NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL



SCHEME OF INSTRUCTION AND SYLLABI

for M.Tech. Sustainable Energy Generation and Storage Technologies (SEG&ST) Program

(Effective from 2023-24)

DEPARTMENT OF CHEMICAL ENGINEERING

Vision and Mission of the Institute

National Institute of Technology Warangal

VISION

Towards a Global Knowledge Hub, striving continuously in pursuit of excellence in Education, Research, Entrepreneurship and Technological services to the society

MISSION

- Imparting total quality education to develop innovative, entrepreneurial and ethical future professionals fit for globally competitive environment.
- Allowing stake holders to share our reservoir of experience in education and knowledge for mutual enrichment in the field of technical education.
- Fostering product-oriented research for establishing a self-sustaining and wealth creating centre to serve the societal needs.

Vision and Mission of the Department

Department of Chemical Engineering

VISION

To attain global recognition in research and training students for meeting the challenging needs of chemical & allied industries and society.

MISSION

- Providing high quality undergraduate and graduate education in tune with changing needs of industry.
- Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.
- Fostering industry-academia relationship for mutual benefit and growth.

Department of Chemical Engineering:

Brief about the Department:

The department was started in the year 1964 and since then it has come a long way in educating budding chemical engineers and scholars. The department celebrated its Golden Jubilee in 2014-15. The department is operating in a new building spanning around 8000 sq. m with ample space in class rooms and laboratories since 2018. The building of the department with green ambience having aesthetic landscaping and gardening has secured first place based on its architectural elegance.

The department of Chemical Engineering offers B.Tech., M.Tech. and Ph.D programs. The department has well qualified faculty dedicated to teaching and research in fundamental and advanced areas. The department houses various laboratories catering to the needs of the curriculum. The Department has good experimental as well as simulation based research facilities. The faculty are actively engaged in industrial consultancy and sponsored research projects. The department has inked MoUs with some of the leading industries and Universities in India and abroad. The graduating students are absorbed into reputed firms through campus placements and good number of students are going for higher studies. The department aims at inculcating lifelong learning skills in the students. The alumni of the department are shouldering high positions in multifarious organizations.

Brief about the Programme:

This is an interdisciplinary program admitting students with different backgrounds such as Chemical Engineering, Energy Engineering, Petrochemical Engineering, Electrical Engineering, Mechanical Engineering, Metallurgical and Materials Engineering, Civil Engineering, Biotechnology and allied disciplines. The program is designed to equip students with in-depth understanding and expertise in renewable energy sources, energy conversion systems, energy storage technologies, and their integration into existing energy infrastructure. A wide range of electives are offered, which provides an opportunity to explore the branch in a desired perspective. Students devote their entire second year for the Master's dissertation Project. Students may work on projects related to energy system design, optimization, modelling and simulation, energy storage system development, or renewable energy integration. As a part of the curriculum, students get hands on experience on software packages such as Ansys, MATLAB and ASPEN PLUS. Education and research are closely integrated within this Master's program in the field of green energy generation and sustainable energy storage technologies.

List of Programs offered by the Department:

Program	Title of the Program
B.Tech.	Chemical Engineering
M.Tech.	Chemical Engineering
	Systems and Control Engineering
	Sustainable Energy Generation and Storage Technologies
PG Diploma	Systems and Control Engineering
Ph.D.	

Note: Refer to the Rules and Regulations for M.Tech. program (weblink) given on the institute website.

M.Tech. – Sustainable Energy Generation and Storage Technologies

Program Educational Objectives

PEO-1	Pursue successful industrial, academic and research careers in specialized fields of sustainable energy generation and storage technologies.
PEO-2	Apply the knowledge of advanced topics in green energy generation and storage to meet contemporary needs of industry and society considering factors such as efficiency, environmental impact, and economic viability.
PEO-3	Attain project management skills necessary for planning, organizing, and executing sustainable energy generation and storage projects, including resource allocation, timeline management, and coordination with stakeholders
PEO-4	Demonstrate a commitment to social responsibility, considering aspects such as ethics, community engagement, equity, and access to clean energy.
PEO-5	Engage in professional development through pursuance of higher education and self-study.

Program Articulation Matrix

PEO / Mission Statements	PEO1	PEO2	PEO3	PEO4	PEO-5
Providing high quality education in tune with changing needs of industry.	3	3	2	1	1
Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.	2	3	2	1	1
Fostering industry-academia relationship for mutual benefit and growth.	3	3	3	1	1

1-Slightly; 2-Moderately; 3-Substantially

M.Tech. – Sustainable Energy Generation and Storage Technologies

Program Outcomes

PO-1	Independently carry out research /investigation and development work to solve practical problems.
PO-2	Write and present a substantial technical report/document.
PO-3	Demonstrate a degree of mastery over sustainable energy generation and storage technologies.
PO-4	Analyse and evaluate the environmental, economic, and social impacts of sustainable energy generation and storage technologies, considering factors such as resource availability, efficiency, lifecycle assessment and project management.
PO-5	Apply experimental, mathematical and computational tools to design and simulate energy generation and storage systems, analysing their performance, efficiency, and potential for integration into existing energy infrastructure.
PO-6	Pursue life-long learning, updating knowledge and skills for professional and societal development.

SCHEME OF INSTRUCTION

M.Tech. (Sustainable Energy Generation and Storage Technologies)

Course Structure

I - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CY 5301	Electrochemistry and Materials for Energy systems	3	0	0	3	PCC
2	PH 6213	Solar Energy Systems	3	0	0	3	PCC
3	CH 5301	Sustainable Energy Engineering	3	0	0	3	PCC
4	CH 5302	Hydrogen Generation and Storage	3	0	0	3	PCC
5	CH 5303	Fuel Cell Systems	3	0	0	3	PCC
6		Elective – I	3	0	0	3	PEC
7	CH 5304	Materials Synthesis and Electrochemical Analysis Lab	0	1	2	2	PCC
8	CH 5305	Energy Generation and Conversion Lab	0	1	2	2	PCC
9	CH 5341	Seminar-1	0	0	2	1	SEM
		TOTAL	18	2	6	23	

I - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	ME 5176	Thermal Energy Storage	3	0	0	3	PCC
2	CH 5351	Energy Management and Life Cycle Assessment	3	0	0	3	PCC
3	CH 5352	Battery Technologies	3	0	0	3	PCC
4		Elective – II	3	0	0	3	PEC
5		Elective – III	3	0	0	3	PEC
6		Elective – IV	3	0	0	3	PEC
7	CH 5353	Energy Storage Lab	0	1	2	2	PCC
8	CH 5354	Energy Systems Simulation Lab	0	1	2	2	PCC
9	CH 5391	Seminar-2	0	0	2	1	SEM
		TOTAL	18	2	6	23	

Note: PCC – Professional Core Courses
PEC – Professional Elective Courses
SEM – Seminar
CVV – Comprehensive Viva-voce
DW – Dissertation Work

SCHEME OF INSTRUCTION

M.Tech. (Sustainable Energy Generation and Storage Technologies)

Course Structure

II - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 6341	Comprehensive Viva-voce				2	CVV
2	CH 6342	Dissertation Part - A				12	DW
		Total				**14**	

II - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 6399	Dissertation Part – B				20	DW
		Total				**20**	

Note: PCC – Professional Core Courses
PEC – Professional Elective Courses
SEM – Seminar
CVV – Comprehensive Viva-voce
DW – Dissertation Work

Credits in Each Semester					
Cat. Code	**Sem-I**	**Sem-II**	**Sem-III**	**Sem-IV**	**Total**
PCC	19	13	-	-	32
PEC	3	9	-	-	12
SEM	1	1	-	-	2
CVV	-	-	2	-	2
DW	-	-	12	20	32
Total	**23**	**23**	**14**	**20**	**80**

Course distribution in Each Semester				
Category	Sem-I	Sem-II	Total	Remarks
Core courses by the department	3	2	5	62.5% of core courses by CH
Core courses by allied departments	2	1	3	37.5% by allied departments (CY, PH, ME)
Elective courses	1	3	4	42.8% of courses listed are from other departments (ME, EE, CS, PH)
Seminar	1	1	2	
Labs	2	2	4	Some of the experiments are planned to be conducted in allied departments

Professional Elective Courses

Elective - I (I Year, I Semester)		
S. No.	**Course Code**	**Course Title**
1	CH 5311	Bioenergy and biofuels
2	CH 5312	Nuclear Power Technology
3	CH 5313	Energy Resources, Economics and Environment
4	CH 5103	Engineering Optimization
5	CH 5115	Waste to Energy
6	EE 5101	Analysis of Power Converters
7	EE 5104	Control and Integration of Renewable Energy Sources
8	EE 5114	Electric Vehicles
9	EE 5301	Elements of Smart Electric Grid
10	ME 5513	Alternate Fuels and Emissions
11	ME 5112	Power Plant Engineering
12	ME 5113	Renewable Sources of Energy
13	CS 5106	Machine Learning
14	CS 5119	Advanced Artificial Intelligence
Electives – II, III, IV (I Year, II Semester)		
S. No.	**Course Code**	**Course Title**
1	CH 5361	Energy Storage Systems
2	CH 5362	Energy, Water and Food Nexus
3	CH 5363	Supercapacitors
4	CH 5364	Energy Technologies for Sustainable Transportation
5	CH 5365	Modelling and Analysis of Process and Energy systems
6	CH 5366	Sustainable Recycling of Energy Materials
7	CH 5153	Computational Fluid Dynamics
8	CH 5169	Energy Audit and Conservation
9	CH 5171	CO_2 Capture and Utilization
10	CH 5170	Statistical Design of Experiments
11	CH 5252	Data Analytics
12	EE 5263	Energy Auditing and Management
13	EE 5366	Transactive Energy Markets
14	EE 5367	Challenges and Solutions in Renewable Integration

Note: In addition to the above listed electives, a student can also register one elective per semester from other departments and two electives per semester from other specializations of the same department, based on suitability of timetable.

DETAILED SYLLABUS

M.Tech. – Sustainable Energy Generation and Storage Technologies

Course Code: CY 5301	ELECTROCHEMISTRY AND MATERIALS FOR ENERGY SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the principles of electrochemistry.
CO2	Gain proficiency in voltammetry techniques.
CO3	Perform chronopotentiometry and electrochemical quartz crystal nanobalance.
CO4	Select suitable materials for fuel cells, batteries and pseudocapacitors.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	3	1	1
CO2	1	1	1	3	1	1
CO3	1	1	1	3	1	1
CO4	1	1	2	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Galvanic Cells and Electrolytic Cells, Nomenclature, Potential Representation, Cathodic and Anodic Currents and Potentials, Electrolytic Cells, Electrodes, Working Potential Window, Supporting Electrolyte, Open Circuit Potential, Reference Electrodes, Cell Setup.

Voltammetry: Steady State and Potential Step Techniques, Linear Sweep Voltammetry, Point-of-Zero Charge, Cyclic Voltammetry: Principles and Applications. Stern Layer Thickness, Diffusion Controlled Reactions. Reversible, Irreversible and Quasi-Reversible Electrochemical Reactions. Electrochemistry of Modified Electrodes and Self-Assembly Electrodes. Microelectrodes, Hydrodynamic Measurements, Rotating Disk and Ring Disk Electrodes, Koutechky Plot Analysis, Mass-Transport Condition, Koutechky-Levich Plot Analysis, Kinetic Controlled Current, and Flow-Cell Analysis. Mechanism of Electrocatalytic Reactions. Applications in Supercapacitors, Fuel Cells, Sensors.

Pulse Methods: Normal Pulse Voltammetry, Differential Pulse Voltammetry, Principles and Applications in Molecular Sensors. Electrochemical Sensors: Principles, Instrumentation, and Applications. Selectivity and Sensitivity.

Chronopotentiometry: Chronopotentiometric Analysis, Principle, Methodology and Instrumentation, Applications in the Development of Capacitors and Electrochemical Supercapacitors, Cyclic Charging Discharging Processes, C-Rate and Electrochemical Capacitance.

Electrochemical Quartz Crystal Nanobalance: Principle, Thin Layer Coatings, Electropolymerization and Electrodeposition of Metals, Adlayer Formations, Automobile Exhaust Analysis, Applications.

Materials for Different Types of Fuel Cells, Batteries and Pseudocapacitors: Synthesis, Properties and Electrochemical Analysis.

Text Books:

1. Electroanalytical Methods: Guide to Experiments and Applications, Fritz Scholz, Springer, 2014, 2nd Edition.
2. Fundamentals of Electroanalytical Chemistry, Monk, P. M. S., John Wiley, 2003.
3. Electrochemical Supercapacitors - Scientific Fundamentals and Technological Applications, Conway, B. E., Springer, 2014.

Reference Books:

1. Analytical Electrochemistry, Joseph Wang, John Wiley, 2006, 3rd Edition.
2. Electrochemistry of Functional Supramolecular Systems, Paola Ceroni, Alberto Credi and Margherita Venturi (Ed.), John Wiley, 2010.

Course Code: PH 6213	SOLAR ENERGY SYSTEMS	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Outline the technologies that are used to harness the power of solar energy.
CO2	Understanding of the available solar energy and the current solar energy conversion and utilization processes.
CO3	Comprehend the challenges in sustainable energy processes, perform cost analysis, design photovoltaic systems for different applications meeting residential and industrial needs, predict and test performance.
CO4	Understand the manufacturing processes involved, environmental challenges that need to be solved, economic aspects, and future potentials.
CO5	Illustrate the concepts of direct energy conversion systems & their applications.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	1	2	2	1
CO3	1	1	2	3	3	1
CO4	1	1	2	2	2	1
CO5	1	1	3	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Solar Energy: Fundamentals of Solar Energy-Spectral Irradiance, Terrestrial Solar Radiation, Atmospheric Effects, Air Mass, Sun's Position, Solar Radiation on a Tilted Surface, Solar Insolation, Measurement and Analysis of Solar Irradiance.

Solar Photovoltaics: Solar Cell and Its Operation, Solar Technologies, Silicon Solar Structure and Parameters, Efficiency of Solar and Spectral Response, Solar Cell Design Principles-Light Trapping, Optical Losses, Anti-Reflection Coatings, Top Contact Design, Metal Grid Pattern. Environmental and Safety Issues, Cell Passivation.

Solar PV Modules and PV Systems: PV Module Circuit Design, Module Structure, Packing Density, Interconnections, Mismatch and Temperature Effects, Electrical and Mechanical Insulation, Lifetime of PV Modules, Degradation and Failure, PV Module Parameters, Efficiency of PV Module, Solar PV Systems-Design of Off Grid Solar Power Plant. Installation and Maintenance.

Storage in PV Systems: Battery Operation, Types of Batteries, Battery Parameters, Application and Selection of Batteries for Solar PV System, Battery Maintenance and Measurements, Battery Installation for PV System.

Solar Thermal Systems: Design of Solar Thermal Systems-Solar Concentrators, Storage of

Solar Generated Heat, Hybrid Systems-Combinations of Solar Thermal and Solar Cell Systems.

Learning Resources:

Text Books:

1. Solar Cells: Operating Principles, Technology and System Applications, Martin A. Green, Published by the University of New South Wales, 1998, 1st Edition.
2. Principles of Solar Engineering, D. Yogi Goswami, Taylor and Francis, 2000, 1st Edition.

Reference Books:

1. Photovoltaic Engineering Handbook, Lasnier, F., Ang, T. G., IOP Publishing UK, 1990, 1st Edition.
2. Semiconductor Devices, Physics, and Technology, Sze, S. M., Wiley, 2001, 2nd Edition.

Online Resources:

1. Energy Education (Link: https://energyeducation.ca/encyclopedia/Photovoltaic_system)

Course Code: CH 5301	SUSTAINABLE ENERGY ENGINEERING	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Quantify the variety of energy resources.
CO2	Perform project economics evaluation.
CO3	Evaluate sustainability metrics.
CO4	Select suitable sustainable energy technologies.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	2	2	3	3	3
CO2	1	2	2	3	3	3
CO3	1	2	2	3	3	3
CO4	1	2	3	3	3	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Sustainability Concepts: Sustainable Development Goals for Clean Energy (SDGS), Emerging Issues in Energy Access, Technologies, Economics. Sustainability Concepts of Energy Generation Technologies, Energy and Resource Utilization.

Sustainable Energy: The Engine of Sustainable Development: Aspects of Energy Production, Nations and Global Patterns of Energy Supply and Utilisation, Environmental Effects of Energy.

Estimation and Evaluation of Energy Resources: Comparison of Different Forms of Energy, Energy Life Cycle, Estimation and Validation of Energy Resources.

Technical Performance: Allowability, Efficiency, Production Rates, Relation of Technical Performance to Sustainability, Thermodynamic Analysis, Chemical Rate Processes, Use and Abuse of Time Scales.

Local, Regional, and Global Environmental Effects of Energy: Adverse Environmental Effects, Attribution of Environmental Damage, Methods of Environmental Protection.

Project Economic Evaluation: Time Value of Money Mechanics, Economy of Scale and Learning Curve, Energy Accounting.

Energy Systems and Sustainability Metrics: System Analysis Approach, Measures, General Principles for Sustainable Development.

Energy, Water and Land Use: Major Planetary Cycles, Land-Use Issues, Ocean-Use Issues, Implications for Sustainable Energy, Charting Pathways for Energy Democracy, Building an Energy Democracy Movement.

Biomass Energy, Biofuel: Characterisation, Biomass Relevance to Energy Production, Properties Relevant to Energy Production, Thermal Conversion, Bioconversion, Economics.

Solar Energy: Resource Assessment, Concentrating Solar Power, Solar Photovoltaic Systems.

Ocean Wave, Tide, Current, and Thermal Energy Conversion: Energy from the Tides and Currents, Energy from Waves, Economic Prospects, Environmental and Sustainability Considerations.

Wind Energy: Wind Resources, Wind Machinery and Generating Systems, Wind Power Economics, Measure of Sustainability.

Energy Carriers: Electric Power, Hydrogen Fuel: Electricity as an Energy Carrier, Hydrogen as an Energy Carrier, Sustainability Issues.

Industrial Energy Usage: Life-Cycle Analysis and Design for Sustainability, Chemical Industries, Cement and Lime Industries, Sustainability Issues.

Synergistic Complex Systems: Complex Systems View, Some Case Studies, Transitional Pathways, Challenge to Society.

Learning Resources:

Text Books:

1. Sustainable Energy: Choosing Among Options, Tester, J. W., Drake, E. M., Driscoll, M. J., Golay, M. W., Peters, W. A., MIT Press, 2012, 2nd Edition.
2. Encyclopedia of Sustainable Technologies, Martin A. Abraham, Volume 3: Sustainable Energy Technologies & Sustainable Chemical Processes by Vladimir Strezov, Joseph Zoeller, Elsevier Science, 2017.
3. Sustainable Energy Technologies, Eduardo Rincon-Mejia, Alejandro de las Heras, CRC Press, Taylor & Francis Group, 2018.
4. Energy democracy: Advancing equity in clean energy solutions, Denise Fairchild, Al Weinrub, Island press, 2017

Reference Books:

1. Sustainable Engineering: Principles and Implementation, Mulligan, C. N., CRC Press, Taylor and Francis Group, 2019.
2. Sustainable Engineering: Principles and Practice, Bakshi, B. R., Cambridge University Press, 2019.
3. European Environment Agency, https://www.eea.europa.eu/en
4. U.S. Environmental Protection Agency, https://www.epa.gov/
5. Sustainable Engineering: Concepts, Design, and Case studies, David Allen, David Shonnard, Prentice Hall, 2011
6. Sustainable Development Goals an Indian Perspective, Hazra Somnath, Bhukta Anindya, Springer International Publishing Switzerland, 2020.

Course Code: CH 5302	HYDROGEN GENERATION AND STORAGE	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: Aat the end of the course, the student will be able to

CO1	Understand the basic properties of hydrogen, including its chemical and physical characteristics, and its role as an energy carrier.
CO2	Select a suitable hydrogen generation and storage technique based on the mechanisms, performance characteristics, and applicability.
CO3	Understand the safety considerations and regulations related to hydrogen handling.
CO4	Analyze the economic viability and environmental impact of hydrogen generation and storage systems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	1	1
CO2	1	1	1	3	2	1
CO3	1	1	2	3	2	1
CO4	1	1	2	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Basic Properties of Hydrogen, Engineering Thermodynamics, Hydrogen and Environment, Hydrogen and Sustainability, Hydrogen Production Methods, Green Hydrogen Sources, Hydrogen as an Energy Carrier, Historical Background and Current Applications.

Hydrogen Generation Methods: Steam methane reforming, Electrolysis (alkaline, PEM, and solid oxide electrolysis), Coal/Biomass Gasification, Solar and Wind-based Hydrogen Production, Emerging Hydrogen Generation Technologies.

Hydrogen Storage Techniques: Compressed Gas Storage, Liquid Hydrogen Storage, Chemical Storage (hydrogenation, metal hydrides), Physical Storage Using Nanostructured and Porous Materials, Underground Hydrogen Storage, Emerging Hydrogen Storage Technologies.

Performance and Efficiency: Efficiency Considerations in Hydrogen Generation, Energy Losses and Efficiency of Different Storage Methods, Performance Assessment of Hydrogen Production and Storage Systems.

Safety and Regulations: Safety Considerations in Hydrogen Handling and Storage, Codes and Standards for Hydrogen Storage Systems, Risk Assessment and Mitigation Strategies, Case Studies of Hydrogen-related Incidents

Learning Resources:

Text Books:

1. Hydrogen Generation, Storage and Utilization, Zhang, J. Z., Li, J., Li, Y., Zhao, Y., John Wiley & Sons, 2014.
2. Sustainable Hydrogen Production, Dinçer, I., Zamfirescu, C., Elsevier, 2016.
3. Advances in Hydrogen Production, Storage and Distribution, Iulianelli, A., Basile, A., Elsevier, 2014.

Reference Books:

1. Hydrogen Fuel: Production, Transport, and Storage, Gupta, R. B., CRC press, 2008.
2. Materials for Hydrogen Production, Conversion, and Storage, Altalhi, T. A., Adnan, S. M., Amin, M. A., John Wiley & Sons, 2023.
3. Hydrogen as an Energy Carrier: Technologies, Systems, Economy, Winter, C. J., Nitsch, J. Springer Science & Business Media, 2012.
4. Handbook of Hydrogen Energy, Sherif, S. A., Goswami, D. Y., Stefanakos, E. L., Steinfeld, A., CRC press, 2014.

Online Resources:

1. Hydrogen Energy: Production, Storage, Transportation and Safety, NPTEL Course (Link: https://onlinecourses.nptel.ac.in/noc22_ch66/preview)

Course Code: CH 5303	FUEL CELL SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand working principle of fuel cell.
CO2	Analyse the performance of fuel cell systems.
CO3	Identify the intricacies in the operation of fuel cell stack and fuel cell system.
CO4	Analyse the fuel cell system design and integration.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	1	1
CO2	3	1	2	3	2	1
CO3	3	1	2	2	2	1
CO4	3	1	2	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Fuel Cells: Fuel Cells as Electrochemical Engines, Generic Fuel Cell and Stack, Classification of Fuel Cells, Potential Applications, History of Fuel Cell Development.

Thermodynamics and Basic Electrochemical Principles: Heat, Work Potentials, Prediction of Reversible Voltage, Fuel Cell Efficiency; Electrode Kinetics, Butler-Volmer Equation, Overpotentials, Tafel Equation, Charge Transfer Reaction, Exchange Currents

Fuel Cell Components and Their Impact 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.

Fuel Cell Testing and Characterization: Test Protocols and Standards, Performance Testing and Measurement Techniques, Durability Testing and Accelerated Aging, Electrochemical and Physical Characterization Techniques.

Principles and technology of different types of fuel cell systems: Alkaline Fuel Cells, Molten Carbonate Fuel Cells, PEM Fuel Cells, Solid Oxide Fuel Cells, Phosphoric acid Fuel Cells, Microbial Fuel Cells, Regenerative Fuel Cells.

Fuel Cell System Design and Integration: Balance of Plant Components, System Configuration and Sizing, Thermal Management and Water Management, Control and Power Management, Hydrogen Production from Renewable Sources and Storage; Safety Issues, Cost Analysis.

Learning Resources:

Text Books:

1. Fuel Cell Technology Hand Book, Hoogers G., CRC Press, 2003.
2. Fuel Cell Engines, Mathew M. Mench, Wiley, 2008.
3. Fuel Cell Fundamentals, O'Hayre, R. P., Cha, S., Colella, W., Prinz, F. B., Wiley, 2006.
4. PEM Fuel Cells: Theory and Practice, Barbir, F., Elsevier/Academic Press, 2013, 2nd Edition.

Reference Books:

1. Fuel Cell Science and Engineering – Materials, Processes, Systems and Technology, Detlef Stolten, Bernd Emonts, Vol-1, Wiley-VCH, 2012.
2. High Temperature Fuel Cells: Fundamentals, Design and Applications, Subhash C. Singal, Kevin Kendall, Elsevier Science, 1985.
3. Fuel Cell Systems Explained, Laminie, J., Dicks, A., John Wiley, New York, 2003, 2nd Edition.

Online Resources:

1. Fuel Cell Technology, NPTEL Course (Link: https://nptel.ac.in/courses/103/102/103102015/)

Course Code: CH 5304	MATERIALS SYNTHESIS AND ELECTROCHEMICAL ANALYSIS LAB	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the factors influencing electrodeposition and optimize experimental conditions.
CO2	Understand the hydrothermal synthesis & electrospinning processes and their application in electrode fabrication.
CO3	Analyze cyclic voltammetry data to understand electrochemical reactions.
CO4	Assess the corrosion resistance of materials.
CO5	Construct and operate electrochemical cells.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	1	3	-
CO2	2	2	3	1	3	-
CO3	2	2	3	1	3	-
CO4	2	2	3	1	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

1. Conductometric Titration for Concentration Determination.
2. Potentiometric Titration for Concentration Determination.
3. Electrodeposition Experiment.
4. Flexible Electrode Preparation.
5. Organic and Inorganic Electrolyte Synthesis.
6. Hydrothermal Synthesis of Metal Oxide Composite Electrode for Pseudocapacitor.
7. Cyclic Voltammetry to Determine Oxidation and Reduction Reaction Potential.
8. Electrochemical Measurement of Corrosion Rate.
9. Galvani and Electrolytic Cell.
10. Synthesis of Membrane for the Fuel Cell.

Learning Resources:

Text Books:

1. Lab manuals
2. Online Journals

Reference books:

1. Advanced Chemistry with Vernier: Experiments for AP, IB, and College General Chemistry, Randall, J., Vernier Software & Technology, 2004.

Course Code: CH 5305	ENERGY GENERATION AND CONVERSION LAB	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Synthesize different fuels from sustainable energy sources.
CO2	Determine the efficiency of different energy conversion technologies.
CO3	Design and analyse sustainable energy systems.
CO4	Interpret the data by performing the experiments.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	2	2	3	2	1
CO2	1	2	2	3	2	1
CO3	2	2	2	3	2	1
CO4	1	2	2	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

1. Chemical Looping Hydrogen Generation from Natural Gas
2. Chemical Looping Combustion of Coal / Biomass
3. Enzymatic Conversion of Starch to Glucose using Amylase Enzymes.
4. Ethanol Production from Saccharomyces Cerevisiae Fermentation
5. Hydrogen Production from Water using Electrolysis
6. V-I Characteristics of Low Temperature PEM Fuel Cell with Hydrogen as the Fuel.
7. V-I Characteristics of Direct Methanol Fuel Cell
8. Biooil Production using Biomass Pyrolysis
9. Biodiesel Production from Edible Oils by Transesterification
10. Measurement and Analysis of Solar Radiation.
11. Measurement and Analysis of Solar PV Module
12. Investigate Piezoelectric Effect in Piezoelectric Materials

Learning Resources:

Text Books:

1. Lab manuals / Exercise sheets

Online Resources:

1. Online Journals

Course Code: CH 5341	SEMINAR - I	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Select a topic from extensive literature review.
CO2	Communicate orally with a group of people.
CO3	Demonstrate comprehension of the topic.
CO4	Prepare a consolidated seminar report.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	1	-
CO2	2	2	1	3	-	2
CO3	1	2	3	3	1	-
CO4	1	3	1	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to sustainable energy generation and storage technologies and allied areas.

The general outline of topics that could be covered in a technical report and seminar: Introduction to the topic, Core concepts and principles, Technical details and implementation, Case studies and examples, Emerging trends and future developments, Challenges and solutions, Industry perspectives and market analysis, Ethical considerations and implications, Resources and references.

Learning Resources:

1. Energy Engineering Journals and Conference Proceedings.
2. Technical Communication, Mike Markel, Selber, S. A., Bedford/St. Martin's, 2017, 12th Edition.
3. the Essentials of Technical Communication, Tebeaux, E., Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical Writing Process, Morgan, K., Spajic, S., Better on Paper publications, 2015, 1st Edition.
5. Managing your Documentation Projects, Hackos, J. T., Wiley, 1994, 1st Edition.

Course Code: ME 5176	THERMAL ENERGY STORAGE	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the principles, concepts, and operation of thermal energy storage systems.
CO2	Select the suitable energy storage materials.
CO3	Design thermal energy storage systems.
CO4	Evaluate the performance of thermal energy storage systems for different applications.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	3	1
CO2	1	1	1	2	3	1
CO3	1	1	2	3	3	1
CO4	1	1	2	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Classification of Energy Resources, Energy Scenario in the World and India, Need for Energy Efficiency, Energy Conservation and Management.

Introduction to Thermal Energy Storage Systems: Introduction, Thermodynamics of Energy Storage, System Types, Environmental Impact.

Sensible Heat Storage Systems: Introduction, Types, Principles of Sensible Heat Storage Systems, Limitations, Advantages and Future Trend.

Latent Heat Storage Systems (Phase Change Materials): Introduction, Types, Selection Criteria, Thermophysical Properties, Thermal Stability, Corrosion, Phase Segregation, Sub Cooling, Applications.

Microencapsulation and Nanoencapsulation of Phase Change Materials: Introduction, Microencapsulation and Nanoencapsulation of Phase Change Materials, Methods, Shape Stabilized Phase Change Materials, Applications.

Design of Latent Heat Storage System: Introduction, Requirements and Considerations for the Design, Design Methodologies, Applications of Latent Heat Storage Systems Incorporating Pcms, Future Trends.

Modelling of Heat Transfer in Phase Change Materials (PCMS): Introduction, Inherent Physical Phenomena in Phase Change Materials, Modelling Methods and Approaches for the

Simulation of Heat Transfer in Pcms for Thermal Energy Storage, Examples of Modelling Applications, Future Trends.

Phase Change Materials for Energy Conservation in Buildings: Introduction, Integration of Pcms into Building Envelop, PCM Containment, Measurement of Thermal Properties of PCM Integrated in Buildings, Experimental and Numerical Studies.

Thermochemical Heat Storage: Introduction, Phenomena and Principles, Thermochemical Energy Storage Systems, Applications, Remarks.

Thermal Energy Storage Systems Applications: Introduction, Solar Air Heating, Solar Water Heating, District Heating, Heat to Waste, Cogeneration and Trigeneration Systems, Concentrated Solar Power, Cooling.

Learning Resources:

Text Books:

1. Thermal Energy Storage Technologies for Sustainability Systems Design, Assessment and Applications, Kalaiselvam, S., Parameshwaran, R., Elsevier, 2014.
2. Advances in Thermal Energy Storage Systems - Methods and Applications, Luisa F. Cabeza, Elsevier, 2015.

Reference Books:

1. Thermal Energy Storage: Systems and Applications, Ibrahim Dinçer, Marc A. Rosen, John Wiley & Sons Ltd., 2010.

Course Code: CH 5351	ENERGY MANAGEMENT AND LIFE CYCLE ASSESSMENT	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Demonstrate the goals, scope and industrial standards of LCA & energy management.
CO2	Interpret the results of inventory analysis and life cycle impact assessment.
CO3	Compare the environmental performance of different renewable energy options.
CO4	Apply various approaches to optimize energy use and reduce energy consumption.
CO5	Apply LCA as a decision-making tool to create sustainable and environmentally friendly energy systems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	2	2	1	1
CO2	3	3	2	3	1	1
CO3	3	2	2	2	2	1
CO4	3	2	2	2	3	2
CO5	3	2	2	2	3	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Life Cycle Assessment (LCA) and Energy Management: Definition and Principles of Life Cycle Assessment, Overview of Energy Management Concepts, Importance and Benefits of LCA and Energy Management, Regulatory and Industry Standards Related to LCA and Energy Management.

Life Cycle Assessment Methodology: Life Cycle Inventory (LCI) Analysis, Life Cycle Impact Assessment (LCIA), Interpretation and Reporting of LCA Results.

Energy Management: Energy Auditing and Energy Management Systems (ENMS), Energy Efficiency Measures in Buildings, Energy Efficiency Measures in Industrial Processes.

Life Cycle Assessment Applications: Integration of Renewable Energy Sources, LCA of Solar Photovoltaic (PV) Systems, LCA of Wind Energy Systems, LCA of Biomass Energy Conversion, LCA of Hydropower Systems, LCA of Geothermal Energy Systems, Comparative LCA of Renewable Energy Technologies.

Eco-Design and LCA Principles: Life Cycle Assessment (LCA) as a Tool for Eco-Design and Product Development, Eco-Design, Strategies and Techniques for Sustainable Product Development, Communicating LCA Results and Findings Effectively.

Integrating LCA and Energy Management: Synergies Between LCA and Energy Management, Energy Performance Indicators and Metrics in LCA, Incorporating LCA in Energy

Management Plans and Strategies, Life Cycle Assessment of Energy Management Strategies, Life Cycle Assessment of Energy Storage Systems, Life Cycle Assessment of Energy Generation Technologies, LCA-Based Decision Support Tools for Energy Management, Life Cycle Assessment of Energy Efficiency Measures in Buildings, Life Cycle Assessment of Energy Management in Industrial Processes, Life Cycle Assessment of Energy Management in Transportation (EVs), LCA of Sustainable Transportation Policies and Infrastructure Development.

Recovery, Recycle of Energy Materials: Analysis of Effective Recycling Initiatives in the Energy Sector, Advancements in Recycling Technologies and Processes.

Learning Resources:

Text Books:

1. Life Cycle Assessment Student Handbook, Curran, M. A., John Wiley & Sons, 2015.
2. Sustainable Engineering: Concepts, Design, and Case Studies, David Allen, David R. Shonnar, Prentice Hall, 2011.
3. Energy Management Handbook, Stephen A. Roosa, Steve Doty, Wayne C. Turner, River Publishers, 2000, 9th Edition.

Reference Books:

1. Life Cycle Assessment: Theory and Practice, Michael, Z. H., Ralph, K. R., Stig, I. O., Springer, 2018.
2. Sustainable Energy Management, Mirjana Radovanovic, Stevan Popov, Sinisa Dodic, Academic Press, 2015.

Course Code: CH 5352	BATTERY TECHNOLOGIES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Differentiate between primary and secondary batteries.
CO2	Describe the basic structure and working principles of rechargeable batteries.
CO3	Identify and analyze different types of materials used in batteries and their role in the development of new battery technologies.
CO4	Apply optimal storage and usage techniques for batteries to ensure safety and longevity.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	1	1	3	3
CO2	2	2	2	1	3	2
CO3	3	3	2	1	3	3
CO4	3	3	2	1	3	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Introduction to Battery Technologies, Historical Background and Evolution of Battery Technologies, Battery Terminology, Primary Vs. Secondary Batteries, Fundamental Aspects and Working Principles of Existing Battery Systems (Lead-Acid, Nickel Cadmium, Nickel Hydrogen and Nickel Metal).

Lithium Batteries:

Li-Ion Batteries: Basic Structure and Working Principle of Li-Ion Batteries, Anode Materials (Intercalation, Conversion and Alloying Anodes), Cathode Materials (Layer, Spinel and Olivine Structured Cathodes), Electrolyte Synthesis and Components, Separators.

Li–O_2 Batteries: Introduction and Principle Operation of Li–O_2 Battery, Anode Materials, Cathode Materials and Electrolytes.

Li-Ion Battery Recycling: Key Issues, Progress, and Future Prospects

Sodium-Ion Batteries: History of Sodium-Ion Batteries, Working Mechanism of Na-Ion Battery, Cathode Materials (Layered Transition Metal Oxide and Polyanionic Compounds), Anode Materials (Carbon, Titanium and Alloyed Anodes), Electrolytes and Additives.

Aluminum Batteries

Al-Ion Batteries: Introduction and Historical Development, Primary Al-Ion Batteries, Rechargeable Al Batteries, Classification of Rechargeable Al Batteries, Cathode Materials for Al-Ion Battery, Electrolytes (Polymer, Ionic Liquid, and Deep Eutectic Electrolytes), Al-Ion Battery Challenges, Corrosion Inhibitors, Summary and Perspectives.

Dual-Ion Batteries: Introduction to Dual-Ion Battery and Working Mechanism, Cathode Materials (Graphitic, Organic Anodes), Anode Materials (Metallic, Alloying and Intercalation Type Anodes).
Flow batteries: Introduction, Redox Flow Battery Technology-brief History, Working Principle, Redox Flow Battery Components and Systems.

Battery Safety: Managing Battery Hazards, Optimal Storage and Usage Techniques, Strategies for Preventing and Addressing Thermal Runaway, Overview of Battery Management Systems.

Learning Resources:

Text Books:

1. Battery Technology Crash Course, Petrovic, S., Springer International Publishing, 2021.
2. Battery Technologies: Materials and Components. Ma, J., John Wiley & Sons, 2021.

Reference Books:

1. The Handbook of Lithium-Ion Battery Pack Design: Chemistry, Components, Types and Terminology, Warner, J. T., Elsevier, 2015.

Course Code: CH 5353	ENERGY STORAGE LAB	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Fabricate primary & secondary batteries and supercapacitor using appropriate materials and techniques.
CO2	Evaluate the performance of batteries and supercapacitors.
CO3	Interpret the electrochemical performance with material physicochemical properties.
CO4	Examine the effect of operating conditions on the performance of energy storage devices.
CO5	Differentiate between Li/Na -ion batteries, supercapacitors and flow batteries.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5
CO1	3	3	1	1	2
CO2	3	3	1	1	2
CO3	3	3	1	1	2
CO4	3	3	1	1	2
CO5	3	3	1	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

1. Fabrication and Testing of Lithium-Ion Half-Cell.
2. Fabrication and Testing of Activated Carbon Electrode-Based Supercapacitor.
3. Assessment of the Rate Performance and Cyclic Stability of the Supercapacitor.
4. Flexible Supercapacitor Fabrication and Testing.
5. Fabrication and Testing of Na-ion Battery.
6. Vanadium Redox Flow Battery Performance Evaluation.
7. Primary Alkaline Battery Packing and Testing.
8. Primary Battery Fabrication and Testing.
9. Discharge and Charging of Lead-Acid Battery.
10. Thermal Energy Storage.

Learning Resources:

Text Books:

1. Lab manuals
2. Online Journals

Reference books:

1. Advanced Chemistry with Vernier: experiments for AP, IB, and College General Chemistry, Randall, J., Vernier Software & Technology, 2004.

Course Code: CH 5354	ENERGY SYSTEMS SIMULATION LAB	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Simulate process equipment, unit operations and flowsheets.
CO2	Apply sensitivity, design specification and case study tools in Aspen.
CO3	Comprehend the fundamentals of process modelling, simulation, and optimization using Aspen software.
CO4	Analyse mass and energy balances, conversion efficiencies, product yields, and other relevant parameters to assess the performance and efficiency of energy systems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	2	3	1
CO2	1	1	2	2	3	1
CO3	1	1	3	3	3	1
CO4	1	1	3	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Solve the following steady state simulation exercises using **Aspen.**

1. Physical property estimations
2. Simulation of individual units like, mixers, splitters, heat exchangers, flash columns and reactors
3. Design and rating of heat exchangers
4. Mass and energy balances
5. Sensitivity and design spec tools
6. Simulation of a flowsheet
7. Simulation of processes involving solids
8. Natural gas combined cycle power plant
9. Chemical looping combustion of coal
10. Syngas production from coal/biomass gasification

Learning Resources:

Text Books:

1. Lab Manuals.
2. Process Modelling and Simulation in Chemical, Biochemical and Environmental Engineering, Verma, A. K., Singh, D., CRC Press, 2017.
3. Process Simulation and Control using Aspen, Jana, A. K., PHI Learning, 2012, 2nd Edition.
4. Learn Aspen Plus in 24 Hours, Adams, T. A., Mc Graw Hill, 2022, 2nd Edition.

Course Code: CH 5391	SEMINAR - II	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Select a topic from extensive literature review.
CO2	Communicate orally with a group of people.
CO3	Demonstrate comprehension of the topic.
CO4	Prepare a consolidated seminar report.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	1	-
CO2	2	2	1	3	-	2
CO3	1	2	3	3	1	-
CO4	1	3	1	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to sustainable energy generation and storage technologies and allied areas.

the general outline of topics that could be covered in a technical report and seminar: Introduction to the topic, Core concepts and principles, Technical details and implementation, Case studies and examples, Emerging trends and future developments, Challenges and solutions, Industry perspectives and market analysis, Ethical considerations and implications, Resources and references.

Learning Resources:

1. Energy Engineering Journals and Conference Proceedings.
2. Technical Communication, Mike Markel, Selber, S. A., Bedford/St. Martin's, 2017, 12th Edition.
3. The Essentials of Technical Communication, Tebeaux, E., Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical Writing Process, Morgan, K., Spajic, S., Better on Paper publications, 2015, 1st Edition.
5. Managing your Documentation Projects, Hackos, J. T., Wiley, 1994, 1st Edition.

Course Code: CH 6341	COMPREHENSIVE VIVA-VOCE	Credits 0-0-0: 2

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Demonstrate an understanding of the courses studied.
CO2	Explain the principles, phenomena and their applications.
CO3	Communicate effectively.
CO4	Comprehend the concepts for solving practical issues.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	2	2	1
CO2	1	1	2	3	2	1
CO3	1	1	2	1	1	1
CO4	1	1	2	3	3	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Sustainable Energy Generation and Storage Technologies Courses of I year.

Course Code: CH 6342	DISSERTATION PART - A	Credits 0-0-0: 12

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Identify the problem based on literature survey/ industry interaction.
CO2	Formulate the problem by defining objectives.
CO3	Develop an effective solution methodology.
CO4	Prepare a technical report.
CO5	Demonstrate the progress of dissertation work.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	3	3	2	2
CO2	3	3	3	3	2	2
CO3	3	3	3	3	2	2
CO4	3	3	3	3	2	2
CO5	3	3	3	3	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Project works relevant to the Sustainable Energy Generation and Storage Technologies.

Course Code: CH 6199	DISSERTATION PART - B	Credits 0-0-0: 20

Pre-Requisites: CH6342 Dissertation Part - A

Course Outcomes: At the end of the course, the student will be able to

CO1	Implement the methodology identified in dissertation part-A.
CO2	Analyze and interpret the results.
CO3	Draw conclusions from the results.
CO4	Prepare a comprehensive dissertation report following ethical principles.
CO5	Demonstrate the outcomes of dissertation work.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	3	3	2	1
CO2	3	3	3	3	2	1
CO3	3	3	3	2	2	1
CO4	3	3	3	3	2	1
CO5	3	3	3	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Dissertation works taken up in I semester, relevant to the Sustainable Energy Generation and Storage Technologies, will be continued.

Elective Courses offered in First Semester

Course Code: CH 5311	BIOENERGY AND BIOFUELS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Describe the nature and principle of different biomass energy extraction systems.
CO2	Choose suitable biomass fuels for different energy applications.
CO3	Address the desirable features of biomass energy sources and their advantages over traditional fuels such as petroleum and coal.
CO4	Identify suitable bioenergy sources in terms of suitable sites, composition and cost-effectiveness.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	2	3	1	3
CO2	3	3	2	3	1	3
CO3	3	3	2	3	1	3
CO4	3	3	2	3	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Bioenergy: Global Energy Outlook, Importance of Bioenergy in Solving the Energy Crisis and Global Warming, Sustainability, Introduction to Various Biomass Feedstocks-Constituents and Characterization.

Introduction to Biofuels: Seed-Based Biodiesel, Bioethanol, Conversion of Waste Vegetable Oil to Biodiesel, Advanced Biofuels Including Algae-Biofuel, Microbial Biofuel and Advanced Innovations in the Enzymatic Conversion of Non-Food Feedstocks; Biohydrogen, Biobutanol and Other Green Fuels.

Biomass Feedstock Preparation and Pre-Treatment: Drying, Devolatilization, Size Reduction, Particle Size Classification, Torrefaction, Pelletizing and Mixing; Physical, Chemical, Physiochemical and Mechanical Pre-Treatments.

Biomass Conversion Technologies for Biofuel: Thermochemical Processes, Combustion, Gasification, Pyrolysis, Hydrothermal Liquefaction, Hydropyrolysis, Torrefaction and Choice of Thermal Process Based on Biomass Type and Product Requirement.

Bioenergy & Biofuels Related Environmental, Economic and Social Issues: Source, Processing and Social Impacts of Biofuel Utilization.

Learning Resources:

Text Books:

1. Biofuels from Plant Oils, Filemon A. Uriarte Jr., ASIAN Foundation, 2010.
2. Bioenergy: Biomass to Biofuels, Anuj Dahiya, Elsevier 2015.
3. Biofuels and Bioenergy Processes and Technology, Sunggyu Lee, Y. T. Shah, CRC Press, Tailor and Francis Group, 2013.
4. Biofuels: Alternative Feedstocks and Conversion Processes, Pandey, A., Larroche, C., Ricke, S. C., Dussap, C. G., Gnansounou, E. Academic Press, USA, 2011.
5. Thermochemical Processing of Biomass into Fuels, Chemicals and Power, Brown, R. C. Wiley, 2011.

Reference Books:

1. Introduction to Chemicals from Biomass, Clark, J., Deswarte, F. John Wiley and Sons, UK, 2008.
2. Understanding Clean Energy and Fuels from Biomass, Mukunda, H. S. Wiley India, 2011.

Course Code: CH 5312	NUCLEAR POWER TECHNOLOGY	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand nuclear fission and nuclear fusion techniques.
CO2	Analyse the interaction of alpha, beta particles and neutrons with matter.
CO3	Evaluate the neutron diffusion theory, fuel depletion, and neutron transport equations.
CO4	Apply engineering aspects to reactor kinetics and control, radiation shielding, and reactor material selection.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	2	3	-	1
CO2	-	-	2	3	-	1
CO3	-	-	2	3	-	1
CO4	-	-	2	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Chemical Engineering Aspects of Nuclear Power: Introduction, Nuclear Fission, Nuclear Fuels, Nuclear Reactor Types, Fuel Processing Flow Sheets, Fuel-Cycle Operations, Fuel Reprocessing, Isotope Separation, Nuclear Fusion.

Nuclear Reactions and Radiations: Introduction, Radioactivity, Interaction of Alpha and Beta Particles with Matter, Interaction of Gamma Rays with Matter, Interaction of Neutrons with Matter, Cross Sections for Neutron Reactions, Variation of Cross Sections with Neutron Energy, The Fission Process.

Neutron Transport Behavior: Neutron Transport Concepts, Neutron Diffusion Theory, Diffusion in Multiplying Systems, Slowing Down of Neutrons, Slowing Down in Infinite Media, Spatial Distribution of Slowed-Down Neutrons, Critical Equations Based on Diffusion Theory, Criticality Measurements.

Nuclear Design Basics: Introduction, Multigroup Diffusion Theory, Fuel Depletion Calculations, Neutron Transport Equation and Its Approximation.

Nuclear Reactor Kinetics and Control: Introduction, Reactor Kinetics, Fission-Product Poisoning, Effect of Temperature on Reactivity, Reactor Stability Analysis, General Features of Reactor Control, Reactivity Control Instrumentation, Reactor Operations.

Radiation Protection and Shielding: Introduction, Health Physics Activities, Radiation Units, Biological Effects of Radiation, Radiation Protection Standards, Radiation Shielding Principles, Radiation Attenuation Calculations, Reactor Shield Analysis, Heating in Shields.

Reactor Materials: Introduction, Mechanical Properties of Materials, Stress Analysis, Radiation Effects in Materials, Corrosion of Metals, Structural and Cladding Materials, Moderator and Reflector Materials, Fuel Materials.

Learning Resources:

Text Books:

1. Nuclear Reactor Engineering Reactor Systems Engineering, Glasstone Samuel, Sesonske Alexander, Springer, 1994, 4th Edition.
2. Nuclear Chemical Engineering, Manson Benedict, Thomas H. Pigford, Hans Wolfgang Levi, McGraw-Hill, 1981, 2nd Edition.
3. Introduction to Nuclear Engineering, Lamarsh, J. R., Baratta, A. J., 2001, 3rd Edition.

Reference Books:

1. Nuclear Reactor Engineering (principles and Concepts), Vaidyanathan G., S Chand & Company, 2013

Course Code: CH 5313	ENERGY RESOURCES, ECONOMICS AND ENVIRONMENT	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Describe renewable and non-renewable energy sources and their availability.
CO2	Assess the interdependencies and trade-offs between energy resources, economics, and the environment.
CO3	Perform data analysis and energy balance calculations.
CO4	Evaluate financial and economic aspects of energy projects.
CO5	Evaluate the environmental impacts associated with energy production and utilization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	3	3	2	1
CO2	1	2	2	3	3	1
CO3	1	2	1	3	3	1
CO4	1	3	2	2	2	1
CO5	1	3	2	3	3	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Energy, Economy and Social Development, Classification of Energy Sources, Energy Chain, Conventional Energy Sources, Non-Conventional Energy Sources, Energy Densities (Heating Values) of Various Fuels, Environmental Aspects of Energy, Energy-Environment-Economy, World Energy Status, Energy Scenario in India

Non-conventional energy sources: Solar Energy—Basic Concepts, Solar Thermal Systems, Solar Photovoltaic Systems; Wind Energy, Biomass Energy, Geothermal Energy, Ocean Energy, Hydropower.

Energy Economics: Energy Data and Energy Balance – Energy Basics, Energy Accounting Framework, Accounting of Traditional Energies, Analysis of Energy Balance Information; Financial and Economic Evaluation, Economics of Non-Renewable Energy Supply, Economics of Renewable Energy Supply.

Energy Environment: Air Pollution, Global Atmospheric Change, the Economics of Environment Protection.

Text Books:

1. Energy Economics: Concepts, Issues, Markets and Governance, Bhattacharyya, S. C., Springer Nature, 2019, 2nd Edition.
2. Non-Conventional Energy Resources, Khan, B. H., McGraw Hill Education (India) Private Limited, Chennai, 2017, 3rd Edition.

3. Introduction to Environmental Engineering and Science, Masters, G. M., Wendell P. E., Pearson New International Edition, 2014, 3rd Edition.
4. Renewable Energy Resources, Twidell, J., Weir, T., Routledge, 2015, 3rd Edition.

Reference Books:

1. Resource Economics, Conrad, J. M., Cambridge University Press, New Delhi, 2010, 2nd Edition.
2. Sustainable Energy Choosing Among Options, Tester J. W., Drake E. M., Driscoll M. J., Golay, M. W, Peters, W. A., PHI Learning Private Limited, New Delhi, 2009.

Online Resources:

1. Energy Resources, Economics and Environment, NPTEL Course (Link: https://onlinecourses.nptel.ac.in/noc22_hs43/preview)

Course Code: CH 5103	ENGINEERING OPTIMIZATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Formulate objective function for a given problem.
CO2	Solve unconstrained single and multi-variable optimization problems.
CO3	Apply linear programming and nonlinear programming techniques.
CO4	Use dynamic programming for optimization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	-	1	1	1
CO2	3	-	1	2	2	1
CO3	3	-	1	2	2	1
CO4	3	-	-	1	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

The Nature and Organization of Optimization Problems: What Optimization is all about, Why Optimize? Scope and Hierarchy of Optimization, Examples of Applications of Optimization, the Essential Features of Optimization Problems, General Procedure for Solving Optimization Problems, Obstacles to Optimization.

Basic Concepts of Optimization: Continuity of Functions, Unimodal Vs Multimodal Functions, Convex and Concave Functions, Convex Region, Necessary and Sufficient Conditions for an Extremum of an Unconstrained Function, Interpretation of the Objective Function in Terms of Its Quadratic Approximation.

Optimization of Unconstrained Functions: one Dimensional Search Numerical Methods for Optimizing a Function of one Variable, Scanning and Bracketing Procedures, Newton and Quasi-Newton Methods of Unidimensional Search, Polynomial Approximation Methods, How one-Dimensional Search is Applied in a Multidimensional Problem, Evaluation of Unidimensional Search Methods.

Unconstrained Multivariable Optimization: Direct Methods, Indirect Methods – First Order, Indirect Methods – Second Order.

Linear Programming and Applications: Basic Concepts in Linear Programming, Degenerate LP's – Graphical Solution, Natural Occurrence of Linear Constraints, the Simplex Methods of Solving Linear Programming Problems, Standard LP Form, Obtaining a First Feasible Solution, Sensitivity Analysis, Duality in Linear Programming.

Nonlinear Programming with Constraints: the Lagrange Multiplier Method, Necessary and Sufficient Conditions for a Local Minimum, Introduction to Quadratic Programming.

Optimization of Staged and Discrete Processes: Dynamic Programming, Introduction to Integer and Mixed Integer Programming, Assignment Problem (Hungarian Method)

Metaheuristic Optimization Methods: Bio-Inspired Approaches

Learning Resources:

Text Books:

1. Optimization of Chemical Processes, Edgar T.F., Himmelblau, D. M., McGraw Hill, 2001, 2nd Edition.
2. Engineering Optimization: Theory and Practice, Singiresu S Rao, John Wiley & Sons Ltd., 2019, 5th Edition.

Reference Books:

1. Optimization: Theory and Practice, Mohan C. Joshi, Kannan M. Moudgalya, Alpha Science International Limited, 2004.
2. Convex optimization, Stephen Boyd, Lieven Vandenberghe, Cambridge University Press, 2004.
3. Applied Optimization with MATLAB Programming, Venkataraman P., Wiley, 2009, 2nd Edition.
4. Design of Thermal Systems, Stoecker W. F., McGraw-Hill, 2011, 3rd Edition.

Course Code: CH 5115	WASTE TO ENERGY	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Demonstrate technologies for generation of energy from solid waste.
CO2	Select thermochemical conversion methods.
CO3	Identify sources of energy from biochemical conversion.
CO4	Analyse the environmental and health impact of waste to energy conversion.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	1	1
CO2	2	2	-	2	2	1
CO3	2	2	2	2	-	1
CO4	2	1	-	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Characterization of Wastes, Agricultural Residues and Wastes Including Animal Wastes, Industrial Wastes, Municipal Solid Wastes. Waste Processing Types and Composition of Various Types of Wastes, Characterization of Municipal Solid Waste, Industrial Waste and Biomedical Waste, Waste Collection and Transportation, Waste Processing-Size Reduction, Separation, Waste Management Hierarchy, Waste Minimization and Recycling of Municipal Solid Waste.

Thermochemical Conversion: Incineration, Pyrolysis, Gasification of Waste Using Gasifiers, Environmental and Health Impacts of Incineration; Strategies for Reducing Environmental Impacts. Energy Production from Wastes Through Incineration, Energy Production Through Gasification of Wastes. Energy Production Through Pyrolysis and Gasification of Wastes, Syngas Utilization.

Biochemical Conversion: Anaerobic Digestion of Sewage and Municipal Wastes, Direct Combustion of MSW-Refuse Derived Solid Fuel, Industrial Waste, Agro Residues, Anaerobic Digestion Biogas Production, and Present Status of Technologies for Conversion of Waste into Energy, Design of Waste to Energy Plants for Cities, Small Townships and Villages, Energy Production from Wastes Through Fermentation and Trans Esterification, Cultivation of Algal Biomass from Wastewater and Energy Production from Algae, Energy Production from Organic Wastes Through Anaerobic Digestion and Fermentation, Introduction to Microbial Fuel Cells, Process Analysis and Reactor Configurations for Methane Production, Energy Assessment, Bio-Methanation from Sludge Digestion.

Energy Production from Waste Plastics, Gas Cleanup Waste, Heat Recovery: Concept of Conversion Efficiency, Energy Waste, Waste Heat Recovery Classification, Advantages and Applications, Commercially Viable Waste Heat Recovery Devices.

Environmental and Health Impacts-Case Studies: Environmental and Health Impacts of Waste to Energy Conversion, Case Studies of Commercial Waste to Energy Plants, Waste to Energy- Potentials and Constraints in India, Eco-Technological Alternatives for Waste to Energy Conversions.

Learning Resources:

Text Books:

1. Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, Robert C. Brown, John Wiley and Sons, USA, 2019.
2. Introduction to Biomass Energy Conversions, Sergio Capareda, CRC Press, USA, 2013.
3. Efficiency of Biomass Energy: An Exergy Approach to Biofuels, Power, and Biorefineries, Krzysztof J Ptasinski, John Wiley & Sons, USA, 2016.
4. Solid Waste Engineering, Vesilind, P. A., Worrell W. A., Cengage India, 2016, 2nd Edition.

Online Resources:

1. Waste to Energy Conversion, NPTEL Course (Link: https://nptel.ac.in/courses/103/107/103107125/)

Course Code: EE 5101	Analysis of Power Converters	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Select appropriate switching devices for power converters.
CO2	Analyze and design power converter configurations for specific applications.
CO3	Select control techniques for low and medium power converters.
CO4	Design power electronic converters to improve power quality.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	1	2	3	1
CO3	1	1	1	1	3	1
CO4	1	1	1	2	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Overview of Switching Power Devices: Static and Dynamic Characteristics of Switching Devices: BJT, MOSFET, IGBT, GTO, Wide Band Gap Devices (GaN, SiC), Design of Driver and Snubber Circuit.

DC-DC Converters: Non-isolated DC-DC Converters: Buck, Boost, Buck-boost, CUK Converters under Continuous and Discontinuous Conduction Operation, Isolated DC-DC Converters: Forward, Fly-back, Push-pull, Half-bridge and Full-bridge Converters, Relationship between I/P and O/P voltages, Design of Filter Inductor and Capacitors.

Inverters: Single-phase and Three-phase Inverters, PWM Techniques: Single, Multiple and Sinusoidal PWM Techniques, Selective Harmonic Elimination, Space Vector Modulation, Current Source Inverter, High Power Inverters: Multi-pulse Inverters, Multi-level Inverters, Diode, Clamped, Cascaded and Flying Capacitor Types, Carrier and Vector Based Multi-Level Modulation Schemes, Concept of Active Power Filters, Introduction to Matrix Converters.

Front-End (AC-DC) Converters: Conventional Methods of Power Factor Improvements, Semi- Converter, Extinction Angle Control, Symmetrical Angle Control, Active Front End Converters, Single Phase, Boost, Voltage Doubler and PWM Rectifiers, Voltage and Current Controlled Three Phase PWM Rectifiers.

Learning Resources:

Text Books:

1. Power Electronics Handbook, Rashid, M. H., Butterworth-Heinemann, 2017, 4th Edition.
2. Power Electronics: Converters, Applications and Design, Mohan, N., Undeland, T. M., Robbins, W. P., John Wiley & Sons, 2003, 3rd Edition.

Reference Books:

1. Power Electronics: Essentials and Applications, Umanand, L., John Wiley India, 2009, 1st Edition.
2. Fundamentals of Power Semiconductor Devices, Jayant Baliga B, Springer, 2008, 1st Edition.
3. High Power Converters and AC Drives, Bin Wu, Wiley-Interscience, 2017, 2nd Edition.
4. Power Electronic Converter Harmonics Multipulse Method for Clean Power, Derek A Paice, IEEE Press, 1995.

Online Resources:

1. High Power Multilevel Converters- Analysis, Design and Operational Issues, NPTEL Course (Link: https://nptel.ac.in/courses/108102157)

Course Code: EE 5104	Control & Integration of Renewable Energy Sources	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand different renewable energy sources and storage devices.
CO2	Model and simulate renewable energy sources.
CO3	Analyze and simulate control strategies for grid connected and off-grid systems.
CO4	Develop converters to comply with grid standards to obtain grid integration.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	1	3	3	1
CO3	1	1	1	2	3	1
CO4	1	1	1	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Electric Grid, Utility Ideal Features, Supply Guarantee, Power Quality, Stability and Cost; Importance & Effects of Renewable Energy Penetration into the Grid, Boundaries of the Actual Grid Configuration, Consumption Models and Patterns.

Dynamic Energy Conversion Technologies: Introduction, Types of Conventional and Nonconventional Dynamic Generation Technologies, Principle of Operation and Analysis of Reciprocating Engines, Gas and Micro Turbines, Hydro and Wind-Based Generation Technologies.

Static Energy Conversion Technologies: Introduction, Types of Conventional and Nonconventional Static Generation Technologies, Principle of Operation and Analysis of Fuel Cell, Photovoltaic Systems and Wind Generation Technologies, MPPT Techniques and Its Classifications, Principle of Operation and Partial Shading Effects, Storage Technologies Batteries, Fly Wheels, Super Capacitors and Ultra-Capacitors.

Control Issues and Challenges: Linear and Nonlinear Controllers, Predictive Controllers and Adaptive Controllers, Load Frequency and Voltage Control, PLL, Modulation Techniques, Control Of Diesel, PV, Wind and Fuel Cell Based Generators, Dimensioning of Filters, Fault-Ride Through Capabilities.

Integration of Energy Conversion Technologies: Introduction & Importance, Sizing, Optimized Integrated Systems, Interfacing Requirements, Distributed Versus Centralized Control, Grid Connected Photovoltaic Systems –Classifications, Operation, Merits & Demerits; Islanding Operations, Stability and Protection Issues, Load Sharing, Operation & Control of Hybrid Energy Systems, Solar Photovoltaic Applications, IEEE & IEC Codes and Standards for

Renewable Energy Grid Integrations.

Learning Resources:

Text Books:

1. Renewable and Efficient Electric Power Systems, Masters, G., IEEE-John Wiley and Sons Ltd. Publishers, 2013, 2nd Edition.
2. Microgrids and Active Distribution Networks, Chowdhury, S., Chowdhury, S. P., Crossley, P., IET Power Electronics Series, 2012.
3. Integration and Control of Renewable Energy in Electric Power System, Ali Keyhani Mohammad Marwali, Min Dai, John Wiley Publishing Company, 2010, 2nd Edition.

Reference Books:

1. Fundamentals, technologies & Applications, Chetan Singh Solanki, Solar Photovoltaic, PHI Publishers, 2019, 3rd Edition.
2. Control of Power Inverters in Renewable Energy and Smart Grid Integration, QuingChang Zhong, IEEE-John Wiley and Sons Ltd. Publishers, 2013, 1St Edition.
3. Power Conversion and Control of Wind Energy Systems, Bin Wu, Yongqiang Lang, Navid Zargari, IEEE- John Wiley and Sons Ltd. Publishers, 2011, 1st Edition.
4. Report on “Large Scale Grid Integration of Renewable Energy Sources - Way Forward” Central Electricity Authority, GoI, 2013.

Online Resources:

1. Power Electronics, NPTEL Course (Link: https://nptel.ac.in/courses/108102145)
2. Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems, NPTEL Course (Link: https://nptel.ac.in/courses/103103206)

Course Code: EE 5114	ELECTRIC VEHICLES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the concepts of electric vehicles, hybrid electric vehicles and their impact on environment.
CO2	Analyze the drive-train topologies and advanced propulsion techniques.
CO3	Analyze hybrid energy storage methodologies.
CO4	Select suitable power converter topologies for motor control and hybrid energy storage.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	2	1
CO2	1	1	2	3	3	1
CO3	1	1	2	3	3	1
CO4	1	1	2	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Conventional Vehicle, Basics of Vehicle Performance, History of Electric Vehicles, Social and Environmental Importance of Electric Vehicles, Impact of Modern Drivetrains on Energy Supplies.

Hybrid Electric Vehicles: Micro Hybrid Vehicles, Mild Hybrid Vehicles, Full Hybrid Vehicles, Parallel Hybrid Vehicles, Series Hybrid Vehicles, Series-Parallel Hybrid Vehicles, Plug-in Hybrid Vehicles, Power Flow Diagrams for Various Operating Modes. Plug-in Hybrid Vehicles: Operating Principle, Architectures: Series-Parallel-Series-Parallel, Challenges Related to Grid Connection. Range-Extended Electric Vehicles: Classification and Configurations, Fuel Cell Electric Vehicles, Solar Electric Vehicles, Electric Bi-Cycles and Their Propulsion Systems, Vehicle-to-Grid, Vehicle-to-Home Concepts, Concept of Hybrid Electric Vehicles.

Electric Drive-Trains: Basic Concept of Electric Traction, Introduction to Various Electric Drivetrain Topologies, Power Flow Control in Electric Drive-Train Topologies, Fuel Efficiency Analysis.

Electric Propulsion Unit: Electric Components Used in Electric Vehicles, Configuration and Control of DC Motor Drives, Induction Motor Drives, Permanent Magnet Motor Drives, Switch Reluctance Motor Drives, Drive System Efficiency.

Energy Storage: Storage Requirements for Electric Vehicles, Battery Based Energy Storage, Fuel Cell Based Energy Storage, Super Capacitor Based Energy Storage and Their Analysis. Power Pack Management Systems, Cell Balancing Techniques, Flywheel Based Energy Storage and Its Analysis, Hybridization of Different Energy Storage Devices, Compressed Air

Storage Systems, Super Conducting Magnetic Storage Systems and Energy Management Systems.

Converters for Hybrid Energy Storage Systems: Converter Configurations for Hybrid Energy Systems Based on Battery and Ultra Capacitors-Cascaded Converter, Multiple Parallel Connected Converter, Dual-Active-Bridge Converter, Multiple-Input Converter,- Multiple Modes Single Converter, Interleaved Converter, Switched Capacitor Converter, Converters for Coupled Inductor Based Hybridization. Fundamentals of Chargers: Charger Classifications and Standards, Selection of AC Charging Systems, DC Charging Systems, Converter Topologies for Charging, Wireless Chargers.

Learning Resources:

Text Books:

1. Advanced Electric Drive Vehicles, Ali Emadi, CRC Press, Taylor & Francis Group, 2015.
2. Electric and Hybrid Vehicles: Design Fundamentals, Iqbal Hussein, CRC Press, 2003, 2nd Edition.

Reference Books:

1. Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, Mehrdad Ehsani, Yimi Gao, Sebastian E. Gay, Ali Emadi, CRC Press, 2005.
2. Electric Vehicle Technology Explained, James Larminie, John Lowry, Wiley, 2003.

Online Resources:

1. Fundamentals of Electric vehicles: Technology & Economics, NPTEL Course (Link: https://nptel.ac.in/courses/108/106/108106170/)
2. Electric Vehicles - Part 1, NPTEL Course (Link: https://nptel.ac.in/courses/108/102/108102121/)

Course Code: EE 5301	ELEMENTS OF SMART GRID SYSTEM	Credits 3-0-0: 3

Pre-requisites: Basics in power systems

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

CO1	Understand the features of smart grid.
CO2	Assess the role of automation and digitization in transmission and distribution.
CO3	Analyse Smart grids and Distributed Energy Resources (DER) with evolutionary Algorithms.
CO4	Investigate operation and the importance of data acquisition devices and their location for voltage and frequency control.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	1	1	1	1
CO3	1	1	1	2	3	1
CO4	1	1	1	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Smart Grid: Basics of Power Systems, Definition of Smart Grid, Need for Smart Grid, Smart Grid Domain, Enablers of Smart Grid, Smart Grid Priority Areas, Regulatory Challenges, Smart-Grid Activities in India.

Smart Grid Architecture: Smart Grid Architecture, Standards-Policies, Smart-Grid Control Layer and Elements, Network Architectures, IP-Based Systems, Power Line Communications, Supervisory Control and Data Acquisition System, Advanced Metering Infrastructure. the Fundamental Components of Smart Grid Designs, Transmission Automation, Distribution Automation, Renewable Integration.

Tools and Techniques for Smart Grid: Computational Techniques, Static and Dynamic Optimization Techniques for Power Applications Such as Economic Load Dispatch, Computational Intelligence Techniques – Evolutionary Algorithms in Power System, Artificial Intelligence Techniques and Applications in Power System.

Distribution Generation Technologies: Introduction to Distribution Energy Sources, Renewable Energy Technologies, Microgrids, Storage Technologies, Electric Vehicles and Plug – in Hybrids, Environmental Impact and Climate Change, Economic Issues.

Communication Technologies in Smart Grid: Introduction to Communication Technology, Two Way Digital Communications Paradigm, Synchro- Phasor Measurement Units (PMUS), Wide Area Measurement Systems (WAMS), Introduction to Internet of Things (IoT), Applications of IoT in Smart Grid.

Smart-Cities: Smart City Pilot Projects, Essential Elements of Smart Cities, Active Distribution Networks, Microgrids, Distribution System Automation, Reliability and Resiliency Studies, Decentralized Operation of Power Network.

Learning Resources:

Text Books:

1. Smart Grids, Infrastructure, Technology and Solutions, Borlase, S., CRC Press, 2013, 1st Edition.
2. Renewable and Efficient Electric Power System, Masters, G., Wiley–IEEE Press, 2013, 2nd Edition.

Reference Books:

1. Synchronized Phasor Measurements and their Applications, Phadke, A. G., Thorp, J. S., Springer, 2017, 2nd Edition.
2. Wind Power in Power Systems, Ackermann, T., Hoboken, N. J., John Wiley, 2012, 2nd Edition.

Course Code: ME 5513	ALTERNATE FUELS AND EMISSIONS	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Understand the need of alternate fuels.
CO2	Evaluate the performance of the engine with alternate fuels and blends with petroleum derived fuels.
CO3	Examine the viable production and storage methods of alternate fuels.
CO4	Measure the pollutant emissions as per standards and describe emission control methods.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	2	1	1	1
CO2	1	1	2	3	2	1
CO3	1	1	2	3	3	1
CO4	1	1	2	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Present Energy Scenario (Worldwide and India), Statistics of Petroleum Fuels-Liquid and Gaseous Fuels in Automobiles, Problems with Highly Exploited Petroleum Derived Fuels, Desirable Properties of a Good Alternate Fuel, Availability and Properties of Alternate Fuels, ASTM Standards.

Alcohols: General Use of Alcohols, Thermo-Combustion Properties as Engine Fuel, Gasolene and Alcohol Blends, Production Methods of Widely Used Alcohols, Performance in SI and CI Engines, Methanol and Ethanol and Gasolene/Diesel Blends Combustion Characteristics in Engine, Emission Characteristics, Modification Required to Operate with Alcohols and Its Blends with Petrol and Diesel, Brief Details of Flexi Fuel Engines(FFE), Use of Higher Alcohols.

Natural Gas, LPG: Use of Natural Gas as CNG and LNG, Availability of CNG and LNG, Properties and Modification Required to Use in Engines, Performance and Emission Characteristics of CNG Using LPG in SI & CI Engines, Production and Storage of CNG/LNG.

Biogas: Production Methods of Biogas, Properties of Biogas as a Fuel, Performance and Emission Characteristics of Engine with Biogas and Its Blends with Petrol/Diesel, Brief Information on Compressed biogas and Its Storage.

Vegetable Oils: Characteristics of Vegetable Oils as Alternate Fuel, Edible and Non-Edible Vegetable Oils, Conversion of Vegetable Oils into Diesel Like Fuel (Biodiesel) - Esterification, Blending and Micro-Emulsions: Performance and Emission Characteristics of Engines with Biodiesel and Blends-B20.

Hydrogen: Suitable Characteristics of Hydrogen Fuel, Hydrogen Production Methods, Storage of Hydrogen, Use of Hydrogen as Fuel in Engines, Hydrogen in Fuel Cells.

Engine Emissions: Harmful Effects of Engine Out Emissions, Mechanism of Formation of Pollutant Emissions Such as Carbon Monoxide, Unburned Hydrocarbons, Oxides of Hydrogen and Aldehydes.

Emission Measurement and Control Methods: Measurement of Pollutants Using Flame Ionization Detection, NDIR, Chemiluminescent Analyzer and Particulate Matter (Soot/Smoke), Emission Norms-EURO and Bharat Stage Engine Emission, Control Methods: in Cylinder and After Treatment Methods.

Learning Resources:

Text Books:

1. Alternative Transportation Fuels: Utilisation in Combustion Engines, M. K. Gajendra Babu, K. A. Subramanian CRC Press, 2013
2. Alternative Fuels and Their Utilization Strategies in Internal Combustion Engines, Akhilendra Pratap Singh, Yogesh C. Sharma, Nirendra N. Mustafi, Avinash Kumar Agarwal, Springer 2020.

Reference Books:

1. Engine Emissions: Pollutant formation and advances in control Technology, Norbe Pundir B. P., Narosa Publishing House, 2013.
2. Alternative Fuels for Transportation, Ramadhas, A. S., CRC Press 2012.

Online Resources:

1. IC Engines: Combustion and Emissions, NPTEL Course (Link: https://nptel.ac.in/courses/112/104/112104033/)

Course Code: ME 5112	POWER PLANT ENGINEERING	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Apply the principles of thermodynamics to analyse the performance of steam, gas, combined and nuclear power plants
CO2	Design and develop power plant components for optimum performance
CO3	Select appropriate site and technology for power plants
CO4	Evaluate economic and environmental implications on power plants.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	2	1
CO2	1	1	2	3	3	1
CO3	1	1	1	2	2	1
CO4	1	1	2	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Energy Resources and Their Availability, Types of Power Plants, Selection of the Plants, Review of Basic Thermodynamic Cycles Used in Power Plants.

Steam Power Plants: Flow Sheet and Working of Modern-Thermal Power Plants, Site Selection, Plant Efficiency

Steam Generators and Their Accessories: High Pressure Boilers, Design of Accessories, Steam Generator Control, Draught System.

Fuel and Combustion: Coal Storage and Preparation, Coal Handling Systems, Coal Combustion, Mass and Energy Balance of Steam Generator, Feeding and Burning of Pulverized Fuel, Fluidized Bed Combustion System, Ash Handling Systems, Dust Collection - Mechanical Dust Collector and Electrostatic Precipitator.

Condensers: Direct Contact Condenser, Surface Condensers, Effect of Various Parameters on Condenser Performance, Design of Condensers, Cooling Towers and Cooling Ponds

Combined Cycles: Gas Turbine Power Plants, Arrangements of Combined Plants (Steam & Gas Turbine Power Plants), Parameters Affecting Thermodynamic Efficiency of Combined Cycles, Integrated Gasification Combined Cycle, PFBC Based Combined Cycle, Re-Powering of Thermal Power Plant.

Nuclear Power Plants: Principles of Nuclear Energy, Basic Nuclear Reactions, Nuclear Cross section, Different Components of Nuclear Power Station, PWR, BWR, CANDU, Liquid Metal Cooled, Gas Cooled, Fast Breeder, Nuclear Waste Disposal.

Non-Conventional Energy Generation: Geothermal Power Plant, Tidal and Wave Power Plant, Solar Power Plant, Wind Power Generation, Direct to Electricity Method - Magneto-Hydrodynamic (MHO) Power Generation

Hydroelectric Power Plants: Rainfall and Run-Off Measurements and Plotting of Various Curves for Estimating Stream Flow and Size of Reservoir, Comparison with Other Types of Power Plants.

Power Plant Economics: Load Curve, Different Terms and Definitions, Base Load and Peak Load Plants, Energy Storage, Cost of Electrical Energy, Tariffs, Methods of Electrical Energy, Performance & Operating Characteristics of Power Plants - Incremental Rate Theory, Input-Output Curves, Efficiency, Heat Rate, Economic Load Sharing, Problems.

Learning Resources:

Text Books:

1. Power Plant Engineering, Nag, P. K., McGraw Hill Education; 2017,4th Edition.

Reference Books:

1. Power Plant Engineering, Sharma, P. C., S.K. Kataria & Sons, New Delhi, 2010.

Online Resources:

1. NOC: Power Plant Engineering, NPTEL Course (Link: https://nptel.ac.in/courses/112/107/112107291/)

Course Code: ME 5113	RENEWABLE SOURCES OF ENERGY	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Identify the renewable energy sources, their utilization and storage.
CO2	Understand the basic concepts of the solar radiation and analyze the solar thermal systems for their utilization.
CO3	Understand the principle of working of solar cells and their modern manufacturing techniques.
CO4	Analyze wind energy, biomass and Fuel cell systems and their applications.
CO5	Design of solar thermal and energy storage systems for specific applications.
CO6	Evaluate the energy conversion from ocean thermal energy, geothermal energy, biomass and magneto hydrodynamic power generation.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	2	1
CO2	1	1	1	2	2	1
CO3	1	1	1	3	2	1
CO4	1	1	2	3	3	1
CO5	1	1	2	3	3	1
CO6	1	1	3	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Overview of the Course, Examination and Evaluation Patterns. Classification of Energy Resources, Environmental Aspects of Energy – Global Warming & Climate Change – Role of Renewables, Energy-Environment-Economy, Energy Scenario in the World and India, Thermodynamics of Energy Sources – A Brief Review.

Energy Storage: Necessity for Energy Storage. Classification of Methods of Energy Storage. Thermal Energy Storage; Sensible Heat Storage, Latent Heat Storage., Mechanical Energy Storage: Pumped Hydel Storage, Compressed Air Storage and Flywheel Storage, Reversible Chemical Reaction Storage. Electromagnetic Energy Storage. Hydrogen Energy Storage. Chemical Battery Storage.

Basic Sun-Earth Relationships: Definitions. Celestial Sphere, Altitude-Azimuth, Declination Hour Angle and Declination-Right Ascension Coordinate Systems for Finding the Position of the Sun, Celestial Triangle and Coordinates of the Sun. Greenwich Mean Time, Indian Standard Time, Local Solar Time, Sunrise and Sunset Times & Day Length.

Solar Radiation: Nature of Solar Radiation, Solar Radiation Spectrum, Solar Constant, Extraterrestrial Radiation on a Horizontal Surface, Attenuation of Solar Radiation, Beam, Diffuse and Global Radiation. Measurement of Global, Diffuse and Beam Radiation. Prediction

of Solar Radiation; Angstrom Model, Page Model, Hottel's Model, Liu and Jordan Model Etc. Insolation on an Inclined Surface, Angle of Incidence.

Solar Thermal Systems: Principle of Working of Solar Water Heating Systems, Solar Cookers, Solar Desalination Systems, Solar Ponds, Solar Chimney Power Plant, Central Power Tower Power Plants Etc. Classification of Solar Concentrators, Basic Definitions Such as Concentration Ratio, Angle of Acceptance Etc., Tracking of the Sun; Description of Different Tracking Modes of Solar Collectors and the Determination of Angle of Incidence of Insolation in Different Tracking Modes, Concept of Green Building and Associated Design Parameters.

Photovoltaic Energy Conversion: Introduction. Single Crystal Silicon Solar Cell, I-V Characteristics, Effect of Insolation and Temperature on the Performance of Silicon Cells. Different Types of Solar Cells. Modern Technological Methods of Producing These Cells. Indian and World Photovoltaic Energy Scenario. Solar Cell, Module, and Array Construction, Maximizing the Solar PV Output and Load Matching.

Wind Energy: Origin of Winds, Nature of Winds, Wind Data Measurement, Variation of Wind Speed with Height, Basics of Fluid Mechanics, Estimation of Wind Energy at a Site: Betz's Law, Wind Turbine Aerodynamics, Wind Turbine Types and Their Construction, Wind-Diesel Hybrid System, Environmental Aspects, Wind Energy Storage, Wind Energy Programme in India and the World.

Fuel Cells: Introduction, Applications, Classification, Different Types of Fuel Cells Such as Phosphoric Acid Fuel Cell, Alkaline Fuel Cell, PEM Fuel Cell, MC Fuel Cell. Thermodynamic Analysis of Fuel Cells, Development and Performance Fuel Cells.

Biomass: Introduction, Photosynthesis, Biofuels, Biomass Resources, Biomass Conversion Technologies, Urban Waste to Energy Conversion, Biomass to Ethanol Conversion, Biomass Energy Scenario in India, Biogas Production, Constant Pressure and Constant Volume Biogas Plants, Operational Parameters of the Biogas Plant, Design of Bio-Digester, Energy Farming

Other Forms of Energy: Ocean Energy: Ocean Thermal Energy; Open Cycle & Closed Cycle OTEC Plants, Environmental Impacts, Challenges, Present Status of OTEC Systems. Ocean Tidal Energy; Single Basin and Double Basin Plants, Their Relative Merits. Ocean Wave Energy; Basics of Ocean Waves, Different Wave Energy Conversion Devices, Relative Merits.

Geothermal Energy: Origin, Applications, Types of Geothermal Resources, Relative Merits.

Magneto Hydrodynamic Power Generation: Applications; Origin and Their Types; Working Principles.

Learning Resources:

Text Books:

1. Non-conventional Energy Resources, Khan, B. H., Tata McGraw Hill, New Delhi, 2017, 3rd edition
2. Energy Technology: Non-Conventional, Renewable and Conventional, Rao, S., Parulekar, B. B., Khanna Publishers, 2010, 1st Edition.

Reference Books:

1. Solar Energy-Principles of Thermal Collection and Storage, Sukhatme, S. P., Nayak, J. K., TMH, 2010, 3rd Edition (6 reprint).
2. Solar Energy Thermal Processes, Duffie, J. A., Beckman, W. A., John Wiley, 2013, 4th Edition.

Online Resources:

1. Non-conventional Energy Resources, NPTEL Course (Link: https://nptel.ac.in/courses/121/106/121106014/)

Course Code: CS 5106	MACHINE LEARNING	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Construct prediction models for statistical data.
CO2	Design Multi-Layer neural network to solve Supervised Learning problems.
CO3	Classify non-linear data like face recognition, disease prediction.
CO4	Apply Genetic Algorithm for optimization problems.
CO5	Design applications like games and agent-based controllers.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	2	1
CO2	1	1	1	1	2	1
CO3	1	1	1	1	1	1
CO4	1	1	3	3	3	1
CO5	1	1	2	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Machine Learning: Issues Related to Machine Learning, Pre-Processing, Inductive Bias, Variance, Feature Extraction, Feature Selection Techniques, Different Types of Learning, Training and Testing, Hypothesis and Cost Function.

Mathematics for Machine Learning: Classification Techniques, Decision Trees (DT) - Construction of Decision Trees Using Different Algorithms, Regression Tree, Tree Pruning, Rule Extraction from Trees, Multivariate Trees. Ensemble Learning: Bagging and Boosting and Different Techniques of Bagging and Boosting.

Artificial Neural Networks (ANN): Different Learning Rules, Single-Layer Perceptron, Multi-Layer Neural Nets, Backpropagation Algorithm, Feed-Forward Networks, Network Training, Radial Basis Function Networks, Recurrent Neural Networks. Bayesian Learning: Probabilistic Reasoning: Prior, Likelihood and Posterior, Belief Networks: Modeling Independencies, Markov Equivalence in Belief Networks, Hidden Markov Models (HMM). Naïve Bayes Classifier, Learning with Hidden Variables, Expectation Maximisation (EM).

Genetic Algorithms: An Illustrative Example, Hypothesis Space Search, Genetic Programming, Models of Evolution and Learning. Instance-Based Learning: Nearest-Neighbour Classification, Condensed-Neighbour Classification. Unsupervised Linear Dimensionality Reduction: Principal Component Analysis (PCA), PCA Vs Singular Value Decomposition, Working on High-Dimensional Data, Latent-Semantic Analysis: Information Retrieval. Supervised Linear Dimensionality Reduction: Fisher's Linear Discriminant. Kernel Methods: Dual Representations, Kernel Construction, Learning with Hyperparameters, Support Vector Machines (Maximum Margin Classifier), Linear and Multiclass SVMS.

Reinforcement Learning: The Learning Task, Q Learning, Nondeterministic Rewards and Actions, Temporal Difference Learning, Generalizing from Examples, Relationship to Dynamic Programming.

Learning Resources:

Text Books:

1. Machine Learning, Tom M. Mitchell, Mc Graw Hill Education, 2017.
2. Pattern Recognition and Machine Learning, Bishop, C. M., Springer Link, 2006.

Course Code: CS 5119	ADVANCED ARTFICIAL INTELLIGENCE	Credits 3-0-0: 3

Pre-requisites: None

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

CO1	Solve searching problems using A*, Mini-Max algorithms.
CO2	Create logical agents to do inference using first order logic.
CO3	Use Bayesian learning for classification problems.
CO4	Understand different phases of Natural Language Processing.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	2	1
CO2	1	1	1	1	2	1
CO3	1	1	1	1	2	1
CO4	1	1	2	1	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Agents and Objects, Evaluation of Agents, Agent Design Philosophies, Multiagent System, Mobile Agents, Agent Communication, Knowledge Query and Manipulation Language. What is AI? The Foundations of Artificial Intelligence.

Intelligence Agents: Agents and Environments, Good Behavior: The Concept of Rationality, The Nature of Environments, Structure of Agents.

Solving Problems by Search: Problem-Solving Agents, Formulating Problems, Searching for Solutions, Uninformed Search Strategies, Breadth-first Search, Depth-first Search, Searching with Partial Information, Informed (Heuristic) Search Strategies, Greedy Best-first search, A* Search: Minimizing the Total Estimated Solution Cost, Heuristic Functions, Local Search Algorithms and Optimization Problems, Online Search Agents and Unknown Environments.

Inference in First Order Logic: Syntax and Semantics of First-Order Logic, Using First-Order Logic, Knowledge Engineering in First-Order Logic; Propositional vs. First-Order Inference, Unification and Lifting, Forward Chaining, Backward Chaining, Resolution.

Symbolic Reasoning Under Uncertainty: Introduction to Nonmonotonic Reasoning, Logics for Nonmonotonic Reasoning, Implementation Issues, Bayesian Learning – Bayes theorem, Concept Learning, Bayes Optimal Classifier, Naïve Bayes Classifier, Bayesian Belief Networks, EM Algorithm.

Natural Language Processing: Phrase Structure Grammars, Syntactic Analysis (Parsing), Augmented Grammars and Semantic Interpretation, Machine Translation, Speech Recognition.

Learning Resources:

Text Books:

1. Machine Learning, Tom M. Mitchell, McGraw Hill Education, 2017.
2. Pattern Recognition and Machine Learning, Bishop, C. M., Springer Link, 2006.
3. Artificial Intelligence: A Modern Approach, Stuart Russell, Peter Norvig, Pearson, 2010, 3rd Edition.
4. Artificial Intelligence, Kevin Knight, Elaine Rich, Nair, B., McGraw Hill, 2017, 3rd Edition.

Elective Courses offered in Second Semester

Course Code: CH 5361	ENERGY STORAGE SYSTEMS	Credits 3-0-0: 3

Pre-Requisites:

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the fundamental concepts of energy storage systems.
CO2	Differentiate thermal energy storage systems.
CO3	Analyze the utilization of kinetic energy and potential energy storage.
CO4	Analyze different hydrogen storage methods.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	1	1	2	3
CO2	3	2	1	1	2	3
CO3	3	2	1	1	2	3
CO4	3	2	1	1	2	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Introduction to Energy Storage Systems, General Concepts, Importance of Energy Storage in Renewable Energy Systems, Storage in the Fuel Distribution System, General Concepts, Mechanical Equivalent of Heat, First Law of Thermodynamics-Conservation of Energy, Enthalpy, Entropy, Energy Available to do Work, Temperature Dependence of G, H and S, Reversible and Irreversible Storage Modes, Outlook on the Advancement of Energy Storage Systems.

Thermal Energy Storage: Introduction to Thermal Energy Storage, Sensible Heat, Latent Heat, Quasi Latent Heat, and Heat Pumps.

Mechanical Energy Storage: Potential Energy Storage, Energy Storage in Pressurized Gas, Potential Energy Storage using Gravity, Hydroelectric Power, Pumped-Hydro Storage, Use of Kinetic Energy in Moving Water, and Kinetic Energy in Mechanical Systems.

Electrochemical Energy Storage: Electrochemical Energy Storage, Major Types of Reaction Mechanisms in Electrochemical Cells (Formation, Displacement, and Insertion reactions), Important parameters (Operation voltage, Energy Quality, Chrge Capacity, Theoretical Specific Energy, Cyclic Behavior, Self-discharge, Energy Storage in Batteries (Primary Batteries, Lead-Acid Batteries, Lithium-ion batteries), Energy Storage in Capacitors (Double Layer Capacitors and Pseudocapacitors).

Hydrogen Storage: Production of Hydrogen, Storage of Gaseous Hydrogen in High-Pressure Tanks, Storage of Liquid Hydrogen in Insulated Tanks, Storage of Hydrogen as Protons in Solids: Metal Hydrides, Other Approaches to Hydrogen Storage.

Learning Resources:

Text Books:

1. Energy Storage: Fundamentals, Materials and Applications, Huggins, R. A., Springer, 2016.
2. Electrochemical Energy Systems - Foundations, Energy Storage and Conversion, Braun, A., de Gruyter, 2018.

Reference Books:

1. Energy Storage: Systems and Components, Rufer, A., CRC Press, 2017.
2. Handbook of Energy Storage: Demand, Technologies, Integration, Sterner, M., Stadler, I., Springer, 2019.
3. Classification of Energy Storage Systems. in Future Grid-Scale Energy Storage Solutions, Arabkoohsar, A., Academic Press, 2023.
4. Electrochemical Energy Storage - Physics and Chemistry of Batteries, Job, R., De Gruyter, 2020.

Course Code: CH 5362	ENERGY, WATER AND FOOD NEXUS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the concept of the Energy-Water-Food Nexus and its importance.
CO2	Analyse the interactions within the Energy-Water-Food Nexus and investigate the emerging paradigm.
CO3	Evaluate the energy and water use in agriculture for food production and security.
CO4	Explore the models and tools used to operationalize the Energy-Water-Food Nexus.
CO5	Assess water, energy, and carbon footprints using relevant case studies.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	2	2	2	1
CO3	1	1	2	2	2	1
CO4	1	1	2	2	3	1
CO5	1	1	1	1	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to the Energy-Water-Food Nexus: The Need for the Nexus Approach, Evolution of the Nexus as a Policy and Development Discourse, The Nexus Contribution to Better Water Management and Its Limitations, Dynamic and Cross Sectoral Analyses of the Water-Energy-Food Nexus, Investigating an Emerging Paradigm, Importance and Relevance of the Nexus in Addressing Global Challenges, Key Principles and Concepts Related to the Nexus.

Energy-Water Interactions: Energy Production and Its Impact on Water Resources, Water Use in Energy Production, The Role of Water in Unconventional in Situ Energy Resource Extraction Technologies, Water Management in Unconventional Oil and Gas Development, Coal Use as a Cause of Water Quality, Water-Energy Efficiency and Conservation Measures.

Water-Food Interactions: Water Use in Agriculture, Water Scarcity and Its Impact on Food Production and Security, Sustainable Water Management Practices in Agriculture.

Energy-Food Interactions: Energy Requirements in the Food Supply Chain, Renewable Energy Applications in the Food Sector, Energy-Efficient Technologies for Food Production.

Operationalizing the Nexus: Modelling the Water Energy Food Nexus, Water Energy Food Nexus: Selected Tools and Models in Practice, Governing for the Nexus - Empirical, Theoretical, and Normative Dimensions; the Role of International Cooperation in Operationalizing the Nexus in Developing Countries, Emerging Lessons of the Nexus Observatory.

Nexus in Practice – Case Studies: The Water, Energy and Food Nexus from a South African Perspective, Water, Energy and Food Nexus - Examples from the USA, Water, Energy, and Food Security Nexus in the West Asian Region; Assessment of Water, Energy, and Carbon Footprints of Crop Production- Case Studies.

Learning Resources:

Text Books:

1. Water-Energy-Food nexus: Principles and Practices, Salam, P. A., Shrestha, S., Pandey, V. P., Anal, A. K., John Wiley & Sons, 2017.
2. Food, Energy, and Water: The Chemistry Connection, Ahuja, S., Elsevier, 2015.
3. The Water–Food–Energy Nexus: Power, Politics, and Justice, Allouche, J., Middleton, C., Gyawali, D., Routledge – Taylor & Francis Group, 2019.

Reference Books:

1. The Water-Food-Energy Nexus: Processes, Technologies, and Challenges, Mujtaba, I. M., Srinivasan, R., Elbashir, N. O., CRC Press, 2017.
2. The Water, Food, Energy and Climate Nexus: Challenges and an Agenda for Action, Dodds, F., Bartram, J., Routledge, 2016.
3. Unfolding Food, Energy, and Water Nexus. in Food, Energy, and Water Nexus: A Consideration for the 21st Century, Ray, C., Muddu, S., Sharma, S., Cham: Springer International Publishing, 2022.

Course Code: CH 5363	SUPERCAPACITORS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the basic concepts of supercapacitors.
CO2	Learn the design considerations for the fabrication of supercapacitors.
CO3	Evaluate the supercapacitor performance.
CO4	Select a suitable supercapacitor for specific application.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	2	-	-	2
CO2	3	2	2	3	-	2
CO3	3	2	2	-	-	2
CO4	3	2	2	-	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Basic Concepts of Electric Capacitors: Electric Charge, Electric Field, and Electric Potential and their Implications for Capacitor Cell Voltage, Capacitance Definition, and Calculation, Capacitor Charging and Recharging Processes, Energy Storage in Capacitors, Types and Structures of Capacitors.

Fundamentals of Electrochemical Double-Layer Supercapacitors and Pseudocapacitors: Electrochemical Double-Layer Supercapacitor Electrode and Electrolyte Interfaces and their Capacitances, Electrode Potential Windows Using Different Electrode Materials and Electrolytes. Capacitances of Porous Carbon Materials. Electrochemical Pseudocapacitance of Electrode and Electrolyte Interfaces, Electrochemical Impedance Spectroscopy and Equivalent Circuits, Energy and Power Densities of Electrochemical Supercapacitors.

Components and Materials for Electrochemical Supercapacitors: Electrode Requirements for Electrochemical Supercapacitors, EDLC Electrode Materials, Pseudocapacitive Materials, Asymmetric Structures, Electrolyte Structures and Materials, Separator Structures, Current Collectors and Sealants.

Electrochemical Supercapacitors Design, Fabrication, and Operation: Design Considerations, Single Cell Manufacturing, Supercapacitor Stack Manufacturing and Construction, Voltage Cell Balancing, Cell Aging and Voltage Decay, Self-Discharging, Major Commercial ES Products.

Applications of Electrochemical Supercapacitors, Perspective, and Challenges: Power Electronics, Memory Protection, Battery Enhancement, Portable Energy Sources, Power Quality Improvement, Adjustable Speed Drives, High Power Sensors and Actuators, Hybrid Electric Vehicles, Renewable and Off-Peak Energy Storage, and Military and Aerospace Applications, Market Challenges, Electrode Material Challenges, Electrolyte Innovations, Development of Computational Tools, Future Perspectives.

Learning Resources:

Text Books:

1. Electrochemical Supercapacitors for Energy Storage and Delivery: Fundamentals and Applications, Aiping Yu, Victor Chabot, Jiujun Zhang, CRC Press, 2017, 1st Edition
2. Electrochemical Supercapacitors Scientific Fundamentals and Technological Applications, Conway, B.E., Kluwer Academic / Plenum Publishers 1999, 1st Edition.

Reference Books:

1. Supercapacitors: Materials, Systems, and Applications, François Béguin, Elżbieta Frąckowiak, Wiley, 2013.
2. The Handbook of Lithium-Ion Battery Pack Design: Chemistry, Components, Types and Terminology, Warner, J. T., Elsevier, 2015.

Course Code: CH 5364	ENERGY TECHNOLOGIES FOR SUSTAINABLE TRANSPORTATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the principles and concepts of sustainable transportation and its role in mitigating environmental impacts.
CO2	Evaluate the technical aspects, performance characteristics, and limitations of different energy technologies for transportation.
CO3	Examine the infrastructure requirements and challenges related to the implementation of energy technologies for sustainable transportation.
CO4	Assess the challenges and opportunities associated with the integration of renewable energy sources in transportation systems.
CO5	Understand the policy and regulatory frameworks supporting the adoption and deployment of sustainable transportation technologies.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	1	2	3	2	1
CO2	-	1	2	3	2	1
CO3	-	1	2	3	2	1
CO4	-	1	2	3	2	1
CO5	-	1	2	3	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Sustainable Transportation: Overview of Sustainable Transportation and Its Importance in Mitigating Environmental Impacts, Key Concepts, Goals, and Challenges of Sustainable Transportation.

Alternative Fuels for Transportation: Introduction to Alternative Fuels, Biodiesel, Ethanol, Methanol, Dimethyl Ether, Natural Gas, LPG, CNG, Hydrogen.

Electric Vehicles: Technology and Design Principles of Electric Vehicles, Battery Technologies, Charging Infrastructure, and Range Considerations.

Hybrid Electric Vehicles: Principles of Hybrid Electric Vehicle (HEV) Technology, HEV Configurations, Energy Management Systems, and Efficiency Analysis.

Fuel Cell Vehicles: Introduction to Fuel Cell Vehicles (FCVs) and Hydrogen as a Fuel Source, Fuel Cell Technologies, Hydrogen Infrastructure, and Challenges for FCVs.

Sustainable Infrastructure for Transportation: Planning and Design Considerations for Sustainable Transportation Infrastructure; Integration of Charging Stations, Hydrogen Re-Fuelling Stations, and Alternative Fuel Infrastructure.

Future Fuels and Challenges: Discussion on the Future of Energy Technologies for Sustainable Transportation, Addressing Challenges and Barriers to Widespread Adoption and Implementation.

Learning Resources:

Text Books:

1. Alternative Fuels for Transportation, Ramadhas, A. S., Simon Thamburaj, Saravanan, R., CRC Press, 2011.
2. Introduction to Sustainable Transportation: Policy, Planning, and Implementation, Preston L. Schiller, Eric C. Bruun, Jeffrey R. Kenworthy, Earthscan, 2010
3. Hybrid Electric Vehicles: Principles and Applications with Practical Perspectives, Chris Mi, Abul Masrur M., Wiley, 2017.
4. Hydrogen and Fuel Cells: Emerging Technologies and Applications, Bent Sørensen, Academic Press, 2005.

Reference Books:

1. Sustainable Energy and Transportation Technologies and Policy, Anirudh Gautam, Sudipta De, Atul Dhar, Jai Gopal Gupta, Ashok Pandey, Springer, 2018

Course Code: CH 5365	MODELLING AND ANALYSIS OF PROCESS AND ENERGY SYSTEMS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the fundamental concepts of linear algebra.
CO2	Analyze and solve ordinary and partial differential equations using suitable techniques and approaches.
CO3	Develop mathematical models and perform analysis for process and energy systems.
CO4	Utilize computer-aided tools and techniques to solve mathematical models.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	1	1
CO2	1	1	2	1	2	1
CO3	1	1	3	3	3	1
CO4	1	1	3	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Linear Algebra: Linear Spaces, Vector Spaces, Function Spaces, Linear Operator Theory, Self-Adjoint Operators, Eigenvalues and Eigenvectors-Eigenfunctions; Review of Linear and Nonlinear Ordinary Differential Equations Solution Methods, Partial Differential Equations.

Modelling of Energy Systems: Classification of Models for Process and Energy Systems, Problem Formulation, Thermal Modelling and Analysis, Computer-Aided Solutions of Process Material Balances: The Sequential and Simultaneous Solution Approaches, Process Energy Balances, Advanced Thermal Models, Combined Thermal, Economic, and Environmental Models, Soft Computing and Statistical Tools for Developing Analytical Models.

Case Studies: Gas Turbine Cogeneration System Performance and Design Calculations, Design and Operation of PV Systems, Design of Solar Thermal Systems.

Learning Resources:

Text Books:

1. Introduction to Applied Mathematics, Gilbert Strang, Wellesley Cambridge Press. 2009.
2. Linear Algebra and Its Applications, Gilbert Strang, Wellesley Cambridge Press, 2009, 4th Edition.
3. Applied Numerical Methods, Gourdin, a., Boumhrat, M., Prentice Hall India, 2000.
4. Modeling, assessment, and optimization of Energy Systems, Sayyaadi, H., Academic Press, 2020.
5. Modeling, analysis and optimization of process and energy systems, Knopf, F. C., John Wiley & Sons, 2011.
6. Energy Systems Engineering: Evaluation and Implementation, Vanek, F. M., Albright,

L. D., Angenent, L. T., McGraw-Hill Education, 2016.

Reference Books:

1. Renewable Energy Systems: The Choice and Modeling of 100% Renewable Solutions, Lund, H., Academic Press, 2009.
2. Exergy, Energy System Analysis and Optimization-Volume III: Artificial Intelligence and Expert Systems in Energy Systems Analysis Sustainability Considerations in the Modeling of Energy Systems (Vol. 3), Frangopoulos, C. A., EOLSS Publications, 2009.

Course Code: CH 5366	SUSTAINABLE RECYCLING OF ENERGY MATERIALS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the importance of recycling in the context of energy materials and their impact on sustainable energy systems.
CO2	Analyze the composition, recyclability, and challenges associated with energy materials.
CO3	Select material recovery techniques and recycling technologies specific to energy materials.
CO4	Gain knowledge of policy frameworks, regulations, economic considerations, and market opportunities relevant to energy material recycling.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	2	1	1
CO2	2	2	2	2	1	1
CO3	2	2	2	2	2	1
CO4	2	2	2	2	2	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Recycling of Energy Materials: Definition and Significance of Recycling in the Energy Sector, Environmental Benefits of Recycling Energy Materials, Overview of Energy Materials used in Solar, Wind, Fuel Cells, Secondary Batteries, Flow Batteries, And Supercapacitors, Analysis of Material Composition and Recyclability.

Material Recovery Techniques for Energy Materials: Mechanical Recycling Methods for Energy Materials, Chemical Processes for Material Recovery and Recycling, Electro Winning and Electro Refining, Challenges in Identifying and Separating Different Energy Materials, Contamination and Impurities Affecting Recycling Processes.

Recycling Technologies for Specific Energy Materials: Recycling Processes and Considerations for Solar Energy Materials, Wind Energy Materials, Recycling Techniques: Chemical Leaching, Electrochemical Recovery, Solvent Extraction, Precipitation. Hydrometallurgical Processes, Ion Exchange, Supercritical Fluid Extraction, Plasma Smelting.

Policy, Regulation, and Economic Aspects of Energy Material Recycling: National and International Policies Promoting Recycling and Waste Management, Regulations Specific to Energy Material Recycling, Economic Considerations for Energy Material Recycling Businesses, Market Potential and Growth Opportunities in the Recycling Sector, Environmental Impacts and Future Trends in Energy Material Recycling.

Evaluation of the Environmental Impacts and Sustainability Considerations: Life Cycle Assessments for Energy Material Recycling Processes, Analysis of Effective Recycling

Initiatives in the Energy Sector, Advancements in Recycling Technologies and Processes, Integration of Renewable Energy Systems with Material Recycling, Strategies for Improving Energy Material Recycling Rates and Recommendations for Efficient Recycling Practices.

Learning Resources:

Text Books:

1. Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists, Worrell, E., Reuter, M. A., Newnes, 2014.
2. Reuse and Recycling of Lithium-Ion Power Batteries, Guangjin Zhao, Wiley Online Library, 2017.

Reference Books:

1. Sustainable Resource Management: Technologies for Recovery and Reuse of energy and Waste Materials, Guo, W., Ngo, H. H., Surampalli, R. Y., Zhang, T. C., John Wiley & Sons, 2021.

Course Code: CH 5153	COMPUTATIONAL FLUID DYNAMICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Write governing equations of fluid flow and heat transfer.
CO2	Discretise the equations using finite difference and finite volume formulation.
CO3	Solve the discretized equations.
CO4	Implement pressure velocity coupling algorithms.
CO5	Generate grid for a given geometry.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	3	3	1
CO2	2	1	1	3	3	1
CO3	2	1	1	3	3	1
CO4	2	1	1	3	3	1
CO5	2	1	1	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: CFD Approach, Need for CFD.

Governing Equations of Fluid Flow and Heat Transfer: Introduction to Laws of Conservation: Mass, Momentum, Energy Equations; Initial and Boundary Conditions; Conservative Form – Differential and Integral Forms of General Transport Equations; Application of Navier-Stokes Equations; Classification of Physical Behaviours – Classification of Fluid Flow Equations.

Discretization of Equations: Finite Difference / Volume Methods – 1D, 2D and 3D Diffusion Problems, Convection and Diffusion Problems; Properties of Discretisation Schemes- Central, Upwind, Hybrid and Higher Order Differencing Schemes.

Solution Methods of Discretised Equations: Tridiagonal Matrix Algorithm (TDMA); Application of TDMA for 2D and 3D Problems; Iterative Methods.

Pressure – Velocity Coupling Algorithms in Steady Flows: Staggered Grid; SIMPLE, SIMPLEC and PISO.

Unsteady Flows: Explicit Scheme, Crank Nicholson Scheme, Fully Implicit Scheme, Pressure-Velocity Coupling Algorithms in Unsteady Flows.

Turbulence Modelling: Prandtl Mixing Length Mode - one Equation Model, k - ε Model.

Grid Generation: Structured and Unstructured Grids, Grid Generation Methods.

Learning Resources:

Text Books:

1. An Introduction to Computational Fluid Dynamics – the Finite Volume Method, Versteeg, H. K., Malalasekera, W., Prentice Hall, 2007, 2nd Edition.
2. Computational Fluid Dynamics – the Basics with Applications, John D. Anderson, Jr., McGraw Hill Education, 2017.

Reference Books:

1. Numerical Computation of Internal and External Flows: the Fundamentals of Computational Fluid Dynamics: 1, Hirsch, C., Wiley, 2007, 2nd Edition
2. Computational Methods for Fluid Dynamics, Ferziger, J. H., Peric, M., Street, R. L., Springer, 2019, 4th Edition.
3. Computational Fluid Dynamics for Engineers and Scientists, Sreenivas Jayanti, Springer, 2018, 1st Edition.

Online Resources:

1. Computational Fluid Dynamics, NPTEL course (link: https://nptel.ac.in/courses/103/106/103106119/)
2. CFD Online (Link: https://www.cfd-online.com)

Course Code: CH 5169	ENERGY AUDIT AND CONSERVATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Implement energy audit for a process plant.
CO2	Plan energy conservation strategies.
CO3	Evaluate the suitability of renewable energy resources.
CO4	Analyze the energy utilization of a process equipment.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	1	3	3	1
CO2	3	2	2	3	3	-
CO3	3	1	1	3	3	-
CO4	3	1	1	3	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Energy Scenario: Energy Use Patterns, Energy Resources, Oil - A Critical Resource, Economic and Environmental Consideration, Future Scenario.

Heat & Work: First & Second Law of Thermodynamics, Heat Engines.

Energy Audit: Energy Conversion, Energy Index, Energy Consumption Representation - Pie Chart, Sankey Diagram & Load Profile, General Audit, Detailed Audit, Waste Heat Recovery.

Targeting and Conservation: Energy Utilization and Conversion – Thermal Efficiency, Heat Exchangers – Heat Recovery, Air Conditioners – Supply and Removal of Heat.

Use of Alternate Energy: Solar Energy, Wind Energy, Nuclear Energy, Biomass, Geothermal Energy, Future Energy Alternatives.

Energy Integration: Pinch Analysis and Process Heat Integration, Energy Management, Key Performance Indicators and Energy Dashboards

Case Studies: Energy Conservation in Alcohol Industry, Fertilizer Industry, and Pulp and Paper Industry, Energy Conservation in Different Units of Refinery Like FCCU, HCU and ADU.

Learning Resources:

Text Books:

1. Energy Management, Murphy, W. R., Mckay, G., Elsevier, 2007.
2. Energy: Its Use and the Environment, Hinrichs, R. A., Kleinbach, M. H., Cengage Learning, 2012.

3. Guide to Energy Management, Capehart, B. L., Turner, W. C., Kennedy, W. J., Keinnedu Fairmant press, 2011, 7th Edition.
4. Energy Auditing and Conservation; Methods, Measurements, Management & Case Studies, Haimes, Y. Y., Ruffner, M. A. H., Taylor & Francis Inc, 1980.

Reference Books:

1. Non-conventional Energy Sources, Rai, G. D., Khanna Publishers, New Delhi, 2010.
2. Energy Management and Efficiency for the Process Industries, Rossiter, A. P., Jones, B. P., AIChE, Wiley, 2015.

Online Resources:

1. Energy Conservation and Waste Heat Recovery, NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105221/)

Course Code: CH 5171	CO_2 CAPTURE & UTILIZATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Identify the necessity of CO_2 capture, storage and utilization.
CO2	Distinguish the CO_2 capture techniques.
CO3	Evaluate CO_2 storage and sequestration methods.
CO4	Assess environmental impact of CO_2 capture and utilization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	2	3	3	1
CO2	3	2	2	3	3	1
CO3	3	2	2	3	3	1
CO4	3	2	2	3	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Global Status of CO_2 Emission Trends, Policy and Regulatory Interventions in Abatement of Carbon Footprint, Carbon Capture, Storage and Utilization (CCS&U).

CO_2 Capture Technologies from Power Plants: Post-Combustion Capture, Pre-Combustion Capture, Oxy-Fuel Combustion, Chemical Looping Combustion, Calcium Looping Combustion.

CO_2 Capture Agents and Processes: Capture Processes, CO_2 Capture Agents, Adsorption, Ionic Liquids, Metal Organic Frameworks.

CO_2 Storage and Sequestration: Geological Sequestration Methods, Biomimetic Carbon Sequestration.

CO_2 Utilization: CO_2 Derived Fuels for Energy Storage, Polymers from CO_2, CO_2 Based Solvents, CO_2 to Oxygenated Organics, Conversion into Higher Carbon Fuels, High Temperature Catalysis.

Environmental Assessment of CO_2 Capture and Utilization: Need for Assessment, Green Chemistry and Environmental Assessment Tools, Life Cycle Assessment (LCA), ISO Standardization of LCA, Method of Conducting an LCA for CO_2 Capture and Utilization.

Learning Resources:

Text Books:

1. Carbon dioxide utilization: Closing the Carbon Cycle, Peter Styring, Elsje Alessandra Quadrelli, Katy Armstrong, Elsevier, 2015.
2. Carbon Capture, Storage and, Utilization: A Possible Climate Change Solution for

Energy Industry, Goel, M., Sudhakar, M., Shahi, R. V., TERI, Energy and Resources Institute, 2015.
3. Carbon Capture and Storage, CO_2 Management Technologies, Amitava Bandyopadhyay, CRC Press, 2014.

Reference Books:

1. Calcium and Chemical Looping Technology for Power Generation and Carbon Dioxide (CO_2) Capture, Fennell, P., Anthony, B., Woodhead Publishing Series in Energy: No. 82, 2015.
2. Developments in Innovation in Carbon Dioxide Capture and Storage Technology: Carbon Dioxide Storage and Utilization, Mercedes Maroto-Valer M., Woodhead Publishing Series in Energy, 2014, Vol 2.
3. Fundamentals of Enhanced Oil and Gas Recovery from Conventional and Unconventional Reservoirs, Alireza Bahadori, Elsevier, 2018.

Online Resources:

Course Code: CH 5170	STATISTICAL DESIGN OF EXPERIMENTS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Plan experiments for a critical comparison of outputs.
CO2	Propose hypothesis from experimental data using statistical approach.
CO3	Implement factorial and randomized sampling from experiments.
CO4	Estimate parameters by multi-dimensional optimization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	3	2
CO2	2	2	2	3	3	2
CO3	2	1	2	3	3	-
CO4	-	-	2	3	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Strategy of Experimentation, Basic Principles, Guidelines for Designing Experiments.

Simple Comparative Experiments: Basic Statistical Concepts, Sampling and Sampling Distribution, Inferences about the Differences in Means: Hypothesis Testing, Choice of Samples Size, Confidence Intervals, Randomized and Paired Comparison Design.

Experiments with Single Factor: An Example, The Analysis of Variance, Analysis of the Fixed Effect Model, Model Adequacy Checking, Practical Interpretation of Results, Sample Computer Output, Determining Sample Size, Discovering Dispersion Effect, the Regression Approach to the Analysis of Variance, Non-parameteric Methods in the Analysis of Variance, Problems.

Design of Experiments: Introduction, Basic Principles: Randomization, Replication, Blocking, Degrees of Freedom, Confounding, Design Resolution, Metrology Considerations for Industrial Designed Experiments, Selection of Quality Characteristics for Industrial Experiments. Parameter Estimation. Response Surface Methods: Introduction, The Methods of Steepest Ascent, Analysis of a Second-Order Response Surface, Experimental Designs for Fitting Response Surfaces: Designs for Fitting the First-Order Model, Designs for Fitting the Second-Order Model, Blocking in Response Surface Designs, Computer-Generated (Optimal) Designs, Mixture Experiments, Evolutionary Operation, Robust Design, Problems.

Design and Analysis: Introduction, Preliminary Examination of Subject of Research, Screening Experiments: Preliminary Ranking of the Factors, Active Screening Experiment Method of Random Balance, Active Screening Experiment Plackettburman Designs, Completely Randomized Block Design, Latin Squares, Graecolatin Square, Youdens Squares, Basic Experiment Mathematical Modelling, Statistical Analysis, Experimental Optimization of

Research Subject: Problem of Optimization, Gradient Optimization Methods, Non-gradient Methods of Optimization, Simplex Sum Rotatable Design, Canonical Analysis of the Response Surface, Examples of Complex Optimizations.

Learning Resources:

Text Books:

1. Design of Experiments in Chemical Engineering, A Practical Guide, Lazic, Z. R., Wiley, 2005.
2. Design of Experiments for Engineers and Scientists, Antony, J., Butterworth Heinemann, 2004.
3. Design and Analysis of Experiments, Montgomery, D. C., Wiley, 2010, 5th Edition.
4. Engineering Experimentation: Planning, Execution, Reporting, Doebelin, E. O., McGraw-Hill, 1995.

Online Resources:

1. Statistics for Experimentalists, NPTEL Course (Link: https://nptel.ac.in/courses/103/106/103106112/)
2. Biostatistics and design of experiments, NPTEL Course (Link: https://nptel.ac.in/courses/102/106/102106051/)

Course Code: CH 5252	DATA ANALYTICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Demonstrate proficiency with statistical analysis of data.
CO2	Use inferential statistics for decision making.
CO3	Apply supervised learning for classification and regression problems.
CO4	Apply unsupervised learning for clustering.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	2	2	3	2
CO2	3	-	2	2	3	2
CO3	3	-	2	2	3	2
CO4	3	-	2	2	3	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Data Analytics, Python Fundamentals.

Data Quality and Pre-Processing: Distance Measures, Dimensionality Reduction, Principal Component Analysis (PCA).

Descriptive Statistics:
Graphical Approach - Frequency Tables, Relative Frequency Tables, Grouped Data, Pie Chart, Bar Chart, Histograms, Ogives, Stem and Leaf Plots, Box Plots, Dot Diagram, Scatter Plots, Pareto Diagram. Measure of Central Tendency and Dispersion **-** Arithmetic Mean, Median and Mode, Variance, Standard Deviation, Quartiles, Range, Mean Absolute Deviation, Coefficient of Variation, Z Scores, Normal Distribution, Confidence Interval Estimation.

Probability Distribution and Inferential Statistics: Random Variables, Probability Distributions, Hypothesis Testing, Single Sample Test, Two Sample Test, Type I Error, Type II Error, Analysis of Variance (ANOVA).

Supervised Learning: Linear Regression, Ridge Regression, Lasso Regression, Logistic Regression, Multiple Linear Regression, Goodness of Fit, Bias–Variance Trade off, K-Nearest Neighbors Algorithm, Linear Discriminant Analysis, Classification and Regression Trees and Pruning, Support Vector Machines, Random Forest, Naive Bayes, Introduction to Neural Networks and Deep Learning.

Unsupervised Learning: Cluster Analysis – K Means, Hierarchical, DBSCAN.

Applications to Different Engineering Systems.

Learning Resources:

Text Books:

1. Applied Statistics and Probability for Engineers, Douglas C. Montgomery, George C. Runger, 6th Edition, John Wiley & Sons Inc., 2016.
2. The Elements of Statistical Learning, Trevor Hastie, Robert Tibshirani, Jerome Friedman, Springer, 2009, 2nd Edition.
3. Introduction to Machine Learning, Ethem Alpaydın, MIT Press, 2014, 3rd Edition.

Reference Books:

1. A General Introduction to Data Analytics, João Mendes Moreira , André C. P. L. F. de Carvalho, Tomáš Horváth, Wiley, 2019.
2. Introduction to Data Mining, Pang-Ning Tan, Michael Steinbach, Anuj Karpatne, Vipin Kumar, Pearson, 2019, 2nd Edition.

Online Resources:

1. Data Analytics with Python, NPTEL Course (Link: https://nptel.ac.in/courses/106/107/106107220/)
2. Introduction to Data analytics, NPTEL Course (Link: https://nptel.ac.in/courses/110/106/110106072/)

Course Code: EE 5263	ENERGY AUDITING AND MANAGEMENT	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the need and significance of energy audit and management.
CO2	Identify the equipment and domain of energy conservation and audit in power system.
CO3	Assess the need and type of instruments for energy audit and energy management.
CO4	Design, analyse and evaluate an energy audit and the benefits of different energy management techniques.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	1	2	2	-
CO2	-	-	1	2	2	-
CO3	-	-	1	2	3	-
CO4	-	-	1	3	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Energy Audit and Demand Side Management (DSM) in Power Utilities: Energy Scenario & Conservation, Demand Forecasting Techniques, Integrated Optimal Strategy for Reduction of T&D Losses, DSM Techniques and Methodologies, Loss Reduction in Primary and Secondary Distribution System and Capacitors, Energy Management, Role of Energy Managers, Energy Audit, Metering.

Energy Audit: Energy Audit Concepts, Basic Elements and Measurements, Mass and Energy Balances, Scope of Energy Auditing in Industries.

Energy Audit of Electrical Equipment: Evaluation of Energy Conservation Opportunities and Environmental Management, Preparation and Presentation of Energy Audit Reports, Case Studies for Induction Motors, Transformers, Cables, Lighting, AC Systems, Pumps, Capacitor Banks and Potential Energy Savings.

Instrumentation: Evaluation and Instrumentation Techniques for Renewable Energy Systems (Solar Thermal, Photovoltaic and Wind Energy), Energy Management Devices, Micro Controller Based Systems.

Energy Conservation: Energy Conservation in HVAC Systems and Thermal Power Plants, Solar Systems, Fan and Lighting System, Different Light Sources and Luminous Efficacy, Energy Conservation in Electrical Devices and Systems, Economic Evaluation of Energy Conservation Measures, Electric Motors and Transformers, Inverters and UPS, Voltages Stabilizers.

Learning Resources:

Text Books:

1. Energy Engineering and Management, Amlan Chakrabarti, PHI, 2018.
2. Energy Auditing in Electrical Utilities, Rajiv Shanker, Viva Books Pvt. Ltd., 2015.

Reference Books:

1. Industrial Energy Management and Utilization, David Robert Brown, Witte, L. C., Philip S. Schmidt, Hemisphere Publishing Co., New York, 1988.
2. Energy Management Handbook, Wayne C. Turner, Wiley Inter-science Publications, New York, 1982.
3. Analysis and Design of Energy Systems, Hodge B. K., Prentice Hall, 2002.

Online Resources:

1. Energy Management Systems and SCADA, NPTEL Course (Link: https://archive.nptel.ac.in/courses/108/106/108106022/)

Course Code: EE 5366	TRANSACTIVE ENERGY MARKETS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand Transactive Energy (TE).
CO2	Understand Transactive Energy resources.
CO3	Detail TE techniques.
CO4	Model TE and understand it's application.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	1	1	1	-
CO2	-	-	1	1	1	-
CO3	-	-	1	2	2	-
CO4	-	-	1	2	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Transactive Energy (TE): Potential Impact of TE, Applications for Utilities and Distribution System Operators, Customer Applications.

Renewable Energy Sources in a Transactive Energy Market: Transactive Energy Products, Transactive Energy Market Participants, Transactive Energy Classification Scheme for Renewable Market Participants, Grid Stability and Protection, Energy Market Management.

Transactive Energy Techniques: Conceptual View of Distributed Power Generation and Management Transactive Energy Construct, End-to-End Transactions of Information, Prices and Power, Centralized and Decentralized Transactive Energy.

Extension of Transactive Techniques from Wholesale to Retail: Price-based Resource Scheduling and Dispatch, Congestion Management, Transmission/distribution Capacity Auction, Market-clearing and Pricing, End-to-End Transactive Solutions Closing the Gap between Wholesale and Retail.

Mathematical Modeling and Economic Interpretation of Transactive Energy-based Distribution System, Case Studies.

Transactive Energy Application to Modern Grid and Concept of Block Chain Techniques.

Learning Resources:

Text Books:

1. eIoT: The Development of the Energy Internet of Things in Energy Infrastructure, Muhanji, S. O., Flint, A. E., Farid, A. M., Springer, 2019, 1st Edition.

Course Code: EE 5367	CHALLENGES AND SOLUTIONS IN RENEWABLE INTEGRATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the available grid codes for the renewable integration in multiple countries.
CO2	Understand market and forecasting challenges due to uncertainties in renewables.
CO3	Assess power quality and inertia issues with increased penetration of RES in electric grids.
CO4	Evaluate solutions and apply for RES operational and uncertainty issues.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	1	1	1	-
CO2	-	-	1	1	1	-
CO3	-	-	1	2	2	-
CO4	-	-	1	2	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Energy System Challenges: Handling Renewable Energy Variability and Uncertainty in Power System Operation, Short- Term Frequency Response Challenges in Power Systems with High Nonsynchronous Penetration Levels, Technical Impacts of High Penetration Levels of Wind Power on Power System Stability, Constraints to the Transformation Rate of Global Energy Infrastructure, Demand Supply Flexibility, Voltage Control, Inertia Response Overview of the Grid Codes, Components of the Grid Codes, Development of the Grid Codes, Classification and Specifications of the Grid Codes, Anomalies in Grid Codes, Fault-Ride Through Criterion.

Integration of Renewable Energy: The Indian Experience Policy Initiatives, Regulatory Initiatives, Transmission Planning Initiatives, Experience with Recs in India.

Challenges German Renewable Energy Sources Pathway: Increasing Challenges of RES Integration into the German Electricity System.

Danish Case Study: The Danish Markets for Balancing the Electricity System, Making wind as a Part of the Balancing Solution, An Hour with Negative Prices for Downward Regulation, Challenges to Participation in the Tertiary Reserve Market, Decentralized Combined Heat and Power Plants of the Balancing Solution.

Texas Case Study: Study of the Impacts of Wind Generation on Ancillary Service, Ancillary Service Requirement Methodology Improvements to Integrate Wind Generation Resources, Regulation-Up and - Down Reserve Service.

Photovoltaic Penetration in Distribution Network: Voltage Imbalance Sensitivity Analysis, Stochastic Evaluation, Monte Carlo Evaluation, Series and Parallel Custom Power Devices, Dynamic and Feasibility Issues Related to Custom Power, Performance of Grid Connected Solar Photovoltaic System with MPPT Controllers, Mathematical Model of Grid Connected Three Phase SPV System, Performance Evaluation of P&O and INC Based MPPT Algorithms, Application of Adaptive Neuro Fuzzy Inference System (ANFIS) for Control of DC-DC Convertor for SPV System.

Market Operations and Forecasting Renewables: Analyzing the Impact of Variable Energy Resources on Power System Reserves, Advances in Market Management Solutions for Variable Energy Resources Integration, Forecasting Renewable Energy for Grid Operations, Incorporating Forecast Uncertainty in Utility Control Center, Reserve Management for Integrating Renewable Generation in Electricity Markets, Scandinavian Experience of Integrating wind Generation in Electricity Market, Economics of Renewable Generation Integration and Long Term Power Purchase Agreements (PPA).

Solution for RES Uncertainties: Enabling and Disruptive Technologies for Renewable Integration, Enhancing Situation Awareness in Power Systems, Overcoming Uncertainty and Variability With Renewable Resources, Managing Operational Uncertainty Through Improved Visualization Tools in Control Centers with Reference to Renewable Energy Providers, Synchro Phasors for Distribution Networks with Variable Resources, Monitoring and Control of RES Using Synchronized Phasor Measurements.

Solution for Operational Issues: Virtual Inertial, Reactive Power Control in Response to Voltage Deviations, Use of Energy Storage Systems, Advanced Control Strategies to Improve Dynamic and Transient Response Time, Derated Operation of the Renewable Resources.

Learning Resources:

Text Books:

1. Renewable Energy Integration: Challenges and Solutions, Hossain, J., Mahmood, A., Springer- Verlag, 2014, 1st Edition.
2. Renewable Energy Integration Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Lawrence E. Jones, Elsevier Inc., 2017, 2nd Edition.

Reference Books:

1. Integrating Variable Renewable Energy: Challenges and Solutions, Bird, L., Milligan, M., Lew, D., Technical Report NREL, 2013.
2. Challenges to Grid Integration of Renewable Energy in India, Akshay Urja, MNRE Technical Report, 2019.
3. Solar PV Integration Challenges, Katiraei, F., Aguero, J. R., IEEE Power and Energy Magazine, 2011.

Online Resources: