling of solar systems.

Solar collector applications: Solar water heating, Solar space heating and cooling, Solar drying, Solar refrigeration, Solar desalination systems, Solar steam generation systems,Solar tri and polygeneration, Solar thermal power systems, Solar furnaces, Solar cookers.

Text and Reference books

1. Soteris. A. Kalogiru., "*Solar Energy Engineering: Processes and systems"*, 1st edition, Academic press, 2009.
2. K. Sukhatme, Suhas P. Sukhatme., "*Solar energy: Principles of thermal collection and storage",* Tata McGraw Hill publishing Co. Ltd, 8th edition, 2008.
3. Duffie, J. A. & W. A. Beckman., "*Solar Engineering of Thermal Processes"*, 3rd edition, John Wiley & Sons, Inc., 2006.
4. G.N. Tiwari., "*Solar energy: Fundamentals, Design, Modeling and Applications"*, CRC Press Inc., 2002.

Course Outcomes:

To provide the students with

- the knowledge of technical and physical principles of solar collectors
- measurement and evaluation of different solar thermalenergy technologies through knowledge of the physical function of the devices
- knowledge of calculating the required size of solar collectors.
- ability of doing comparisons of different solar thermalenergy systems

Subject Code: ME 5533
Subject Name: Energy Storage (Elective-I)

Introduction: Energy storage; Significance; Types of Energy Storage – (a) Sensible Thermal Energy Storage, (b) Latent Energy Storage; Thermal Management System design using Latent Thermal Energy Storage

Assessment of Thermal Energy System: (a) Evaluation of thermo-physical properties of storage materials, (b) Distinction between energy and exergy, (c) Energy and exergy in performance assessment of systems, (d) Exergy and environment assessment

Optimization of Thermal Energy Systems: Thermochemical heat storage system, thermal energy storage system for heating and hot water in residential buildings

Hydrogen energy storage: Hydrogen based fuel cell; Solar hydrogen production

Battery Electrical Energy Storage Systems: Types of batteries & electrical behavior; Influence in interconnected systems

Pumped storage systems: configuration, operation

Other electrical energy storage system: Flywheel, super-capacitors etc.

Integration of energy storage systems with distributed generation systems and electric grid; energy storage system optimization

Text & Reference Books:

1. Khalilpour, K.R., Anthony V. A., Community Energy Networks with Storage-Modeling Frameworks for Distributed Generation, Springer (2016).
2. Cabeza, L.F., Advances in Thermal Energy Storage Systems: Methods and Applications, Woodhead Publishing, UK (2015).
3. Kalaiselvam, S., Parameshwaram R., Thermal Energy Storage for Sustainability-Systems Design, Assessment and Applications, Academic Press Inc. (2014).

Course Outcomes:

To provide the students with

- knowledge of various thermal and electrical energy storage devices.
- knowledge of optimization of energy storage for optimal use.

Subject Code: EC 5594
Subject Name: Radio Frequency Energy Harvesting for Low Power Applications (Elective-I)

Introduction: Overview of various Energy Harvesting Techniques; Photo-Voltaic Energy Harvesting, Thermal Energy Harvesting, Mechanical Energy Harvesting, Wind Energy Harvesting, Acoustic Energy Harvesting, Electromagnetic (EM)/Radio Frequency (RF) Energy Harvesting.

Antennas for RFEH Systems: Introduction, Circularly Polarized Antennas, High Gain Antennas, Wideband Antennas, Multiband Antennas, High Efficiency Antennas, Low Power Antennas

Rectifiers for RFEH Systems: An Overview of Matching Networks, Rectifiers, Diode-based Rectifiers, MOSFET-based Rectifiers, Comparison of Various Rectifier Topologies

Rectennas for RFEH Systems: Introduction, Circularly Polarized Rectennas, Wideband Rectennas, High Gain Rectennas, Multiband Rectennas, High Efficiency Rectennas, Low Power Rectennas.

Matching Networks: Introduction, Matching Networks for RFEH Systems, Matching Networks for WPT Systems, Matching Networks for Near-Field WPT Systems, Matching Networks for Far-Field WPT Systems, Adaptive Matching Methods, Resistance Compression Networks.

Some Applications: Introduction, Rectennas for Wireless Power Transmission; Single-Band Applications, Dual-Band Applications, Broad-Band Antenna Applications, Rectennas for Wireless Energy Harvesting; Single-Band Applications, Dual-Band Applications, Multi-Band Applications, Broad-Band Applications, Wireless Sensor Networks and Implementable Devices, Environment for Rectenna Testing.

Text/Reference Books

1. Taimoor Khan, Nasimuddin and Yahia M.M. Antar, "*Elements of Radio Frequency Energy Harvesting and Wireless Power Transfer Systems*", CRC Press, Taylor & Francis Group, Florida, USA, 2020, ISBN: 978-0-367-24678-5.
2. OlfaKanoun, "Energy Harvesting for Wireless Sensor Networks: Technology, Components and System Design**",** De GruyterOldenbourg; 1st Edition, 2015.
3. Borg Kristian, "Energy Harvesting in Wireless Applications**",** LAP Lambert Academic Publishing, 2015.

Course Outcomes:

To provide the students with

- Understand key benefits of ambient RF/Wireless energy and harvesting techniques.
- Understand fundamental requirement of designing key components of RF energy harvester.
- Understand fundamentals requirement of designing of antenna, rectifier, matching circuits.
- Understand the designing of Rectenna for RF energy harvesting.
- Understand the applicability of rectenna for different applications.

Subject Code: PH 5130

Subject Name: Materials Science in Energy Engineering (Elective I)

Materials Structure and Stoichiometry: Introduction to Crystalline and Non-Crystalline Materials, Bravais Lattices, Reciprocal Lattice, X-ray, Electron and Neutron Diffraction, crystal defects, Diffusion.

Electronic and Optical Properties of Materials: Free Electron Theory, Fermi Energy, Density of States for 1D, 2D and 3D, Conductivity, Electron Mobility, Band Theory, Semiconductors, Carrier Concentration, Interaction of Solids with Radiation, Luminescence, Photoconductivity.

Materials for Solar Energy Conversion: Oxide Semiconductors, Nitride Semiconductors, Chalcogenide Semiconductors, Perovskite Materials -Synthesis, Characterization, Applications along with Mechanism in Solar Cell, Solar Photocatalysis and Hydrogen Production.

Electrochemical energy storage materials: Secondary batteries and components, materials for anode, cathode and electrolyte for Li-ion batteries. Principles of supercapacitors include an electric double layer and pseudo-capacitive charge-storage, Electrode materials for supercapacitors: graphene oxide, transition metal oxides, TMDCs, and conducting polymers. Working of proton exchange membrane fuel cell (PEMFC), Membranes for fuel cells: Nafion – Polymer blends and composite membranes.

Text and Reference books

1. Charles Kittel, "Introduction to Solid State Physics", 8th Edition, Wiley, 2012
2. Donald Neamen and Dhrubes Biswas, "Semiconductor Physics and Devices (SIE)" 4th Edition, Mc Graw Hill Education India, 2012.
3. Horst Krisch, "Semiconductor Photocatalysis: Principles and Applications", Wiley, 2014.
4. Monica Lira-Cantu(Editor),"The Future of Semiconductor Oxides in Next-Generation Solar Cells", 1st Edition, Elsevier, 2017.
5. Huggins, Robert A. *Advanced Batteries: Materials Science Aspects*. Springer, 2008. ISBN: 9780387764238
6. F. Barbir, 'PEM fuel cells: theory and practice', Elsevier, Burlington, MA, (2005).
7. Brodd et al, "What are Batteries Fuel Cells, and Supercapacitors?", Chem Rev 104, 4245 (2004)

Course Outcomes:

To provide the students with

- fundamental knowledge on crystal structure and stoichiometry.
- knowledge of electronic and optical properties of semiconducting materials.
- understanding of materials and its properties for solar energy conversion.
- the materials prospective to electrochemical energy storage devices like batteries, fuel cell and supercapacitors

The course outcome can be mapped to PO1, PO 2, PO 3, PO 4, 5 and PO 6 of the proposed "M.Tech in Renewable Energy" program.

Subject Code: ME 5401
Subject Name: Advanced Thermodynamics (Elective-II)

Review of basic thermodynamics: Laws of thermodynamics, entropy, entropy balance for closed and open systems. Exergy: Concept of reversible work & irreversibility; Second law efficiency; Exergy change of a system: closed & open systems, exergy transfer by heat, work and mass, exergy destruction, exergy balance in closed & open systems; Exergy analysis of industrial systems–power systems and refrigeration systems.

Cycle analysis and optimization: Regenerative reheat Rankine cycle and Brayton cycle, combined cycle power plants, multi-stage refrigeration systems.

Thermodynamic optimization of irreversible systems: Finite time thermodynamics principles, optimization studies of various thermal systems, Minimization of entropy generation principle.

Properties of Gas Mixtures: Equation of state and properties of ideal gas mixtures; Change in entropy on mixing; Partial molal properties for non-ideal gas mixtures; Equations of state;

Thermodynamics of Reactive System: Conditions of equilibrium of a multiphase-multicomponent system; Second law applied to a reactive system; Condition for reaction equilibrium.

Text & Reference Books:

1. R. E. Sonntag, C. Borgnakke& G.J. Van Wylen, Fundamentals of Thermodynamics.Wiley publication.
2. K. Annamalai, I.K. Puri& M. A. Jog, Advanced Thermodynamics Engineering. CRC press.
3. Bejan, Entropy Generation Minimization. AIP publishing.
4. Bejan, Entropy Generation through Heat and Fluid Flow. Wiley publication.
5. M. J. Moran, H. N. Shapiro, D.B. Boettner& M. N. Bailey, Principles of Engineering Thermodynamics, 8th ed., Wiley publication.

Course Outcomes:

To provide the students with

- fundamental concepts relevant to thermodynamics.
- concepts of work, power, and heat in thermodynamics; determine work and learn heat sign conventions; determine work involved with moving boundary systems.
- understanding of energy analysis of refrigeration and heat pump thermodynamic cycles.
- understanding of principles of conservation of mass, conservation of energy, and the application of second law of thermodynamics to thermodynamic cycles.

Subject Code: ME 5435

Subject Name: Alternative Energy Sources (Elective-II)

Energy scenario and renewable energy sources: global and Indian situation. Potential of non-conventional energy sources, economics.

Solar energy: radiation, flat-plate and concentrating collectors, fluid flow and heat transfer analysis, estimation of solar radiation, active systems, solar pond, passive space conditioning, power generation, photovoltaics.

Wind energy and principle of its convention. Types of wind machines and their designs.

Principles and applications of Wave energy, Tidal energy, Biomass energy, OTEC and Geothermal energy.

Hydrogen energy: Hydrogen as a renewable energy source, Hydrogen Fuel for Vehicles, Production and storage of Hydrogen.

Text & Reference Books:

1. J.W. Twidell and T. Weir, Renewable Energy Sources. Taylor & Francis
2. V. V. N. Kishore, Renewable Energy Engineering and Technology- Principles and Practice.TERI publishing.
3. P. Gevorkian, Sustainable Energy Systems Engineering. McGraw Hill.
4. Godfrey Boyle, Renewable Energy, Power for a Sustainable Future. Oxford University press.
5. B. H. Khan, Non-Conventional energy Sources. McGraw Higher Ed.
6. S.P. Sukhatme, J.K. Nayak. Solar Energy-Principles of Thermal Collection and Storage.N McGraw Hill.
7. F. Kreith and J. F. Kreider, Principles of Solar Engineering. Elsevier.

Course Outcomes:

To provide the students with

- understanding of the need of energy conversion and its various methods
- knowledge of different solar collectors and their applications.
- understanding of Wind energy as alternate form of energy and to know how it can be tapped
- understanding of the Geothermal and Tidal energy, mechanism of generation and their applications
- knowledge of how to generate bio gas and its impact on the environment

Subject Code: ME 5541
Subject Name: Zero Energy Buildings (Elective-II)

Introduction: Zero Energy Buildings (ZEBs) and its Concepts; Different definitions of ZEBs; Relevance of such systems; Steps to Achieve ZEBs; Challenges Involved in the Design of Such Systems; Sources of Renewable Power for ZEBs.

Design Concepts of ZEBs: Thermal loads and energy use in buildings; Design considerations in ZEBs; Building fabric/ envelope; HVAC and Lighting Systems; Integration with Solar/ Renewable Energy Systems.

Building Energy & Operation Management: Building Management Systems; Optimal resource dispatch (thermal and electrical), demand side management with ZEB operation including HVAC, lighting control; Operation of building micro-grids in grid connected/islanded modes; provision of ancillary services sharing among the various buildings.

Comfort considerations in ZEBs: Thermal Comfort, Visual Comfort, Acoustic Comfort, Indoor Air Quality.

Economics of ZEBs: Carbon Footprint Mitigation; Economic assessment of ZEBs; ZEB Case Studies; Future prospects & direction.

Text & Reference Books:

1. Arora, C. P., Refrigeration and Air Conditioning, McGraw Hill Education (2017).
2. Athienitis A. and O'Brien W., Modeling, Design, and Optimization of Net-Zero Energy Buildings, Ernst &Sohn, (2015).
3. Goswami, D. Y., Principles of Solar Engineering, CRC Press Taylor & Francis Group (2015).
4. Chwieduk, D., Solar Energy in Buildings, Elsevier (2014).
5. Holman, J. P., Heat Transfer, McGraw Hill Education (2010).
6. Duffie, J. A., Beckman, W. A., Solar Engineering of Thermal Processes, John Wiley & Sons (2006).

Course Outcomes:

To provide the students with

- thorough understanding of Zero Energy Building definitions.
- understanding solar energy utilization in buildings.
- understanding of other Renewable sources of power generation for buildings.
- understanding of energy conservation studies in building perspective
- understanding of contemporary HVAC equipment and possible integration of renewable energy
- understanding of introduction to novel materials and designs for ZEB construction
- understanding of tangible strategies for reducing energy demands in different climatic zones

Subject Code: ME 5542
Subject Name: Carbon Audit and Management (Elective-II)

Introduction: Energy and society; Greenhouse gas emissions from the energy sector and their time trend; Relative contribution of various sectors to global greenhouse gas emissions.

Sources and estimation of carbon emissions: Climate change and other potential impacts of enhanced greenhouse effect caused by emissions from different sectors, storage and utilization of energy carriers; Measurement and estimation of carbon emissions from different sectors and utilization of various energy carriers.

Carbon auditing: Carbon footprints; Carbon audit; Estimation of direct and supply chain carbon footprints; Need for reducing carbon footprints; Identification of niche areas for carbon management.

Carbon Management: Tools and accounting techniques for carbon audit and management; Sustainability accounting; Life cycle assessment approach; Integrated supply chain analysis with respect to carbon; Standards; Carbon management policies; Carbon management regulations and protocols.

Carbon Management Applications: Carbon management in energy generation, transport, water and wastewater, manufacturing, information and communication technology etc.; Carbon management in new buildings and cities; Carbon implications of waste reduction and recycling; Strategies for carbon storage in soil and in oceans.

Carbon Credits and Carbon Economics: Carbon credits; Trading schemes; Carbon economics; Low carbon investments; Carbon labeling challenges and opportunities in carbon management in energy sector and energy intensive industries and applications; Energy generation for a low carbon society for sustainable development.

Text & Reference Books:

1. Subramanian S. M., The Carbon Footprint Handbook, CRC Press (2015).
2. UNDP, Carbon Handbook, United Nations Development Programme (2014).
3. Emmanuel R., Keith B., Carbon Management in the Built Environment, Routledge (2012).

Course Outcomes:

To provide the students with

- identify the effects of carbon emissions on the environment and consequent challenges.
- acquire necessary knowledge and skills to conduct carbon audits and life cycle analysis to identify carbon management opportunities.
- implement efficient and effective carbon management strategies in the energy sector and energy intensive industries and document the same.

Subject Code: ME 5543
Subject Name: Energy and Environment (Elective-II)

Introduction: Concepts of pollution and climate change, sources of environmental pollution , Power Generation sector: , conventional energy sources , life cycle analysis of conventional sources , renewable energy sources (solar) , life cycle analysis of renewable energy sources (solar) , renewable energy sources (wind) , life cycle analysis of renewable energy sources (wind)

Transport sector: conventional and renewable fuel based systems life cycle analysis of conventional and renewable fuel-based systems
Process heating: conventional and renewable energy based systems, life cycle analysis of conventional and renewable energy based systems

Pollutant emission reduction measures for conventional and renewable energy, Sources, Prospects of renewable energy based systems in rural and urban areas Environmental impact of pollution on human health and living beings, Environmental Ethics.

Analysis of Wastewater: Gravimetric methods for water and wastewater, determination of various physicochemical parameters, working principles of electrodes, different types of electrodes.
Air Pollution Measurements: Sampling techniques for air pollution measurements; analysis of particulates and common chemical air pollutants, analysis of oxides of nitrogen, oxides of sulphur, carbon monoxide, hydrocarbon and poly aromatic hydro carbons.Meteorological Bases of Atmospheric Pollution–Transport and Dispersion of Air Pollutants–AirPollution Modelling and Prediction.

Text & Reference Books:

1. Twidell J. and Weir T., Renewable Energy Resources, Routledge, Taylor & Francis (2015).
2. Gerber L., Designing Renewable Energy Systems: A Life Cycle Assessment Approach, CRC Press (2014).
3. Singh A., Pant D., Olsen S. I. (Editors), Life Cycle Assessment of Renewable Energy Sources, Springer, (2013).
4. Kaltschmitt M., Streicher W., Wiese A., Renewable Energy: Technology, Economics and Environments, Springer (2007).

Course Outcomes:

To provide the students with,

- knowledge about key challenges and technologies in energy use
- utilization of energy resources, energy conversion and environmental consequences
- knowledge about environment as a framework for energy use and the exploitation of energy resources
- life cycle thinking and environmental impacts from energy production

Subject Code: ME 5452
Subject Name: Batteries and Fuel Cells (Elective-III)

Energy Resources, Energy Crisis, Need for Energy storage: Fuel cell and Battery.
Battery –Introduction, Types of Batteries and their operational principle.
Fuel Cells- principle - working - thermodynamics and kinetics of fuel cell process – performance evaluation of fuel cell – comparison on battery Vs fuel cell.
Types of fuel cells – AFC, PAFC, SOFC, MCFC, DMFC, PEMFC – relative merits and demerits.
Application of fuel cell and economics: Fuel cell usage for domestic power systems, large scale power generation, Automobile, Space.
Economic and environmental analysis on usage of Hydrogen and Fuel cell. Future trends in fuel cells.

Text & Reference Books:

1. B. Hart and G.J.Womack, Fuel Cells: Theory and Application

2. Viswanathan and M AuliceScibioh, Fuel Cells – Principles and Applications,

3. L. Rebecca and Busby, Hydrogen and Fuel Cells: A Comprehensive Guide,

4. Bent Sorensen (Sorensen), Hydrogen and Fuel Cells: Emerging Technologies and Applications,

Course Outcomes:

Students will be able to:
1. understand the concepts of fuel cells and its working principles.
2. learn the application of various types of fuel cells for domestic and large scale applications.
3. learn the Economic and environmental analysis on usage of Hydrogen and Fuel cell

Subject Code: ME 5551
Subject Name: Solar Passive Concepts (Elective-III)

Introduction: Solar radiation, its types and measurements, thermal comfort, solar space heating and cooling.

Building with Solar Exposure: Requirements for passive solar building design, Various building forms and designation, Mutual shading of buildings, Building orientations with respect to sun, Efficiencies of building forms, Building fenestration designs.

Solar Passive Concepts & Components: Passive solar design, Passive heating concepts- direct gain, indirect gain, isolated gain, sun space and green houses, Passive cooling concepts – Thick walls and roofs, Overhangs and wing walls, Trombe wall, Cavity wall, Roof pond, Vary therm wall, Sky therm, Earth sheltered structure, Evaporative cooling, Radiative cooling, Ventilation components. Green buildings, met zero and net positive building, building integrated passive systems.

Heat Transfer in Buildings: Modes of heat transfer- basic concepts, Surface coefficients, overall thermal transmittance for various walls and roofs, Heat transfer due to ventilation/infiltration, intermittent heat transfer, heat transfer through building integrated passive systems.

Mathematical Modelling of Passive Concepts: Approximate methods- degree day method, steady state method, Correlation methods, Analytical methods- thermal circuit analysis, Finite difference approach, Response factor method, finite volume method.

Evaporative Cooling: Historical background, Basic principle and classification, Direct and Indirect types of evaporative cooling, two stage evaporative cooling, Earth cooling, Earth air tunnel systems.

Solar Passive Buildings: For cold climate- the hedge type, warehouse type, sunroom (green house), trombe wall type, etc. For tropical climate – skytherm systems, designs for arid, and hot and humid climate.

Text and Reference books:

1. Solar Passive Building- Science & Design; M.S. Sodha, N.K. Bansal& A. Kumar
2. Passive Building Design- A Hand Book of Natural Climate Control; N.K. Bansal& G. Hanser.
3. Thermal Control in Passive Solar Buildings; S.C. Kaushik, G.N. Tiwari, J.K. Nayak
4. ASHRAE Hand Book Of Fundamentals;ASHRAE

Course Outcomes:

To provide the students with

- understanding of fundamentals of solar radiation, its availability, geometry of solar radiation and equations for predicting availability
- knowledge of the types of collectors and procedure for analysing performance of collectors
- knowledge of various thermal energy storage systems
- understanding of direct and indirect use of solar energy and other application of solar energy
- knowledge of solar thermal power generation methods.
- critical thinking and reasoning about issues associated direct and indirect use of solar energy

Subject Code: ME 5552
Subject Name: Fuel and Combustion Technology (Elective-III)

Introduction and classification of different types of fuel, Petroleum cracking, Synthetic petrol, Refining of gasoline, Reforming, Chemical structure of fuel and knocking.Octane Rating of fuels, Cetane Rating, Diesel engine fuel, Kerosene, LPG as a fuel.

Classification, Calorific value, Types, Determination by Bomb calorimeter, Dulong's Formula, Analysis of Coal, Proximate and Ultimate analysis, Flue gas analysis, Carbonization of Coal, Manufacture of metallurgical coke by Otto Hoffman's byproduct oven.

Combustion of liquid fuels, fuel atomization, types of injectors and spray characteristics, burning droplet in its ballistic trajectory, characteristics of spray combustion, characteristics and design considerations of coal burners.

Fundamentals of thermochemistry; Combustion air calculation; Calculation of calorific value of fuels; Adiabatic flame temperature calculation; Mechanism and kinetics of combustion; Flame properties; Combustion burners; Combustion furnaces; Internal combustion engines.

Text and Reference books:

1. Modern Petroleum Technology, Vol. 1, Upstream, Ed. by Richard A. Dave, IP, 6th ed., John Wiley & Sons. Ltd.
2. Modern Petroleum Technology, Vol 2, Downstream, Ed. by Alan G. Lucas, IP, 6th ed., John Wiley & Sons. Ltd.
3. Combustion, Irvin Glassman, 2nd ed., Academic Press.
4. Modern Petroleum Refining Processes, B.K. Bhaskar Rao, 4th ed., Oxford & IBH Publishing Co. Pvt. Ltd.
5. Fuels Combustion and Furnaces, John Griswold, Mc-Graw Hill Book Company Inc.
6. Fuels and Combustion, Samir Sarkar, 3rd. ed Universities Press.

Course Outcomes:

To provide the students with

- basic understanding about the types of fuel.
- different processes of producing different types of fuels.
- detailed concept on phenomenon of combustion.
- understanding of different reaction mechanisms during combustion.
- understanding of thermo chemistry from combustion perspective.
- analytical skill to assess the possible pollutant species under different combustion conditions.

Subject Code: ME 5553
Subject Name: Hydropower Technologies (Elective-III)

Energy Resources Planning and Potential: Power resources, Conventional and Nonconventional, Need & advantages, Wind data analysis, Hydrological analysis, Wind Power and Hydropower development in India, Wind energy potential, Hydropower potential, Estimation of Hydropower potential, Comparison of Hydro, thermal and nuclear power.

Hydropower Plants: Classification of hydropower plants -Run of river plants, Storage or Valley dam plants, Pumped storage plants, Introduction to micro hydro, Base load and Peak load plants, advantages & disadvantages, Components of hydropower plants. Selection, Classification, Principles and design of impulse & reaction turbines, Governing of turbines, Water hammer, Surge tanks, Draft tubes, Cavitation.

Economic Aspects: Economic considerations –pricing of electricity, laws and regulatory aspects, Policies, Electricity act –2003, Investment in the power sector, Carbon credits, Participation of private sector.

Text and Reference books:

1. Water Power Engineering –M. M. Dandekar and K. N. Sharma. Vikas publishers.
2. Handbook of Hydroelectric Engineering –P.S. Nigam. Nem Chand publisher.
3. Modern Power System Planning –Wang X. Wiley McGraw Hill.
4. Water Power Engineering - Barrows, H.K. Tata McGraw Hill Publishing Company Ltd., New Delhi.
5. David Wood: Small Wind Turbines- Analysis, Design, and Application. Springer, 2011.
6. James F. Manwell, Jon G. McGowan, Anthony L. Rogers. Wind Energy Explained: Theory, Design and Application. Wiley International, 2nd Edition, 2009.

Course Outcomes:

To provide the students with

- understanding of wind and hydro energy resource assessment techniques.
- understanding of the principles of conversion of these resources to useful form of energy
- understanding of the working principles of the conversion devices, their limitations, cost of energy generation and environmental issues.

Subject Code: ME 5554
Subject Name: Energy generation from Waste (Elective-III)

Introduction

The Principles of Waste Management and Waste Utilization. Waste Management Hierarchy and 3R Principle of Reduce, Reuse and Recycle. Waste as a Resource and Alternate Energy source.

Waste Sources & Characterization

Waste production in different sectors such as domestic, industrial, agriculture, postconsumer, waste etc. Classification of waste – agro based, forest residues, domestic waste, industrial waste (hazardous and non-hazardous). Characterization of waste for energy utilization. Waste Selection criteria.

Technologies for Waste to Energy

Biochemical Conversion – Energy production from organic waste through anaerobic digestion and fermentation. Thermo-chemical Conversion – Combustion, Incineration and heat recovery, Pyrolysis, Gasification; Plasma Arc Technology and other newer technologies.

Waste to Energy Options

Landfill gas, collection and recovery. Refuse Derived Fuel (RDF) – fluff, briquettes, pellets. Alternate Fuel Resource (AFR) – production and use in Cement plants, Thermal power plants and Industrial boilers. Conversion of wastes to fuel resources for other useful energy applications. Energy from Plastic Wastes – Non-recyclable plastic wastes for energy recovery. Energy Recovery from wastes and optimization of its use, benchmarking and standardization. Energy Analysis

Waste To Energy & Environmental Implications

Environmental standards for Waste to Energy Plant operations and gas clean-up. Savings on non-renewable fuel resources. Carbon Credits: Carbon foot calculations and carbon credits transfer mechanisms.

Text and Reference books:

1. John Pichtel, Waste Management Practices: Municipal, Hazardous, and Industrial, Second Edition, CRC Press.
2. Banwari Lal and Patwardhan, Wealth from Waste: Trends and Technologies by, TERI Press.
3. S.N Mukhopadhyay, Fundamentals of waste and Environmental Engineering, TERIPress.
4. George Tchobanoglous,Frank Kreith, Handbook of Solid Waste Management, Second Edition,The McGraw-Hill.

Course Outcomes:

To provide the students

- with the knowledge about the operations of Waste to Energy Plants.
- the various aspects of Waste to Energy Management Systems.
- with knowledge to carry out Techno-economic feasibility for Waste to Energy Plants.
- with the knowledge in planning and operations of Waste to Energy plants

Subject Code: EE 5256
Subject Name: Energy Market Policies with Renewable Energy Share (Elective-III)

Introduction : Basic concepts of Energy Market (EM), its role, structure, classifications, roles of various entities.

Concepts of energy trading: Market mechanisms to sell electrical energy into EM, concepts of market equilibrium, its importance for global welfare and sustainability.

Challenges with Renewable Energy Sources like Solar, Wind etc, variability, power quality issues.

Challenging aspects of higher Renewable Energy (RE) share to EM operation :imbalance management, system stability, energy pricing etc.

Policies adopted at international and national level for RES and its higher share into Grid and EM.

Regulatory frameworks and policies for RE pricing and its trading.

Text & Reference Books

1. Lawrence E. J., Renewable Energy Integration, Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier Publications(2016).
2. Mayor L-I. V., Clean Energy Law and Regulation, Widdy, Simmonds & Hill Publishing (2017).
3. Perez- Arriaga I. (Ed.), Regulations of the Power Sector, Springer (2013)
4. S.Hunt & K.Bhattacharya, Making competition work in electricity. John Wiley & Son’s
5. D.Kirschen & G.Strbac, Fundamentals of power system economics. John Wiley & Son’s
6. Clark W Gellings, Effective power marketing. Pennwell publishers.

Course Outcomes:

To provide the students with

- The fundamental concepts of electrical energy market, its role and working models
- The understanding of the challenges with high penetration of RE based electricity
- The knowledge of regulatory frameworks for various RE based electric energy
- The ability to define the energy pricing mechanisms for RE based electricity

Subject Code: ME 5246
Subject Name: Theory of Uncertainty (Elective-IV)

Introduction: Fundamentals of Uncertainty, Types of Uncertainty, Principles of Uncertainty, Indeterminacy, Frequency, Belief Degree, Sources of Uncertainty, Propagation of uncertainty, Uncertain Logic, Uncertain Inference, Uncertain Process, Probability theory and Chance theory, Model calibration, Model validation and verification, Surrogate models, Parameter selection, Sensitivity Analysis, Various Scale-based applications, Noisy data interpretation.

Uncertainty Measures and Variable: Measurable Space, Uncertain space, Independence, Polyrectangular theorem, Conditional Uncertain Measure, Uncertain Variables, Distribution, Operational Laws, Expected value, Variance, Moment, Entropy, Distance, Conditional Uncertainty Distribution, Uncertain Sequence, Uncertain Vector.

Uncertain Programming: Numerical Method, Machine Scheduling Problem, Multi-objective Programming, Goal Programming, Multilevel Programming.

Uncertainty Modeling methods and Sampling Techniques: Deterministic and Non-deterministic Approach, Probabilistic and Non-probabilistic modeling, High dimensional model representation, Response Surface methods, Random variable and Random field Approach, Kriging model, Model reduction, Various Sampling and optimization techniques and Solutions.

Risk and Reliability Analysis: Loss Function, Structure Function, Risk Index and Reliability Index, Series and Parallel System, k-out-of-n System, First order reliability method (FORM), Second order reliability method (SORM), Solution of engineering real-life problems.

Text & Reference Books:

1. T.J. Sullivan. Introduction to Uncertainty Quantification.Springer.
2. Eduardo Souza de Cursi and Rubens Sampaio.Uncertainty Quantification and Stochastic Modeling with Matlab.Springer.
3. Ralph C. Smith. Uncertainty Quantification: Theory, Implementation, and Applications. SIAM.
4. FlavioCanavero. Uncertainty modeling for engineering applications.Springer.
5. Ahmed Zobba and Shady Abdel Aleem.Uncertainties in modern power systems. Academic Press, ISBN: 9780128204917.
7. Hydrogen and Fuel Cells: Emerging Technologies and Applications, A Comprehensive Guide, Bent Sorensen (Sorensen)
8. S. Dey, T. Mukhopadhyay and S. Adhikari.Uncertainty Quantification in Composite Structures –A Metamodel Based Approach. CRC Press.
9. Roger Ghanem, David Higdon and HoumanOwhadi (Eds.). Handbook of Uncertainty Quantification. Springer

Course Outcomes:

To provide the students with

- understand the fundamental knowledge of uncertainty with its significance and applications in engineering systems with emphasis on energy.
- ability to apply the concept in identifying the sources of uncertainty in the systems.
- Ability to analyse the route-map for propagation of uncertainty in the systems.
- Ability to evaluate for quantification of uncertainty in the systems.
- ability to design and implement the system considering uncertainty.

Subject Code: ME 5443

Subject Name: Energy Audit and Management (Elective-IV)

Energy Scenario–world and India, Energy Resources Availability in India, Energy consumption pattern, Energy conservation potential in various Industries and commercial establishments, Energy intensive industries–an overview. Energy conservation and energy efficiency– needs and advantages, Energy auditing– types, methodologies, barriers. Role of energy manager–Energy audit questionnaire.

Instruments for energy auditing: Instrument characteristics–sensitivity, readability, accuracy, precision, hysteresis, Error and calibration, Measurement of flow, velocity, pressure, temperature, speed, Lux, powerand humidity, Analysis of stack, water quality,power and fuel quality.

Thermal Utilities: Operation and energy conservation-Boilers,Furnaces, Waste Heat Recovery Systems. Thermal energy transmission / protection systems: Steam traps–refractories–optimum insulation thickness–insulation–piping design.

Financial management: Investment–need, appraisal and criteria, financial analysis techniques–break even analysis–simple payback period, return on investment, net presentvalue, internal rate of return, cash flows.
Energy audit -Definition, Need, Types of energy audit, Energy audit Instruments. Cogeneration-Types and Schemes, Optimal operation of cogeneration plants- Case study. Computer aided energy management.

Text & Reference Books:

1. Marguerite A. H. Ruffner, Energy Auditing and Conservation; Methods, Measurements, Management and CaseStudy. Hemisphere Publishing Corporation
2. Smith, CB Energy Management Principles.2nd ed., Elsevier.
3. Write, Larry C, Industrial Energy Management and Utilization.CRC press.
4. P. O'Callaghan, Energy Management.McGraw-Hill.

Course Outcomes:

To provide the students with

- understanding of the energy management, conservation processes, principles of energy auditing, energy flow diagram, economics of energy conservation opportunities.
- understanding of the energy management information systems, various key features of Energy Conservation Act and ECBC.
- understanding of the scope for energy conservation in electrical and thermal energy utilities.

Subject Code: ME 5561
Subject Name: Ocean Renewable Energy (Elective-IV)

Introduction to wave mechanics; Basic equation; Conservation of mass, momentum and energy in fluid mechanics; Surface stress on a particle; Hydrostatics; Translational equation of motion, Review of vector analysis; Line integrals, Velocity potential, Cylindrical coordinates; Bernoulli equation;

Small amplitude water wave theory formulation and solution; Governing equation, assumptions and boundary conditions; Solution of linearized water wave boundary value problem for a horizontal bottom;

Wave properties; Water particle kinematics for progressive waves; Wave classification by relative depth; Particle velocity; Acceleration and orbit geometry; Pressure field; Wave energy; Energy flux and group celerity; Momentum flux; Radiation stress; Wave refraction; Wave diffraction; Combined refraction and diffraction;

Nonlinear properties derivable from small amplitude waves; Nonlinear wave equation; Validation of stokes expansion; Solitary wave; Cnoidal wave; Validity of nonlinear wave theories;

Wave body interaction; Potential flow approach; Force due to real fluid; Morison equation; Total force calculation; Methodology for determining drag and inertia coefficients; Wave force on pipelines resting on the sea floor; Numerical methods for wave loading on arbitrary shapes objects;

Wave maker theory; Simplified theory for plane wave makers in shallow water; Complete wave maker theory for plane waves produced by a paddle; Planar wave energy absorbers; Cylindrical wave makers; Plunger wave makers;

Text and Reference books:

1. Robert G Dean & Robert A. Dalrymple "Water wave mechanics for engineers and scientists" World scientific publishers.
2. Robert M. Sorensen "Basic wave mechanics: for costal and ocean engineering" John Wiley& sons, Inc.
3. Robert L. Wiegel "Oceanographical Engineering". Prentice-Hall India
4. Maarten W. Dingemans "Water wave propagation over uneven bottom Part 1 - Linear wave propagation".

Course Outcomes:

To provide the students with

- good understanding of the fundamentals of tidal turbines and wave energy converter performances
- the knowledge of how to assess the performances of these technologies.

Subject Code: ME 5562
Subject Name: Hydrogen Energy (Elective-IV)

Introduction of Hydrogen Energy Systems: Current uses; Infrastructure requirement for hydrogen production, storage, dispensing and utilization; Hydrogen production plants.

Hydrogen Production Processes: Thermal – Steam Reformation, Thermo chemical Water Splitting, Gasification, Pyrolysis; Nuclear thermo catalytic and partial oxidation methods; Electrochemical – Electrolysis, Photo electro chemical; Biological – Photo Biological, Anaerobic Digestion, Fermentative Micro-organisms.

Hydrogen Storage: Physical and chemical properties; General storage methods; Compressed storage –Composite cylinders, Glass micro sphere storage – Zeolites; Metal hydride storage; Chemical hydride storage; Cryogenic storage.

Hydrogen Utilization: Overview of Hydrogen utilization in I.C. Engines, gas turbines, hydrogen burners, power plant, refineries, domestic and marine applications; Hydrogen fuel quality, performance, COV, emission and combustion characteristics of Spark Ignition engines for hydrogen, back firing, knocking, volumetric efficiency, hydrogen manifold and direct injection, fumigation, NOx controlling techniques, dual fuel engine, durability studies, field trials, emissions and climate change.

Hydrogen Safety: Safety barrier diagram, risk analysis, safety in handling and refueling station, safety in vehicular and stationary applications, fire detecting system, safety management, simulation of crash tests.

Text & Reference Books:

1. Ball M. and Wietschel M., The Hydrogen Economy Opportunities and Challenges, Cambridge University Press (2009).
2. Bockris J.O. M., Energy options: Real Economics and the Solar Hydrogen System, Halsted Press and London publisher (1980).
3. Babu M.K.G., Subramanian K.A., Alternative Transportation Fuels: Utilization in Combustion Engines, CRC Press (2013).

Course Outcomes:

To provide the students with

- understanding the fundamentals of hydrogen energy systems
- understanding the production processes of hydrogen energy
- understanding the methods of hydrogen energy storage
- knowledge of hydrogen energy utilization
- knowledge of safety measures requirement with hydrogen energy utilization

Subject Code: ME 5563
Subject Name: Zero Emission Vehicles (Elective-IV)

Introduction: Introduction to zero emission vehicles, different types of power train / vehicles.

Fundamentals of Internal combustion (IC) engines: Spark ignition and Compression ignition engines; Emissions formation mechanisms in internal combustion engines (UHC, CO, NOx, N2O, PM, etc.), Overview of technologies for achieving zero emission; Lean burn combustion (PCCI and HCCI); Controlled auto ignition; Homogeneous charge preparation strategies.

Hydrogen fuelled IC engines: Back firing; Power drop; Fuel induction techniques; Technologies for improvement of power and thermal efficiency; NOx emission reduction technologies and strategies: exhaust gas recirculation, water injection, after treatment devices (selective catalyst reduction, Lean NOx Trap, particulate trap, oxidation catalyst, etc.)

Hybrid vehicles: Introduction; Classification; Advantages and disadvantages; IC engines with electrical motor system; Regeneration of energy through breaking: Power-torque characteristics; Fuel economy improvement for urban driving cycle.

Battery operated vehicles: Type of battery for vehicle applications; Accessories of battery operated vehicles; Battery recharging systems; Variable frequency drive.

Fuel cell vehicles: Introduction; Fuel cell system; Classification; Speed-Torque and Speed-power characteristics; Operational issues; Overall efficiency; Power output; Comparison of fuel cell and IC engines at same conditions for their efficiency and transient performance.

Environment impact (assessment of CO_2 emission) of zero emission vehicles.

Text & Reference Books:

1. Babu M. K. G., Subramanian K. A., Alternative Transportation Fuels: Utilization in Combustion Engines, CRC Press(2013).
2. Willard W. P., Engineering Fundamentals of the Internal Combustion Engine, Pearson Prentice Hall(2008).
3. Addy M. W., Khair M. K., Diesel Emissions and Their Control, SAE International (2006).
4. Ferguson C. R., Allan T. K., Internal Combustion Engines Applied Thermosciences, John Wiley & Sons, Inc. (2001).
5. Turns S. R., An Introduction to Combustion, McGraw-Hill Companies(2000).
6. Heywood J. B., Internal Combustion Engine Fundamentals, McGraw-Hill, Inc. (1988).

Course Outcomes:

To provide the students with

- knowledge of various transportation vehicles with zero/near-zero emissions in details.
- Knowledge-base for development of sustainable transportation vehicle.