

As Per NEP 2020

University of Mumbai



Title of the program

- | | | |
|---|---|---------|
| A- P.G. Diploma in Energy Science and Technology | } | 2024-25 |
| B- M.Sc. (Energy Science and Technology) (Two Year) | | |
| C- M.Sc. (Energy Science and Technology) (One Year)- | | |

University Department of Physics (Autonomous)

Syllabus for

Semester – Sem I & II

Ref: GR dated 16th May, 2023 for Credit Structure of PG

Preamble

1. Introduction

M.Sc in Energy Science and Technology is a two year degree program which is designed for young, bright and enthusiastic students to pursue higher studies in Energy Science and Technology at University of Mumbai. The candidates who have completed a Bachelor program (B.Sc or equivalent) from a recognized institution with minimum of 50% marks in major (Chemistry and Mathematics as subsidiary subjects). Candidates from universities/institutes which do not offer major/honours must have at least 55% marks in physics as well as in aggregate with Physics, Chemistry and Mathematics as subject combination, are eligible to apply for this program. On successful completion of this program, the students will be awarded Master of Science degree in Energy Science and Technology from Mumbai University. Award of the M.Sc. in Energy Science and Technology degree shall be in accordance with the academic regulations of the university on the requirements of the given program. An admission test is usually adopted as qualifying criteria for short-listing and selection for all the categories. During the next academic year 2024-25, University Department of Physics is proposing to start a new PG programme in M.Sc. (Energy Science and Technology) under NEP-2020 program with effect from academic year 2024-25.

2. Aims and Objectives

Create the facilities and environment in all the educational institutions to consolidate the knowledge acquired at undergraduate level and to motivate and inspire the students to create deep interest in Energy Science and Technology, to develop broad and balanced knowledge and understanding of physical concepts, principles and theories of Energy Science and Technology. Learn, design and perform experiments in the labs to demonstrate the concepts, principles and theories learned in the classroom.

3: Learning outcomes

1. The students would be able to have strong foundation knowledge and comprehend the basic concepts and principles in Energy Science and Technology.
2. The students would be able to progress in their academic performance through structured curricula.
3. The students would be able take up competitive exams in different sectors, can be entrepreneurs and succeed in higher education in Energy Science and Technology

4. The students would be able to experience a well resourced environment for learning Energy Science and Technology
5. To motivate and inspire the students to create deep interest in Energy Science and Technology to develop broad and balanced knowledge and understanding of physical concepts, principles and theories of Energy Science and Technology

4 Any other points:

1. During the course work students will be provided hands on training on highly sophisticated state of art equipment's.
2. Students will be provided internship at the various government lab and nearby industries.
3. Collaborative activities with national and international institutes/industries to cater the need of regional development.

R: _____

**Credit Distribution Structure for One Year PG /Two Years
M.Sc. (Energy Science and Technology)**

Year	Level	Sem	Major		RM	OJT / FP	RP	Cum. Cr.	Degree
			Mandatory	Elective					
1	6.0	Sem 1	3 x 4 + 2 x 1 = 14	4	4	--	--	22	
			EST-(501)-Mathematical Foundation for Energy Science	EST - (505) Elective 1 (List attached)	EST - (506) Research Methodology	--	--		
			EST -(502)-Numerical Methods for Energy Applications						
			EST -(503)-Materials Science for Energy						
			EST -(504) Energy Practical Lab-1						
		Sem 2	3 x 4 + 2 x 1 = 14	4	--	4		22	
			EST -(511)-Energy Resources, Economics and Environment	EST - (515) Elective 2 (List attached)	--	EST - (516) Research Project			
			EST -(512)-Thermodynamics in Energy Conversion						
			EST -(513)-Methods in Analytical techniques						
			EST -(514) Energy Practical Lab-2						
			3x4+2=14	4		4		22	
Cum. Cr. for PG Diploma			28	8	4	8		44	
Exit Option: 1 yr PG Diploma (44 credits) after Three Year UG Degree									
Year	Level		Major		RM	OJT / FP	RP	Cum. Cr.	Degree
			Mandatory	Elective					
2	6.5	Sem-3	3 x 4 + 2 = 14		--	--	4	22	
			EST-(601)-Chemistry for Energy Science	EST-(605) Elective 3 (List attached)	--	--	EST-(606) Research Project		
			EST-(602)- Introduction to renewable energy technologies						
			EST-(603)-Energy Systems Modeling and Analysis						
			EST-(604) Energy Practical Lab-3						
			3 x 4+2= 14	4	--	--	4	22	
		Sem-4	EST -(611) Research Project (This is one semester project which should be carried in Energy based industry) -(??)						
								22	
Cum. Cr. for 1 yr PG Degree			26	8	--	--	10	44	
Exit Option: 1 yr PG Degree (44 credits) after Four Year UG Degree (Energy Science)									
Cum. Cr. for 2 yr PG Degree				5 6	16	4	--	14	88

Exit Option: 2 yr PG Degree (88 credits) after Three Year UG Degree (M.Sc. Energy Science and Technology)

LIST OF ELECTIVES

	Elective-1 EST-(505A-505G)	Elective-2 EST-(515A-515G)	Elective-3 EST -(605A-605G)
A	Energy Audit and Management	Energy Resource Assessment and Forecasting	Petroleum Production
B	Solar Photovoltaic Devices and Systems	Solar Thermal Power Generation	Solar Thermal Technologies and Applications
C	Energy Storage	Fuel Cell	Supercapacitors
D	Green Energy Systems	Bioenergy: Resources, Technologies and Applications	Bioconversion and Processing of Waste
E	Oil and Gas:Reservoirs to Refinery	Wind and Small Hydro Energy Systems	Energy conservation of Thermal Systems
F	Nuclear Energy	Hydrogen Storage	Hydrogen Energy
G	Energy Technology: Current scenario and forecasting	Computational Fluid Dynamics	Modeling and Simulation of Energy Systems

V. Bambole

Sign of HOD

Prof. Vaishali A. Bambole
Department of Physics

**Professor & Head
Department of Physics
University of Mumbai**

Garje

Sign of Dean

Prof. Shivram Garje
Science and Technology

Programme Specific Outcomes (PSO) and Course Outcomes (CO)

Learning outcomes

1. **PSO1:** The students would be able to have strong foundation knowledge and comprehend the basic concepts and principles in Energy Science and Technology.
2. **PSO2:** The students would be able to progress in their academic performance through structured curricula.
3. **PSO3:** The students would be able take up competitive exams in different sectors, can be entrepreneurs and succeed in higher education in Energy Science and Technology.
4. **PSO4:** The students would be able to experience a well resourced environment for learning Energy Science and Technology.
5. **PSO5:** To motivate and inspire the students to create deep interest in Energy Science and Technology to develop broad and balanced knowledge and understanding of physical concepts, principles and theories of Energy Science and Technology.

EST-501 Mathematical and Statistical Foundation for Energy Science

The course is structured to make a solid foundations for mathematical methods used in Energy sciences and technology. It tries to equip learners with ordinary and partial differential equations and teach them the techniques to solve them. The course also tries to exposed learners to mathematical transforms like Fourier transforms and their applications arising in energy sciences. The last unit is designed to make a solid foundation for the statistics concepts and statistical testing. It is expected that learners will used programming languages like and packages such as MATLAB while learning the key mathematical and statistical concepts.

Course outcomes:

At the end of the course, the learner is able to

1. Understand the ordinary differential equations arising in energy sciences and apply different methods to solve them (CO1)
2. Understand the partial differential equations arising in energy sciences and apply different methods to solve them (CO2)
3. Understand the Fourier series and Fourier transform arising in different contest in Energy sciences (CO3)
4. Have a solid foundation in basics of Statistics and hypothesis testing (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

EST-502 Numerical Methods for Energy Applications

The course is structured to make a solid foundations for use of numerical methods and computational techniques to problems arising in energy sciences and technology. Different discretization techniques for solving partial differential equations will be taught and a special emphasize will be on the finite volume methods for problems arising inn energy sciences and technology. Advance techniques and emerging applications of machine learned potentials will be taught to the learners.

Course outcomes:

At the end of the course, the learner is able to

1. Different discretization techniques for solving differential equations which include finite element and finite volume methods (CO1)
2. Understand context in which non-linear equations arises and apply techniques to solve them(CO2)
3. Understand and apply finite volume methods in the context of electrochemical devices (CO3)
4. Have a exposure to the emerging applications of machine learning and computational techniques arising in the context of energy sciences and related case studies (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

EST-503: Materials Science For Energy

The course is structured to expose basics concepts of materials science as applicable to energy materials and devices. To better appreciate the structure property relation, a unit on basics of crystal structure is designed. The quantum chemistry aspects of materials are exposed to the learner and a wide variety of materials with relevant physical processes are taught. A separate unit for material property aims to cover in depth the physical processes relevant to materials useful for energy sciences and technology.

Course outcomes:

At the end of the course, the learner is able to

1. Understand the crystal structure and make a model of atomic structure relevant to the problem at hand (CO1)
2. Apply the concepts in quantum chemistry for better insights into the materials properties and underlying physics and chemistry of the materials (CO2)
3. Understand the categorization of materials and thermodynamic aspects governing the temperature dependent properties and their energy related aspects(CO3)
4. Understand a wide range of properties of materials with structure-property relation including thermal electrical optical, magnetic properties etc. (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

EST -(511)-Energy Resources, Economics and Environment

The course is structured to expose basics concepts of energy science as a discipline. The learner is exposed to energy as a resource and concepts related to supply and demand side of energy. The economics of energy with its key features and its policy impact is to be appreciated by the learner. The emergence of non-renewable energy resources and its markets are covered. The learner is expected to apply these concepts in the Indian context. One of the integral aspects of energy is its relation to the environment. The learner is expected to appreciate the energy issues and its environmental impacts and appreciate the concept of sustainable development. The course is designed to include the relevant case studies for better appreciation of concepts taught in the course.

Course outcomes:

At the end of the course, the learner is able to

1. Understand the emergence of energy science as a discipline and energy as a resource(CO1)
2. Apply the framework of economics to the energy and have appreciation for its policy implications (CO2)
3. Understand the role of non-renewable energy and the existing market structure especially in the Indian context (CO3)
4. Understand a wide range of energy issues and its relation to environmental implication and appreciate the concept of sustainable development. (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

EST-512 Thermodynamics in Energy Conversion

The course is structured to expose the learners to the basics concepts in Thermodynamics. The course design aims to teach thermodynamics geared towards the application in the field of energy sciences and technology. The concepts in thermodynamics will be explained drawing from the examples and case studies in the field of energy sciences and technology. Energy conversion efficiency aspects are applied for the various forms of energy conversion processes. The open and closed thermodynamics cycles forms bedrock of applications of thermodynamics to energy technology. These aspects are aimed to be covered in depth. In the final unit, learners are expected to apply the basics framework of thermodynamics and relevant concepts to specific application in the field of energy sciences and technology.

Course outcomes:

At the end of the course, the learner is able to

1. Understand the basic framework of thermodynamics as applied to energy sciences and technology (CO1)
2. Apply the thermodynamic concepts to energy conversion processes for enhancing the efficiency of conversion (CO2)
3. Understand the role of phase diagrams and phase transformations and role of closed and open cycles with practical examples (CO3)
4. Apply the thermodynamic concepts in the analysis of specific applications relevant to energy science and technology (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

EST -(513)-Methods in Analytical techniques

The course is structured to expose the learners to standard operating procedures in laboratories for fabrication and characterization of samples. The course gives a exposure to the vacuum technology and its application while performing sample characterization. Thin film technology forms a major chunk of technological application and it is included in the course. Various materials characterization techniques are included in the syllabus so as to help the learner to apply these techniques for understanding the underlying phenomena of a particular application. The characterization techniques cover bulk to surface characterization techniques and also the widely used and routinely used techniques as well the sophisticated techniques.

Course outcomes:

At the end of the course, the learner is able to

1. Understand the standard operating procedure and the routinely used characterization techniques. (CO1)
2. Apply the knowledge of vacuum technology to the sample characterization (CO2)

3. Understand the key characterization techniques which are routinely used for materials characterization (CO3)
4. Apply the characterization techniques for understanding the underlying phenomena in the technological application (CO4)

Mapping of Course Outcomes with Programme Specific Outcomes

	PSO1	PSO2	PSO3	PSO4	PSO5
CO1	3	--	1	--	2
CO2	3	--	2	2	3
CO3	3	--	3	3	2
CO4	3	--	1	2	2

1: Low 2: Moderate 3: High

Syllabus

EST-501 Mathematical and Statistical Foundation for Energy Science

Unit I: Ordinary Differential Equations

Ordinary Differential Equations: ODE of the 1st order, solution techniques, ordinary linear differential equations of nth order, Operator method, systems of differential equations, Phase plane, Critical points, Stability. Power series, radius of convergence. Power series methods for solutions of ordinary differential equations.

Unit II: Partial Differential Equations

Boundary conditions and boundary value problems, The diffusion equation, which models e.g. the spreading out of heat energy and chemical diffusion processes; The heat equation, Arrhenius equation, Boltzmann Transport Equation, The wave equation Application of concepts to some problems in energy studies

Unit III: Introduction to Fourier series

Fourier series with arbitrary periods Using Fourier series to solve differential equations. Use of Laplace transform to solve differential Equations. Concepts of Fourier transform and Fast Fourier transform, Inverse Fourier transform

Unit IV: Foundations of Statistical Concepts

Basic definition of probability, random variables, probability density function, probability distribution function, expectation, moment generating functions; sampling statistics, order statistics, properties of sample mean, Central Limit Theorem. Hypothesis testing, Regression models., Demonstration of above concepts using R programming language.

Reference Books:

1. E. Kreyszig, Advanced Engineering Mathematics, 9th ed., John Wiley & Sons 1999.
2. W. E. Boyce and R. C. DiPrima, Elementary Differential Equations and Boundary Value Problems, 3rd ed., Wiley, 1977.
3. G. F. Simmons, Differential Equations with Applications and Historical Notes, McGraw-Hill, New York, 1991.
4. Douglas C. Montgomery, Larry Faris Thomas and George C. Runger, Engineering Statistics, 3rd ed., John Wiley & Sons, 2003.
5. Dennis Wackerly, William Mendenhall, and Richard L. Schaeffer, Mathematical Statistics with Applications, 7th edition, Duxbury Resource Center, 2007.
6. John A. Rice, Mathematical Statistics and Data Analysis, 3rd edition, Thomson Learning, 1994.
7. Roger Berger, and George Casella, Statistical Inference, 2nd edition, Thomson Learning, 2004.
8. Ajit C. Tamhane and Dorothy D. Dunlop, Statistics and Data Analysis: From Elementary to Intermediate, Prentice Hall, 1999.
9. Robert L. Jaffe and Washington Taylor, Physics of Energy, Cambridge University Press, 2019

EST-502 Numerical Methods for Energy Applications

Unit-1: Finite element Method:

Theoretical Approaches of Finite Elements Method (FEM), Finite difference method, Finite element method, Boundary value problems, Finite element analysis.

Unit-2: Numerical methods for solving non-linear equations

Initial Value Problems, Boundary Value Problems, Ordinary Differential Equations, Partial Differential Equations, nonlinear function First derivative of the nonlinear function, Second derivative of the non linear function, Initial approximation of the zero of the function, n -dimensional Jacobian matrix, Column vector of nonlinear functions, Partial derivative with respect to the unknown x , Jacobian matrix.

Unit-3: Finite Volume method for Numerical Investigations of Electrochemical devices:

Concentration, mol/m^3 , Diffusivity, m^2/s , Faraday's constant, C/mol , Current, , Current, density, A/m^2 , Reference current density, A/m^2 , Thermal conductivity, W/(m K) , Absolute permeability, Molecular weight, Pressure, Temperature, Mass fraction, Velocity, m/s , Open circuit voltage, Charge transfer coefficient, Porosity, Specific active surface area, $1/\text{m}$, Overpotential, Dynamic viscosity, Potential, Density, Electric/membrane conductivity, S/m ,

Unit-4: Machine Learning Potentials:

Graph network, Neural network (NNP), Spectral neighbor analysis (SNAP), Gaussian regression method (GAP), Deep neural network (DEEP-MD), Moment tensor Potential,

References:

1. FitSNAP: Atomistic machine learning with LAMMPS. Journal of Open Source Software, 8(84), 5118, <https://doi.org/10.21105/joss.05118>
2. Morawietz, T.; Singraber, A.; Dellago, C.; Behler, J. How van Der Waals Interactions Determine the Unique Properties of Water. Proc. Natl. Acad. Sci. U. S. A. 2016, 113 (30), 8368–8373. <https://doi.org/10.1073/pnas.1602375113>
3. Numerical Methods for Energy Applications, Naser Mahdavi Tabatabaei & Nicu Bizon , Springer, 2021
4. The original GAP paper: A.P. Bartók, M.C. Payne, R. Kondor, and G. Csányi. *Gaussian approximation potentials: The accuracy of quantum mechanics, without the electrons*. Phys. Rev. Lett. **104**, 136403 (2010).
5. Moment tensor potentials as a promising tool to study diffusion processes I. I. Novoselov, A.V. Yanilkin, A.V. Shapeev, E.V. Podryabinkin

EST-503: Materials Science For Energy

Unit-1: Crystal Structures

Crystal Systems and its various types, Brillouin zones, structures, lattices and symmetry, point group symmetry, Space Groups, etc.

Unit-2: Chemical Bonds and Molecular structures

Understand Kössel-Lewis approach to chemical bonding; • explain the octet rule and its limitations, draw Lewis structures of simple molecules; • explain the formation of different types of bonds; • describe the VSEPR theory and predict the geometry of simple molecules; • explain the valence bond approach for the formation of covalent bonds; • predict the directional properties of covalent bonds; • explain the different types of hybridisation involving s, p and d orbitals and draw shapes of simple covalent molecules; • describe the molecular orbital theory of homonuclear diatomic molecules; • explain the concept of hydrogen bond.

Units-3: Defects in Solids

Defects in Crystals; Phase Diagrams and Phase Transformations; Diffusion in Materials; Materials and Energy Related Applications (Carbon, Polymers, Ceramics, Semiconductors, Liquid crystals, Nano-materials);

Units-4: Materials Properties

Thermal Properties and Lattice Vibrations in Materials, Electrical Properties of Materials (Metals, Semiconductors, Insulators, Optical, Magnetic and Dielectric Properties of Materials;

References:

10. Fundamentals of Materials Science and Engineering: An Integrated Approach, W.D. Callister, Volume I, John Wiley & Sons Inc. (2005).
11. The Structure of Materials, S. Allen, E.L. Thomas, John Wiley & Sons Inc. (1999).
12. Structural Nanocrystalline Materials: Fundamentals and Applications, C. Koch, I. Ovid'ko, S. Seal, S. Veprék, Cambridge University Press, 1st edition, (2007).
13. Introduction to Solid State Physics, C. Kittel, Eighth Edition, John Wiley & Sons (2004).
14. Solid State Physics, Ashcroft and Mermin, Cengage Learning India Private Limited (2011).
15. Introduction to Polymers, R. J. Young, P. A. Lovell, Third Edition, CRC Press (2011).
16. Introduction to Ceramics, W.D. Kingery, H.K. Bowen, D.R. Uhlmann, Wiley-Interscience (1976).

EST -(504) Energy Practical Lab-1

- i. Loop analysis (KVL and KCL);
- ii. Maximum power transfer theorem; Efficiency of transformer;
- iii. Power factor improvement;
- iv. Diode Characteristics;
- v. Solar Cell and Module Characteristics
- vi. Transistor and Operational amplifier Characteristics;
- vii. Thermocouple & measurement of Temperature,
- viii. Thermoelectric measurements: Seebeck/Peltier effect;
- ix. Electrical Four-Probe Measurement.
- x. Wilkinson's Catalyst
- xi. Carrier Lifetime measurements

EST -(511)-Energy Resources, Economics and Environment

Unit I: Basics concepts related to Energy and energy science as a field of study. Work, Energy, and Power Forms of Energy and energy Conservation Energy as an economic resource resource; classification, measurement and accounting . Broad overview of energy supply and demand side trends (Historical, current and future)

Unit II: Energy Economics and its key features, Basic framework for Analysis. Overview of Energy Markets. Tools for analysis of Energy markets. Energy Market Demand Side Analysis, Stakeholders and Behaviour aspects. Policy impact.

Unit III:Energy Market Supply Side: Economics and policies of non-renewable energy supply. Economics of electricity supply and renewable energy and related policies , Centralized Supply Vs Decentralized supply (Analysis in the Indian Context), Policy impact

Unit IV: Energy and Environment:Energy usage and environmental cost. Environmental issues and Concept of sustainable development Energy usage and relation to Climate change. Energy Policy and

Books and references

- I. [Energy and the Environment](#), 2nd edition, by Ristinen and Kraushaar, Wiley, 2006, ISBN: 0-471-73989-8
- II. Bhattacharyya, Subhes. C. (2011).Energy Economics: Concepts, Issues,Markets and Governance. Springer.London, UK. (Selected chapters)
- III. Stevens, P. (2000). An Introductionto Energy Economics. In Stevens, P.(ed.) The Economics of Energy, Vol.1, Edward Elgar, Cheltenham, UK.
- IV. Selected contemporary journal articles
- V. GEA, 2012: Global Energy Assessment - Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. (mainly Chapter 1 - Energy Primer pp. 99-150, Chapter 3- Energy and Environment-pp. 191-254.Chapter 4 –Energy and Health pp. 255-324).
- VI. Conrad, J. M., Resource Economics, 2nd Edition, Cambridge University Press, New Delhi, 2010.
- VII. 3.Tester J.W., Drake E.M., Driscoll M. J., Golay, M.W, Peters, W.A.,Sustainable Energy Choosing Among Options, PHI Learning Private Limited,New Delhi, 2009.
- VIII. J.M. Conrad and C.W. Clark, Natural Resource Economics, Cambridge University Press (1987).
- IX. Charles Kolstad, Environmental Economics, Vol. 1, Oxford University Press (1999).

EST-512 Thermodynamics in Energy Conversion

Unit I:

Thermodynamic system, State, Thermodynamic variables, Thermodynamic processes, Zeroth Law and First Law, energy transfer by heat, work, mass, and conversion between different forms of energy, Concept of irreversibility, irreversibility in simple processes such as mixing, heat transfer, friction, distinction between reversible and irreversible processes

Unit II:

General form of second law, Carnot cycle and limit to efficiency, inevitability of heat rejection in thermodynamic cycles, Reformulation of second law in terms of system variables, concept of thermodynamic potentials, Maxwell Relation and Thermodynamic potentials, Practical utility of thermodynamic potentials, Energy conversion, devices or applications based on energy conversion, and concept of efficiency, COP, electrical energy conversion, mechanical energy conversion, chemical energy conversion

Unit III:

Phase transformation, Energy conversion by phase transformation, Energy storage by Phase transformation, Open and Closed thermodynamic cycles and their evaluation for energy conversion. Thermodynamics and Power plants, Approaches to increase the efficiency, Efforts to use the rejected heat using thermo-electrical generators,

Unit IV:

Thermodynamics of Batteries, Reactions and energy conversion, Thermodynamics of fuel cell, Thermodynamics of Hydrogen storage, Thermodynamics of thermoelectric devices, Photo-thermovoltaic systems

References:

1. Yogi Goswami, Frank Kreith - Energy conversion-CRC Press (2008)
2. Henning Struchtrup, Thermodynamics of energy conversion, Springer, 2014
3. M. Modell and R.C. Reid, Thermodynamics and its Applications, Prentice-Hall, Englewood Cliffs, New Jersey, 1983.
4. H. B. Callen, Thermodynamics and an Introduction to Thermostatistics, John Wiley & Sons, New York, 1985.
5. R. T. DeHoff, Thermodynamics in Materials Science, McGraw-Hill, Singapore,

EST -(513)-Methods in Analytical techniques

Unit I – Prerequisites for Analytical techniques

Concepts of clean room, standard operating procedures for preparation and handling samples, humidity control systems, Materials used at low pressure, vapour pressure Impingement rate, Flow of gases, Production of low pressures; High Vacuum Pumps and systems, Ultra High Vacuum Pumps and System, Measurement of pressure, Leak detections

Unit 2--Thin film deposition techniques

Preparation of Thin Films: Thermal evaporation, e-beam deposition, Cathode Sputtering, DC sputtering, Magnetron sputtering, Chemical vapour Deposition, Laser Ablation, Molecular Beam epitaxy, electro-plating, sol-gel method (Spin and Dip coatings), Langmuir-Blochett Films

Unit-3: Materials Characterization-1

Structural: X-ray Diffraction (XRD); Scanning Electron Microscopy (SEM); Transmission Electron Microscopy (TEM); Electron diffraction analysis, Electronic Structure: X-ray Photoelectron Spectroscopy (XPS); X-ray Absorption Spectroscopy (XAS); Photo-luminescence (PL)

Unit-4: Materials Characterization-2

Molecular Structure: Infrared (IR); Fourier Transform IR (FTIR); and Raman Spectroscopy, Composition Analysis: Energy Dispersive X-ray (EDX); Auger Electron Spectroscopy (AES); and Secondary Ion Mass Spectrometry (SIMS), Surface Morphology: Scanning Tunneling Microscopy (STM); Atomic Force Microscopy (AFM); Optical: UV-Vis.

References:

1. A User's Guide to Vacuum Technology: by [John F. O'Hanlon](#), First published: 20 June 2003, Print ISBN: 9780471270522 | Online ISBN: 9780471467168, DOI: 10.1002/0471467162,
2. Physical Methods, R.S. Drago, Saunders College Publishing, 2nd Edition, (1992).
3. Microanalysis of Solids, B.G. Yacobi, D.B. Holt and L.L. Kazmerski, Plenum Press, (1994).
4. Elements of X-Ray Diffraction, B.D. Cullity, S.R. Stock, Addison_Wesley Metallurgy Series, 3rd Ed., 2001.
5. Electron microscopy and Analysis, P.J. Goodhew, F. J. Humphreys, R. Beanland, Taylor and Francis, 2001.
6. Transmission Electron Microscopy, Volumes 1-4, Kluwer Academic/ Plenum Publishers, D.B. Williams, C. B. Carter, 2nd Ed., 2009.
7. Scanning Electron Microscopy and X-ray Microanalysis, J. Goldstein, D.E. Newbury, D.C. Joy, C.E. Lyman, P. Echlin, E. Lifshin, L. Sawyer, J.R. Michael, Springer, 3rd Ed., 2003.
8. Spin Dynamics: Basics of Nuclear Magnetic Resonance, M.H. Levitt, Wiley, 2nd Ed., 2008.
9. Fundamentals of Fourier Transform Infrared Spectroscopy, B.C. Smith, CRC Press, 2nd Ed., 2011.

10. Handbook of Thin Film Deposition: 4th Edition - February 23, 2018,
Editors: Krishna Seshan, Dominic Schepis, Paperback ISBN: 9780128123119

EST -(514) Energy Practical Lab-2

1. Synthesis of UV and Visible active semiconductors (ZnO and TiO₂)
2. Find fill factor and efficiency of the solar cell
3. Photo-catalysis of methylene blue with TiO₂
4. Calculate Photo current in a silicon p-n junction
5. Prepare the sample of simple metal phosphate for example Co(PO₄)/MnPO₄ using SILAR / hydrothermal / sol-gel method. Characterize with XRD and test its super-capacitive properties.
6. Prepare the sample of WO₃ doped with Li, B, C, and N using Sol-gel method / hydrothermal / SILAR method and study Cyclic Voltammetry; Diffusion Coefficient Measurements and Measurement of Electrode Surface Area using BET.
7. Synthesis of Cu₂O by Electrodeposition and Thermal Annealing: Study optical and electrical characteristics.
8. Resistivity of semiconductor samples by van-der Pauw method at different temp and determination of band gap
9. Multi-scale Sampling of a Heterogeneous Water/Metal Catalyst Interface.
10. Diffusivity of Li-Ion in LiPF₆ and LiFePO₄ Electrolytes
11. Calculate the band of the semiconductors using experimental and computational techniques and compare it.
12. High throughput screening of Li based Cathode materials and prediction of Open-Circuit-Voltage-of-LIB-Cathode-Materials.

Electives

Electives-1

EST-505-A Energy Audit and Management

Unit I:

Basic Concepts related to energy audits, types, need for energy audit, benefits of energy audits, Global standards ISO 14001 and ISO 50001, Legal framework for energy audit and Management: Global and Indian scenario

Unit II:

Steps in Energy audit process, reporting of energy audit and action report, energy audit of industrial units, energy units of house holds, Energy Accounting, Principles of energy conservation, Energy Conservation Methods, sample problems and case studies

Unit III:

Cost Analysis of Energy Savings, concept of simple payback period, Present worth or Return on Investment method, Life cycle cost methods and examples demonstrating the methods.

Unit IV:

Energy Planning and Management, Legal instruments and regulatory framework for energy Management, Integrated Rural Energy Planning in Indian context, Some case studies, Concept of optimal mix of renewable energy technologies

Reference Books:

1. L. C Witte, PS Schmidt and DR Brown: Industrial Energy Management and Utilization (Hemisphere Publishing Corporation, Washington, 1998).
2. J. L Threlkeld: Thermal Environmental Engineering, Second Edition (Prentice Hall, 1970)
3. Y P Abbi and Shashank Jain: Handbook on Energy Audit and Environment Management, (TERI Press, 2006)
4. W. C Turner: Energy Management Handbook, Seventh Edition, (Fairmont Press Inc., 2007)
5. George Polimeros: Energy Cogeneration Handbook, (Industrial Press, Inc., New York, 1981)

EST-505B Solar Photovoltaic devices and systems

Unit I: Harvesting solar radiation

Harvesting of Solar Light, Solar spectrum, Interaction of photon with material (Photocell, Photodiode, Photomultiplier tube), Concept of Photovoltaic Effect, Semiconducting materials, Band gap, mechanism of excitation of charge carriers, charge transport, radiation propagation in materials

Unit II: Physics of pn junction,

PN characteristics, Solar cells and its characteristics, Ideal case and non-ideal case, loss mechanism and recombination models, SQ limit, Role of contacts, single and multi-junction device configuration and role of different layers (ETL Electron Transport Layer, Hole transport Layers, HTL), concept of ferroelectric photovoltaic cell, Performance of solar cells using external parameters, Device simulation and parameter optimization

Unit III: Si solar cell technology, processing methods

Thin film technology, Dye-sensitize Solar cells and Quantum dot solar cells, Novel approaches for design of solar cells: materials and device aspects, Use of plasmonics, rugged geometry etc. Perovskite solar cells

Unit IV: Concept of PV system and its components

Grid-connected and off-grid PV, PV Module Array, Battery Bank, Battery and its parameters SOC, DoD, cycle lifetime, Charge controller, inverters, Topologies for PV system, Criteria for choosing a topology, PV systems and Tilt angle, Temperature effects, Concept of Module Ideality factor and Maximum Power Point tracking, Economic aspects of PV system, embedded systems, the Internet of things and block chain technologies for PV systems

References:

1. Honsberg, C., and S. Bowden. *Photovoltaics: Devices, Systems and Applications CD-ROM*.
2. Wenham, S., M. Green, et al., eds. *Applied Photovoltaics*. 2nd ed. Routledge, 2006. ISBN: 9781844074013.
3. Luque, A., and S. Hegedus, eds. *Handbook of Photovoltaic Science and Engineering*. John Wiley & Sons, Ltd, 2003. ISBN: 9780471491965.
4. Yu, P., and M. Cardona. *Fundamentals of Semiconductors: Physics and Materials Properties*. 3rd ed. Springer, 2004. ISBN: 9783540413233.
5. Nelson, J. *The Physics of Solar Cells*. Imperial College Press, 2003. ISBN: 9781860943409.
6. Bube, R. *Photovoltaic Materials*. World Scientific Publishing Company, 1998. ISBN: 9781860940651.
7. Green, M. *Silicon Solar Cells: Advanced Principles and Practice*. Centre Photovoltaic Devices & Systems, 1995. ISBN: 9780733409943.
8. Poortmans, J., and V. Arkhipov. *Thin Film Solar Cells: Fabrication, Characterization and Applications*. 1st ed. Wiley-Blackwell, 2006. ISBN: 9780470091265.

9. M. Parans Paranthaman, Winnie Wong-Ng, Raghu N. Bhattacharya Semiconductor Materials for Solar Photovoltaic Cells, Springer 2016
10. Chetan Singh Solanki, Solar Photovoltaics: Fundamentals, Technologies And Applications, 3rd Edition, PHI learning
11. Chenming, H. and White, R.M., Solar Cells from B to Advanced Systems, McGraw Hill Book Co, 1983.
12. Ruschenbach, HS, Solar Cell Array Design Hand Varmostrand, Reinhold, NY, 1980
13. Stefan C W Krauter, Solar electric power generation - photovoltaic energy systems, Springer, 2006

EST-505C Energy Storage

Unit I:

Energy sources, Need of energy in modern society, role of energy storage systems, applications. Thermal, Mechanical, Chemical, Electrochemical, Electrical. Efficiency of energy storage systems. Performance matrix for energy storage devices and systems. Energy storage materials and their design

Unit II:

Batteries, Super capacitors, Superconducting Magnetic Energy Storage (SMES), charging methodologies, Hydrogen production and storage, fuel cells. Different mechanical and thermal energy storage like pumped hydro storage, flywheel energy storage, compressed air storage, latent heat storage and thermochemical storage.

Unit III:

Practical utilisation of Fuel cells, supercapacitors, batteries. Strategies to improve efficiency for practical application, Sustainability and environmental impact of dead storage device.

Unit IV:

Simulation of energy storage systems and its management, smart park, Electric Vehicle charging facility, HESS in micro-grid and smart grid, microbial fuel cell, hydrogen fuel cell and so on. Methane as an energy storage gas. Methane economy

References:

1. Robert Huggins, Energy Storage : Fundamentals, Materials and Applications-Springer (2015)
2. Frank S. Barnes, Jonah G. Levine, Large Energy Storage Systems Handbook-CRC Press (2011)
3. John S. Connolly, Photochemical Conversion and Storage of Solar Energy, Academic Press (1982)
4. Jean-Marie Tarascon, Patrice Simon, Electrochemical Energy Storage, Wiley (2015)
5. Andre G. Ter-Gazarian, Energy Storage for Power Systems, The Institution of Engineering and Technology (2011)
6. H. P. Garg, S. C. Mullick, A. K. Bhargava, Solar Thermal Energy Storage-Springer Netherlands (1985)
7. Yaşar Demirel, Energy Production, Conversion, Storage, Conservation, and Coupling, Springer-Verlag London (2012)
8. Robert Schlögl, Chemical Energy Storage, Walter de Gruyter (2013)
9. Baxter, Richard, Energy Storage - A Nontechnical Guide, PennWell (2007)
10. Ahmed Faheem Zobaa, Energy Storage :Technologies and Applications, InTech (2013)

EST-505D-Green Energy Systems

Unit-1:SOLAR RADIATION

Role and potential of new and renewable sources, the solar energy option, Environmental impact of solar power, structure of the sun, the solar constant, sun-earth relationships, coordinate systems and coordinates of the sun, extraterrestrial and terrestrial solar radiation, solar radiation on tilted surface, instruments for measuring solar radiation and sun shine, solar radiation data, numerical problems. Photo voltaic energy conversion – types of PV cells.

Unit-2:WIND ENERGY

Sources and potentials, horizontal and vertical axis windmills, performance characteristics, betz criteria, types of winds, wind data measurement. Bio-mass: Principles of Bioconversion, anaerobic/aerobic digestion, types of bio-gas digesters, gas yield, utilization for cooking, bio fuels, I. C. engine operation and economic aspects.

Unit-3:GEOTHERMAL and OCEAN ENERGY

Resources, types of wells, methods of harnessing the energy. Ocean energy, otec, Principles of utilization, setting of otec plants, thermodynamic cycles. Tidal and wave energy: Potential and conversion techniques.

Unit-4: GREEN MANUFACTURING SYSTEMS

Environmental impact of the current manufacturing practices and systems, benefits of green manufacturing systems, selection of recyclable and environment friendly materials in manufacturing, design and implementation of efficient and sustainable green production systems with examples like environmental friendly machining, vegetable based cutting fluids, alternate casting and joining techniques, zero waste manufacturing.

REFERENCES:

1. Solar Energy – Principles of Thermal Collection and Storage/Sukhatme S. P. and J. K. Nayak/TMH.
2. Non-Conventional Energy Resources- Khan B.H/ Tata McGraw Hill, New Delhi, 2006.
3. Green Manufacturing Processes and Systems - J. Paulo Davim/Springer 2013.
4. Alternative Building Materials and Technologies – K. S Jagadeesh, B. V Venkata Rama Reddy and K. S Nanjunda Rao/New Age International.
5. Principles of Solar Engineering D. Yogi Goswami, Frank Krieth & John F Kreider /Taylor & Francis.
6. Renewable Energy Technologies -Ramesh & Kumar /Narosa.
7. Non-conventional Energy Source- G. D Roy/Standard Publishers.
8. Renewable Energy Resources-2nd Edition/ J. Twidell and T. Weir/ BSP Books Pvt.Ltd.
9. Fuel Cell Technology -Hand Book / Gregor Hoogers / BSP Books Pvt. Ltd.

EST-505E Oil and Gas: From reservoirs to Refineries

Unit-1: Oil and Gas as energy resource

Role of Oil and gas in energy mixing, Historical aspects of Oil and gas sector and its related technologies, Thermodynamics aspects of reservoirs and reservoir engineering, Surveys and Assessment

Unit-2: Oil and gas production-1

Introduction, exploration and drilling, onshore and offshore production, upstream, Process sections, the reservoir, well casing and completion, sub-sea wells, injection, Well work-over, intervention and stimulation

Unit-3: Oil and gas production-2

Midstream processes, Pipelines and risers, production, test and injection manifolds, separation, Gas treatment and compression, Oil and gas storage, metering and export, midstream facilities

Unit IV : Refineries

Fractional and vacuum distillation, utility systems, blending, Conversion processes; thermal cracking, hydro cracking and catalytic cracking; alkylation and polymerization, isomerization and catalytic reforming. Treatment processes; desalting, drying, Hydro-treating, solvent extraction, extractive distillation and solvent de-waxing

References:

1. Oil and Gas Production Handbook: An Introduction to Oil and Gas Production, Second Edition, ABB, Gerald L. Kaes - Refinery Process Modeling-Elliott & Fitzpatrick (2000)
2. Dwijen K. Banerjee , Oil sands, heavy oil, & bitumen [electronic resource] : from recovery to refinery Tulsa, Okla. : PennWell Corp., c2012,
3. Eugeniy G. Leonov, Valeriy I. Isaev, Applied Hydroaeromechanics in Oil and Gas Drilling, Wiley-AIChE, 2009

EST-505F:Nuclear Energy

Unit-1:Atomic & nuclear structure:

Overview of atomic structure, equivalence of mass and energy, stability of nucleus, radioactive decay, binding energy, different nuclear reactions, natural radioactivity. Interaction of radiation with matter: Interactions of charged particle, α - and β -particle, photons, radiation detectors. Neutron physics: Nuclear interactions, concept of cross-section, cross-section measurement, neutron interactions, neutron scattering, fission chain reaction.

Unit-2:Neutron diffusion and scattering:

One-speed diffusion equation and its solution, neutron diffusion in multiplying media, diffusion in elementary reactors, multi-group neutron diffusion theory, moderation and scattering, diffusion of thermal neutrons. Time-dependent neutron transport: Delayed neutrons, diffusion in transient reactors, reactor kinetics.

Unit-3:Nuclear fuel:

Properties of fuel and cladding, nuclear fuel cycle, isotope separation, fuel reprocessing, radioactive waste disposal. Nuclear reactor control: Control rod and chemical shim, effect of temperature on reactivity, fission product poisoning.

Unit-4:Thermal reactors:

General thermodynamic consideration, thermal hydraulic analyses of simple block and cylindrical reactors. Thermal reactors: Pressurized and boiling water reactor, heavy water reactor, Gen-III+ and Gen-IV designs. Breeder reactors: Concept of breeding and breeding potential, fast breeder reactor.

References:

1. J. R Lamarsh & AJ Baratta, Introduction to Nuclear Engineering, 3rd Eds., Pearson, 2001.
2. R. L Murray & KE Holbert, Nuclear Energy: An Introduction to the Concepts, Systems and Application of Nuclear Processes, 7th Eds., Elsevier, 2015.
3. M. M El-Wakil, Power Plant Technology, McGraw-Hill Education, 2017.
4. D. G Cacuci (Eds.), Handbook of Nuclear Engineering, Vol I: Nuclear Engineering Fundamentals, Springer, 2010.
5. C. E Brennen, Introduction to Nuclear Power Generation, Dankat Publishing Company, 2005.
6. N. Tsoulfanidis, Nuclear Energy, Springer, 2018.
7. N. E Todreas & MS Kazimi, Nuclear Systems I & II, Taylor & Francis, 1993.
8. R. A Knief, Nuclear Engineering: Theory and Technology of Commercial Nuclear Power, 2nd Eds., American Nuclear Society, 2008.
9. E. E Lewis, Fundamentals of Nuclear Reactor Physics, Academic Press, 200

EST-505G Energy Technology : Current Scenario and Forecasting

Unit 1: Historical overview of development of energy technology

Fossil Fuels, , Steam Engines, Oil and Internal Combustion, Engines, Electricity, Technical Innovations , Coals , Hydrocarbons, Electricity. Impact of technology developments, Drivers of Technology developments, Research ecosystem for energy technology development

Unit II : Basics of Technology Forecasting

Its relevance for informed decision making, Databases for finding state of the art in technology landscape, Combining prior art and state of the art for prediction, Searching Patent databases. Technology forecasting models and techniques. Case studies on Forecasting,

Unit III: Technology for Energy Production

Solar Power Conversion Technology, Solar Photovoltaic, Technology generations of Solar cells, Solar Thermal technology, Wind energy Technological advancements, geothermal and tidal energy production, recent trends and near future commercializable candidates

Unit IV: Technology for Energy Storage

Devices for storage of energy, forms of storage, chemical storage and batteries, Batteries, Super capacitors, Superconducting Magnetic Energy Storage (SMES), charging methodologies, Hydrogen production and storage, fuel cells. recent trends and near future commercializable candidates

References:

1. Yaşar Demirel (auth.) - Energy_ Production, Conversion, Storage, Conservation, and Coupling-Springer-Verlag London (2012) Economics and energy Abdiel Worthy
2. Alan Thomas Roper, Scott W. Cunningham, Alan L. Porter, Thomas W. Mason, Frederick A. Rossini, Jerry Banks(auth.) - Forecasting and Management of Technology, Second Edition
3. Patrick A. Narbel, Jan Petter Hansen, Jan R. Lien (auth.) - Energy Technologies and Economics-Springer International Publishing (2014) (1)
4. Robert A. Huggins Energy Storage Fundamentals, Materials and Applications Second Edition
5. John Twidell and Tony Weir Renewable Energy Resources Second edition.
6. Bent Sørensen Renewable Energy Its physics, engineering, use, environmental impacts, economy and planning aspects Third Edition
7. Vaclav Smil - Energy and Civilization_ A History-The MIT Press (2017)
8. Martin Kaltschmitt, Wolfgang Streicher, Andreas Wiese - Renewable Energy Technology, Economics and Environment-Springer (2007) -Mart : 1.1, 1.1.1, 2.1, 2.1.1, 2.1.3
9. Vaclav Smil - Energy and Civilization_ A History-The MIT Press (2017)

EST-515A Energy Resource Assessment and Forecasting

Unit I: Energy Resources and Potentials non-renewable resources and its assessment, Resource assessments for renewable energy including solar, wind, biomass, marine, geothermal, and hydro-power, Study of different report on assessment and forecasting Global, regional and Indian context

Unit II: Overview of Solar Power conversion technology, PV power forecasting, Role of Atmospheric Models in Solar Energy Assessment and forecasting

Unit III: Physical, statistical Methods and Recent Forecasting methods using Machine learning and AI. Use of Databases and use Databases and its integration to models

Unit IV: Wind resource assessment Methodology, Atmospheric modelling, Role of Numerical weather predication models, Mesoscale modelling, Model validation, sensitivity analysis and validation, Generation and use of wind potential maps. Us eof scenario in forecasting. Use of Data analysis toolboxes for Wind energy simulation and Assessment, Recent advances

References:

1. National Institute of Wind Energy Report, 2019, India's Wind Potential Atlas at 120m agl
2. Michael C. Brower(auth.), Wind Resource Assessment: A Practical Guide to Developing a Wind Project, Wiley, 2012
3. Jan Kleissl, Solar Energy Forecasting and Resource Assessment. Elsevier, 2013
4. D. Renné, R. George, S. Wilcox, T. Stoffel, D. Myers, and D. Heimiller, Solar Resource Assessment, Technical Report NREL/TP-581-42301 February 2008
5. Mohammadreza Aghaei, Solar Radiation - Measurement, Modeling and Forecasting Techniques for Photovoltaic Solar Energy Applications, Intechopen Publishers, 2022
6. M. Lange and U. Focken, Physical Approach to Short-Term Wind Power Prediction. Springer, 2006
7. T. Hastie, R. Tibshirani, and J. Friedman, The Elements of Statistical Learning, 2 Edition. Springer-Verlag New York, 2009.
8. <https://www.frontiersin.org/articles/10.3389/fenrg.2022.875790/full>
9. <https://www.nrel.gov/docs/fy08osti/42301.pdf>
10. <https://www.energy.gov/eere/analysis/renewable-energy-resource-assessment-information-united-states>
11. <https://www.nrel.gov/docs/fy14osti/61741.pdf>
12. <https://espjeta.org/Volume3-Issue3/JETA-V3I3P104.pdf>
13. https://niwe.res.in/assets/Docu/India's_Wind_Potential_Atlas_at_120m_agl.pdf

EST-515B Solar Thermal Power Generation

Unit I: Review of basic concepts

The Potential of Solar Thermal Power Plants for the Energy Supply: Capacity Factor, Availability of Solar Energy, and Land Availability, Thermodynamic approach to Power Plant. Components of a Solar Thermal System, Solar Thermal energy systems Materials for Opto-caloric Performance and Thermal Fluids

Unit II: Solar Components

Linear concentrating systems, parabolic troughs and Linear Fresnel reflectors Collector Systems (Flat Plate and concentrating), concentrating solar thermal technologies, Performance of Solar Thermal Collectors and Systems

Unit III: Solar Systems

Solar Power Towers and Solar Dish/Engine systems. Physics of Solar Ponds, Modelling and optimization of solar thermal systems,

Unit IV: Solar Thermal Power Systems and Applications

Solar Drying, Desalination, Chemistry Applications, and Material Processing, Solar Cooling, Domestic Water Heating, system design, Domestic Space Heating, Domestic and community Cooking Systems, Designing Solar Thermal systems for Industrial Applications, Case studies

References:

1. S.P. Sukhatme and J. Nayak: Solar Energy: Principles of Thermal Collection and Storage, Third Edition (Tata McGraw Hill, 2008)
2. Renewable Energy Engineering and Technology – A Knowledge Compendium, ed. V.V.N. Kishore (TERI Press, 2008)
3. Stefan C.W. Krauter, Franz Alt, Hermann Scheer, Solar Electric Power Generation - Photovoltaic Energy Systems: Modeling of Optical and Thermal Performance, Electrical Yield, Energy Balance, Effect on Reduction of Greenhouse Gas Emissions, Springer, Year: 2006
4. John A. Duffe, William A. Beckman, Nathan Blair, Solar Engineering of Thermal Processes, Photovoltaics and Wind, 5th Ed., John Wiley & Sons, Inc.
5. John R. Howell, Richard B. Bannerot, Gary C. Vliet, Solar-thermal Energy Systems: Analysis and Design, McGraw Hill, 1982
6. Werner Vogel, Henry Kalb, Large-Scale Solar Thermal Power: Technologies, Costs and Development, Wiley-VCH, 2010
7. A. Mani (auth.), H. P. Garg, M. Dayal, G. Furlan, A. A. M. Sayigh (eds.), Physics and Technology of Solar Energy: Volume 1 Solar Thermal Applications, Springer, Netherlands, 1987
8. Jagadish; Agnimitra Biswas, Modeling and Optimization of Solar Thermal Systems: Emerging Research and Opportunities, Publisher: Engineering Science Reference, Year: 2020

Unit-1:Overview of fuel cells

Low and high temperature fuel cells; Fuel cell thermodynamics - heat, work potentials, prediction of reversible voltage, fuel cell efficiency.

Unit-2:Fuel cell reaction kinetics

electrode kinetics, overvoltages, Tafel equation, charge transfer reaction, exchange currents, electrocatalyses - design, activation kinetics, Fuel cell charge and mass transport - flow field, transport in electrode and electrolyte.

Unit-3: Fuel cell components and their impacts on performance

Fuel cell performance characteristics – current/voltage, voltage efficiency and power density, ohmic resistance, kinetic performance, mass transfer effects – membrane electrode assembly components, fuel cell stack, bi-polar plate, humidifiers and cooling plates

Unit-4:Fuel cell characterization

In-situ and ex-situ characterization techniques, i-V curve, frequency response analyses; Fuel cell modelling and system integration: - 1D model - analytical solution and CFD models.

References:

1. O' Hayre, R.P.,S. Cha, W. Colella, F.B.Prinz, Fuel Cell Fundamentals, Wiley, NY (2006).
2. Bard,A. J. , L. R., Faulkner,Electrochemical Methods, Wiley, N.Y.(2004)
3. Basu,S.(Ed) Fuel Cell Science and Technology,Springer, N.Y.(2007).
4. Liu, H.,Principles of fuel cells, Taylor & Francis, N.Y. (2006).
5. Fuel Cells for automotive applications – professional engineering publishing UK. ISBN 1- 86058 4233, 2004.
6. Fuel Cell Technology Handbook SAE International Gregor Hoogers CRC Press ISBN 0-8493-0877-1-2003.

Unit-1:

Introduction to Bioenergy, biomass harvesting; availability and assessment of biomass for bioenergy applications; characterization of biomass feedstock (physico-chemical properties, ultimate, proximate, compositional, calorific value, thermo gravimetric, differential thermal and ash fusion temperature analyses); classification of biomass feedstock: first, second and third generation biofuels; hybrid biofuels, basic principles of chemical thermodynamics; carbon neutral fuels.

Unit-2:

Different pre-treatment processes of biomass, Different production routes for biomass conversion to biofuels: biochemical methods (anaerobic, enzymatic- saccharification and fermentation process, and dark fermentation, ABE fermentation); chemical processes (transesterification, hydro-processing, micro-emulsification);

Unit-3:

Thermochemical methods (combustion, gasification, pyrolysis, partial oxidation, auto-thermal reforming) for biofuels production including synthesis gas, bio-hydrogen, ethanol, butanol, biogas, methanol, dimethyl ether and paraffinic fuels; Biomass compaction (briquetting and palletisation); biofuel quality upgradation; and biomass and biofuel fuel quality norms.

Unit-4:

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; utilization of bio-fuels in gas turbine, internal combustion engines and fuel cells; analysis of carbon neutral and carbon credit.

References:

1. Jay J. C., Biomass to Renewable Energy Processes, Taylor and Francis, CRC Press, 2018
2. Konur O., Bioenergy and Biofuels, Taylor and Francis, CRC Press, 2018
3. Love J. and Bryant J. A., Biofuels and Bioenergy, John Wiley & Sons, 2017
4. Henderson O. P., Biomass for Energy, Nova Science Publishers, 2011
5. Mukunda, H. S., Understanding Clean Energy and Fuels from Biomass, Wiley India, 2011

Unit-1:

Introduction, General theories of wind machines, Basic laws and concepts of aerodynamics, Micro-sitting, Description and performance of the horizontal-axis wind machines, Blade design, Description and performance of the vertical-axis wind machines

Unit-2:

The generation of electricity by wind machines, case studies, Overview of micro mini and small hydro, Site selection and civil works, Penstocks and turbines, Sizing Small Wind Turbines, turbine blades, Offshore wind turbines, Onshore wind turbines.

Unit3:

Speed and voltage regulation, Investment issues, load management and tariff collection, Distribution and marketing issues, case studies, Wind and hydro based stand-alone / hybrid power systems, Control of hybrid power systems, principles of wind turbine power generation, wind resource, rotor aerodynamics, structural design, power conversion and control.

Unit-4:

Wind diesel hybrid systems, Siting a Small Electric Wind System, Grid-Connected Small Wind Electric Systems, Off-Grid or Stand-Alone Renewable Energy Systems, Hybrid Wind and Solar Electric Systems.

References:

1. Manwell J. F., McGowan J. G. and Rogers A. L., Wind Energy Explained-Theory,
2. Design and Application John Wiley & Sons, Ltd., 2002.
3. Hansen M. O. L., Aerodynamics of Wind turbines, Earthscan, 2008.
4. Bianchi F. D., Battista H. D. and Mantz R. J., Wind Turbine Control Systems- Principles, Modelling and Gain Scheduling Design, Springer, 2007.

Unit-1: Introduction to hydrogen storage

Underground hydrogen storage, fundamentals of hydrogen compression and expansion, Mechanical and non-mechanical hydrogen compressors; compressed hydrogen tank types and design considerations, Hydrogen liquefaction, liquid state hydrogen storage tanks, fundamentals of hydrogen storage in adsorption based materials

Unit-2: Kinetics

Fundamentals and thermodynamics of absorption based hydrogen storage, metal hydrides, types of metal hydrides, metal hydride based systems design, Surface adsorption

Unit-3 Storage of Hydrogen fuel

Selection of materials for energy harvesting and storage applications; Chemical, absorbent's and reversible hydrides, Other significant materials for Hydrogen storage; Thermal energy storage systems, Physical based routes such as compressed gas, Cold/Cryo compressed, Liquid H₂. Materials based routes: Liquid Organic, Interstitial hydrides, complex hydrides, chemical hydrogen.

Unit-4: Electrochemical devices

The electrochemical potentials, and the effect of temperature on the Gibbs Energy and entropy of the system, Poisson's Equations and the conditions for equilibrium, the Nernst Equation, diffusion, migration, and convection in charged and uncharged species in electrochemical systems.

References:

1. Gupta, R. B., Hydrogen Fuel: Production, Transport and Storage, CRC Press, Taylor & Francis Group, 2009.
2. Global Hydrogen Review 2021, IEA (2021), Paris, <https://www.iea.org/reports/global-hydrogen-review-2021>
3. AgataGodula-Jopek, Hydrogen Production by Electrolysis, Wiley-VCH, Germany, 2015
4. Tzimas, E., Filiou, C., Peteves, S. D., & Veyret, J. B. "Hydrogen storage: state-of-the-art and future perspective. Netherlands": European Communities, 2003.
5. Michael Hirscher, "Handbook of Hydrogen Storage", Wiley-VCH, 2010.

EST-515G Computational Fluid Dynamics

Unit-1 Basics and Foundation of CFD

Review of basic fluid mechanics Review of equations and importance of terms Review of equations and non-dimensionalization, Vorticity-Stream function equation, classification of equation and the solution nature Classification of equations, types of boundary conditions and description about standard test cases. Turbulence Modelling

Unit-2: Theoretical Aspects

Information about grid; Taylor's series expansion, Taylor's series expansion, CD / FD / BD for first & second derivative; FD formula for non-uniform mesh; mixed derivative, Derivation for higher derivative; FD formula by Polynomial procedure Different Approximation Methods Properties associated with discretization Errors due to approximation and their analysis-consistency, convergence, Stability analysis, FD formulation for model equations and explanation FV formulation for diffusion equation – 1D, Example and extension to 2D and 3D FV formulation for convection and diffusion equation, Treatment of convective terms-different interpolations. Steps involved in CFD, Information about Computational domain and grid with illustration

Units3: CFD Methods

Illustration on the performance by different approximation for convection terms Time integration methods Arrangement of variables; Introduction to Pressure velocity coupling MAC, SIMPLE, Variants of SIMPLE, Projection Method Introduction to Turbulent flows Deriving governing equations, Reynolds stresses, modelling strategy, Introduction to Standard models and explanation, Matrix inversion – Direct, Iterative procedure, Direct solver / Iterative solver Iterative solver,

Unit-4 CFD Applications

Heat Transfer and Thermal Management Simulation in CFD, Battery Simulation with CFD: Equations for Thermal Model, Mechanism and Configuration of Lithium-Ion battery, Equations for Thermal Model with Heat Generation, Heat Exchanger of Battery, Thermal Lumped Model, Heat Generation, Prismatic and Cylindrical Lithium-Ion Batteries, Governing Equations for Electrochemical kinetics, The equation for Phase transition & Ion transport, Equations for Energy Dissipation, Equations of Electrical model for Lithium-ion batteries

References:

1. Ferziger J.H. & Peric M. (1999) Computational Methods for Fluid Dynamics, Springer, Berlin, Germany.
2. Hirsch C. (1988) Numerical Computation of Internal and External Flows, John Wiley & Sons, New York, USA.
3. Patankar S.V. (1980) Numerical Heat Transfer and Fluid Flow, Hemisphere, Washington D.C., USA.
4. Versteeg H.K. & Malasekera W. (1995) An Introduction to Computational Fluid Dynamics: The Finite Volume Method, Longman Scientific & Technical, Harlow, Essex, UK.
5. Anderson J.D. (1995) Computational Fluid Dynamics: The Basics with Applications, McGraw-Hill, Inc.
6. <https://dragonfly.tam.cornell.edu/teaching/mae5230-cfd-intro-notes.pdf>.

Letter Grades and Grade Points

Semester GPA/Program CGPA	% Marks	Letter Grade Results
9.00-10.00	90-100	O(Outstanding)
$8.00 \leq 9.00$	$80.0 \leq 90.0$	A+(Excellent)
$7.00 \leq 8.00$	$70.0 \leq 80.0$	A(Very Good)
$6.00 \leq 7.00$	$60.0 \leq 70.0$	B+(Good)
$5.50 \leq 6.00$	$55.0 \leq 60.0$	B(Above Average)
$5.00 \leq 5.50$	$50.0 \leq 55.0$	C (Average)
$4.00 \leq 5.00$	$40.0 \leq 50.0$	P (pass)
Below 4.00		F (Fail)
Ab(Absent)		Ab(Absent)

Syllabus
M.Sc.(Energy Science and Technology)
(Sem. I & II)
Team for Creation of Syllabus

Name	College Name	Sign
Prof Vaishali Bambole	University Department of Physics	<i>Vaishali Bambole</i>
Prof Balasaheb J. Nagare	University Department of Physics	<i>B. Nagare</i>
Mr. Nitin Bijewar	University Department of Physics	<i>N. Bijewar</i>

Vaishali Bambole
Sign of HOD

Prof. Vaishali A. Bambole
Department of Physics
Professor & Head
Department of Physics
University of Mumbai

Shivram Garje
Sign of Dean

Prof Shivram Garje
Science and Technology

O.P. Singh
7/8/22

Appendix B

Justification for M.Sc.(Energy Science and Technology)

1.	Necessity for starting the course:	This course is applied in nature. It is designed with a view to cater the need of the society.
2.	Whether the UGC has recommended the course:	Yes
3.	Whether all the courses have commenced from the academic year 2023-24	No. It is proposed for 2024-25
4.	The courses started by the University are self-financed, whether adequate number of eligible permanent faculties are available?:	self-financed At present, There is no infrastructure facility.
5.	To give details regarding the duration of the Course and is it possible to compress the course?:	PG Diploma in Energy Science:1 year M.Sc. (Energy Science and Technology): 2 Year
6.	The intake capacity of each course and no. of admissions given in the current academic year:	Intake-30
7.	Opportunities of Employability / Employment available after undertaking these courses:	Government sector, Industry and self employments, All industries which are working on Energy such as TATA, Reliance and General Electric, etc

Sign of HOD

Prof. Maishali A. Bambole

Department of Physics

Professor & Head

Department of Physics

University of Mumbai

Garje
Sign of Dean

Prof Shivram Garje

Science and Technology