CURRICULUM & SYLLABI

M.Tech. SUSTAINABLE ENERGY GENERATION AND STORAGE TECHNOLOGIES (SEG&ST)

Effective from AY: 2024-25



NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

WARANGAL, TELANGANA

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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
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.

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

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, includingresource 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	PEO-1	PEO-2	PEO-3	PEO-4	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

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

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.

CURRICULUM

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

1st Semester

S.No.	Code	Course Title	L-T-P	Credits
1	CY16061	Electrochemistry and Materials for Energy Systems	3-0-0	3
2	CH26001	Sustainable Energy Engineering	3-0-0	3
3	CH26003	Hydrogen Generation and Storage	3-0-0	3
4		Professional Elective - I	3-0-0	3
5		Professional Elective - II	3-0-0	3
6	CH16009	Material Synthesis and Applications Laboratory	0-1-2	2
7	CH26005	Energy Generation and Conversion Laboratory	0-1-2	2
			Total Credits	19

2nd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	ME16062	Thermal Energy Storage	3-0-0	3
2	CH26002	Electrochemical Energy Storage Systems	3-0-0	3
3		Professional Elective – III	3-0-0	3
4		Professional Elective - IV	3-0-0	3
5		Professional Elective - V	3-0-0	3
6	CH26004	Electrochemical Energy Storage Systems Laboratory	0-1-2	2
7	CH26006	Energy Systems Simulation Laboratory	0-1-2	2
8	CH26096	Minor Project	0-0-0	2
			Total Credits	21

3rd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	CH27089	Seminar and Technical Writing	0-0-0	2
2	CH27091	Summer Internship / Research Experience	0-0-0	2
3	CH27093	Comprehensive Viva-voce	0-0-0	2
4	CH27097	Dissertation: Part A	0-0-0	8
			Total Credits	14

4th Semester

S.No.	Code	Course Title	L-T-P	Credits
1	CH27098	Dissertation: Part B	0-0-0	12
			Total Credits	12

Professional Elective Courses:

Professional Electives – I & II		
S. No.	**Code**	**Course Title**
1	CH26021	Fuel Cell Systems
2	CH26023	Nuclear Power Technology
3	CH26025	Energy Resources, Economics and Environment
4	CH26027	Waste to Energy
5	CH16005	Data Analytics and Machine Learning
6	CH16021	Circular Economy for Sustainable Development
7	CH16023	Advanced Mass Transfer
8	PH18025	Solar Energy Systems
9	EE16025	Electric Vehicles
10	EE16026	Control and Integration of Renewable Energy Sources
11	ME56025	Alternate Fuels and Emissions
12	ME16023	Power Plant Engineering
13	ME16025	Renewable Sources of Energy

Professional Electives – III, IV & V		
S.No.	**Code**	**Course Title**
1	CH26022	Energy Management and Life Cycle Assessment
2	CH26024	Energy, Water and Food Nexus
3	CH26026	Modelling and Analysis of Process and Energy systems
4	CH26028	Sustainable Recycling of Energy Materials
5	CH26030	Bioenergy and biofuels
6	CH16002	Computational Fluid Dynamics
7	CH16004	Steady State Process Simulation
8	CH16022	Wastewater Treatment
9	CH16024	Engineering Optimization
10	CH16026	CO_2 Capture, Sequestration and Utilization
11	CH16028	Energy Audit and Conservation
12	CH16030	Novel Separation Techniques
13	CH16050	Heat Integration and Process Scheduling
14	CH16060	Advanced Process Control
15	EE36024	Transactive Energy Markets
16	EE36005	Challenges and Solutions in Renewable Integration

SYLLABI

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

1st Semester

CY16061 **3-0-0 (3)**

Electrochemistry and Materials for Energy Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the principles of electrochemistry and electrochemical techniques
CO-2	Apply electrochemical techniques to investigate and analyze the performance of electrochemical systems
CO-3	Analyze the data obtained from various electrochemical techniques
CO-4	Evaluate different materials and mechanisms to determine their effectiveness and potential for optimization in various applications
CO-5	Create and design new electrochemical devices and systems and improvements in the synthesis and application of materials

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	1	1	2	1	1	1
CO-2	1	1	1	3	2	1
CO-3	1	1	1	3	1	1
CO-4	1	1	2	3	2	1
CO-5	1	1	1	2	2	3

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. Introduction to Electrochemical Capacitors, Batteries, Fuel Cells and Sensors.

Voltammetry: Cyclic Voltammetry and Linear Sweep Voltammetry: Principles and Applications in Supercapacitors, Fuel Cells and Sensors. Diffusion Controlled Reactions. Stern Layer Thickness, 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.

Chronopotentiometry and Chronoamperometry: Principles and Applications of Chronopotentiometry and Chronoamperometry in Electrocatalysis, Supercapacitors, Batteries, Fuel cells and Sensors. Electrochemical Sensors: Principles, Instrumentation, Performance Factors and Applications.

Electrochemical Impedance Spectroscopy: Principles Instrumentation and Applications. Equivalent circuit models in electrochemistry, Nyquist and Bode Plot Analysis.

Pulse Methods: Normal Pulse Voltammetry, Differential Pulse Voltammetry, Principles and Applications in Molecular Sensors.

Electrocatalysis: Mechanism of Electrocatalytic Reactions, Role of electrocatalysts in various electrocatalytic reactions.

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

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

Learning Resources:

Text Books:

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

Reference Books:

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

CH26001 **3-0-0 (3)**

Sustainable Energy Engineering

Pre-Requisites: **None**

Course Outcomes:

CO-1	Quantify the variety of energy resources
CO-2	Perform project economics evaluation
CO-3	Evaluate sustainability metrics
CO-4	Select suitable sustainable energy technologies

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	2	3	3	3
CO-2	1	2	2	3	3	3
CO-3	1	2	2	3	3	3
CO-4	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: Characterization, 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. Tester, J. W., Drake, E. M., Driscoll, M. J.,Golay, M. W., Peters, W. A., Sustainable Energy: Choosing Among Options, MIT Press, 2012, 2nd Edition.
2. Martin A. Abraham, Encyclopedia of Sustainable Technologies, Elsevier Publications, 2024, 2nd Edition.
3. Eduardo Rincon-Mejia, Alejandro de las Heras, Sustainable Energy Technologies, CRC Press, 2018.
4. Denise Fairchild, Al Weinrub, Energy democracy: Advancing equity in clean energy solutions, Island press, 2017.

Reference Books:

1. Mulligan, C. N., Sustainable Engineering: Principles and Implementation, CRC Press,Taylor and Francis Group, 2019.
2. Bakshi, B. R., Sustainable Engineering: Principles and Practice, Cambridge UniversityPress, 2019.
3. David Allen, David Shonnard, Sustainable Engineering: Concepts, Design, and Case Studies, Prentice Hall, 2011.
4. Hazra Somnath, Bhukta Anindya, Sustainable Development Goals an Indian Perspective, Springer, 2020.

CH26003 **3-0-0 (3)**

Hydrogen Generation and Storage

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the basic properties of hydrogen, including its chemical and physical characteristics, and its role as an energy carrier
CO-2	Select a suitable hydrogen generation and storage technique based on the mechanisms, performance characteristics, and applicability
CO-3	List the safety considerations and regulations related to hydrogen handling
CO-4	Analyze the economic viability and environmental impact of hydrogen generation and storage systems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	1	2	1	1
CO-2	1	1	1	3	2	1
CO-3	1	1	2	3	2	1
CO-4	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. Gupta, R. B., Hydrogen Fuel: Production, Transport, and Storage, CRC press, 2008.

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

Reference Books:

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

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc22_ch66/preview

CH16009 **0-1-2 (2)**

Materials Synthesis and Applications Laboratory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Develop the ability to accurately perform conductometric, potentiometric titrations
CO-2	Conduct cyclic voltammetry and electrodeposition experiments and analyze oxidation, reduction, and corrosion processes
CO-3	Synthesize carbon xerogels and thin films
CO-4	Analyze the concentration of substance using spectroscopy technique

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	2	1	1	1	3
CO-2	3	2	1	1	1	3
CO-3	3	2	1	1	1	3
CO-4	3	2	1	1	1	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

1. Conductometric Titration for Concentration Determination
2. Potentiometric Titration for Concentration Determination
3. Electrodeposition
4. Cyclic Voltammetry to Determine Oxidation and Reduction Reaction Potential
5. Electrochemical Measurement of Corrosion Rate
6. Demonstrating Structural Color and Wettability using Soft-lithography Technique
7. Synthesis of Activated Carbon from Coconut Shell
8. Thin Film Preparation using Spin and Dip Coating Techniques
9. Synthesis of Resorcinol-Formaldehyde Xerogel
10. Spectroscopic Determination of Methylene Blue Dye Concentration

Learning Resources:

Text Books:

1. Lab manuals.

CH26005 **0-1-2 (2)**

Energy Generation and Conversion Laboratory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Synthesize different fuels from sustainable energy sources
CO-2	Determine the efficiency of different energy conversion technologies
CO-3	Design and analyse sustainable energy systems
CO-4	Interpret the data by performing the experiments

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	2	3	2	1
CO-2	1	2	2	3	2	1
CO-3	2	2	2	3	2	1
CO-4	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. Measurement and Analysis of Solar Radiation
10. Measurement and Analysis of Solar PV Module
11. Performance Evaluation of Solar Water Heater

Learning Resources:

Text Books:

1. Lab manuals / Exercise sheets.

Other Suggested Readings:

1. Online Journals.

2nd Semester

ME16062 **3-0-0 (3)**

Thermal Energy Storage

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the principles, concepts, and operation of thermal energy storage systems
CO-2	Select the suitable energy storage materials
CO-3	Design thermal energy storage systems
CO-4	Evaluate the performance of thermal energy storage systems for different applications

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	2	2	1	1
CO-2	1	1	2	2	1	1
CO-3	1	1	3	3	3	1
CO-4	1	1	3	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 EnergyStorage, System Types, Environmental Impact.

Sensible Heat Storage Systems: Introduction, Types, Principles of Sensible Heat StorageSystems, 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 WaterHeating, District Heating, Heat to Waste, Cogeneration and Trigeneration Systems, Concentrated Solar Power, Cooling.

Learning Resources:

Text Books:

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

Reference Books:

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

CH26002 **3-0-0 (3)**

Electrochemical Energy Storage Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Explain fundamental electrochemical principles such as redox reactions, cell potentials, and ionic conductivity of electrolytes
CO-2	Apply electrochemical techniques like cyclic voltammetry and galvanostatic charge-discharge to characterize electrochemical systems
CO-3	Analyze various battery technologies and their components, focusing on performance and key characteristics
CO-4	Describe the design and functionality of flow batteries, including the roles of electrodes, electrolytes, membranes, and stack design
CO-5	Evaluate the principles, materials, and applications of supercapacitors, comparing them with batteries and identifying challenges and future directions
CO-6	Analyze various recycling processes for energy storage systems and their impact on sustainability and environmental challenges

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	1	2	-	-	2	1
CO-2	1	2	-	-	2	1
CO-3	1	2	-	2	2	1
CO-4	3	3	1	-	2	1
CO-5	1	3	1	2	2	1
CO-6	1	3	1	2	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Battery Fundamentals and Technologies: Electrochemical energy storage mechanisms. cell vs. battery. History of battery development. Battery Classification: Primary and secondary batteries; Based on electrode materials and electrolytes (aqueous vs. non-aqueous).

Existing Battery Systems: Basic operation and key characteristics (Lead-Acid, Nickel Cadmium, Nickel Hydrogen, Nickel Metal Hydride). Lead acid batteries: Effect of Temperature- Peukert's Law, Discharge Rate, Sulfation, Overcharging, Plate Thickness; Nickel cadmium: components, advantages and limitations.

Lithium-Ion Batteries: Classification: Based on cathode and anode materials (LFP, LCO). Working Principle: Charge/discharge cycles, role of the electrolyte. Critical Components and Materials: Anode Materials: Graphite, silicon, lithium titanate; Cathode Materials: Layered oxides, spinel oxides, olivine phosphates. Electrolytes: Organic solvents with lithium salts, ionic conductivity, safety. Separators: Microporous polymer membranes. Advantages and Limitations: Capacity, cycling stability, safety.

Advanced Battery Technologies: Lithium-Air Batteries: Ultra-high energy density potential, working principle, challenges (electrode stability, electrolyte decomposition). **Sodium-Ion Batteries:** History, working mechanism, components and materials (anodes: hard carbon, sodium titanate; cathodes: layered oxides, polyanionic compounds), advantages and limitations. **Aluminum-Ion Batteries:** Introduction, historical development, rechargeable types (chloroaluminate, aluminum-sulfur), specific requirements for electrolytes, challenges, and future prospects. **Dual-Ion Batteries**: Working mechanism, cathode and anode materials, advantages and limitations.

Flow Batteries: Concept and Working Principle. Electrolytes: Different redox couples and performance properties; Electrodes: Porous carbon materials; Membranes and Stack Design: Flow field design, materials selection.

Supercapacitors: Introduction and Comparison with Batteries: Basic principles (electric charge, electric field, potential, capacitance), charging/discharging, energy storage mechanisms. Materials for Supercapacitors: Electrolytes: Aqueous, organic, ionic liquids. Energy Storage Mechanisms: Electrostatic vs. pseudocapacitive. Electrode materials: Carbon materials (activated carbon, CNTs, graphene), metal oxides/sulfides, conducting polymers.

Recycling Processes: Recycling Methods: Hydrometallurgy, pyrometallurgy, chemical, biological, direct recycling. Future Prospects: Innovations and sustainability in recycling technologies.

Learning Resources:

Text Books:

1. Allen J. Bard, Larry R. Faulkner, Electrochemical Methods: Fundamentals and Applications, Wiley, 2000, 2nd Edition.
2. Beard, K.W., Linden's handbook of batteries. McGraw Hill Education, 2019.
3. Brian E. Conway, Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications, Volume: 1, Springer, 1999.

Reference Books:

1. Vladimir S. Bagotsky, Alexander M. Skundin, Yurij M. Volfkovich, Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors, Wiley, 2015.
2. Aiping Yu, Victor Chabot, Jiujun Zhang, Electrochemical Supercapacitors for Energy Storage and Delivery: Fundamentals and Applications, CRC Press, 2017, 1st Edition.
3. François Béguin, Elżbieta Frąckowiak, Supercapacitors: Materials, Systems and Applications, Wiley, 2013.
4. Warner, J. T., The Handbook of Lithium-Ion Battery Pack Design: Chemistry, Components, Types and Terminology, Elsevier, 2015.

CH26004 **0-1-2 (2)**

Electrochemical Energy Storage Systems Laboratory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Fabricate primary & secondary batteries and supercapacitor using appropriate materials and techniques
CO-2	Evaluate the critical parameters of batteries and supercapacitors
CO-3	Interpret the electrochemical performance with material physicochemical properties
CO-4	Examine the effect of operating conditions on the performance of energy storage devices

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	1	1	2	3
CO-2	3	3	1	1	2	3
CO-3	3	3	1	1	2	3
CO-4	3	3	1	1	2	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

1. Fabrication and Testing of Lithium-Ion Half-Cell-Anode material
2. Fabrication and Testing of Activated Carbon Electrode-Based Supercapacitor
3. Assessment of the Rate Performance and Cyclic Stability of the Supercapacitor/Battery
4. Flexible Supercapacitor Fabrication and Testing
5. Fabrication and Testing of Na-ion Battery Half Cell- Anode
6. Vanadium Redox Flow Battery Performance Evaluation
7. Fabrication and Testing of Lithium-Ion Half-Cell-Cathode material
8. Fabrication and Testing of Lithium-Ion Full-Cell
9. Discharge and Charging of Dual-ion Battery
10. Fabrication and Testing of Na-ion Battery Half Cell- Cathode

Learning Resources:

Reference Books:

1. Laboratory manuals.

CH26006 **0-1-2 (2)**

Energy Systems and Simulations Laboratory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Simulate process equipment, unit operations and flowsheets
CO-2	Apply sensitivity, design specification and case study tools in Aspen
CO-3	Comprehend the fundamentals of process modelling, simulation, and optimization using Aspen software
CO-4	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:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	2	2	3	1
CO-2	1	1	2	2	3	1
CO-3	1	1	3	3	3	1
CO-4	1	1	3	3	3	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

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
11. Band gap and Density of states (DOS) for Battery materials
12. Theoretical capacity and voltage of electrode material
13. Simulation of Li-ion battery using NTGK Model with Reduced Order Method (ROM) in Ansys

Learning Resources:

Reference Books:

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

CH26096 **0-0-0 (2)**

Minor Project

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world projects
CO-2	Plan and monitor project tasks individually or as a team
CO-3	Demonstrate practical experience in project execution
CO-4	Communicate project findings clearly through reports and presentations

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	-	3	3	2	2
CO-2	2	-	-	-	3	-
CO-3	3	-	2	2	-	3
CO-4	1	3	-	-	3	-

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Description:

Students are expected to choose real world or relevant problems and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel can decide the suitability and worthiness of the project

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria.

Criteria	**Description**	**Weightages**
I	Identification of Problem Domain	20 marks
II	Study of Existing Systems and establishing clear objectives	20 marks
III	Planning of project and work distribution within the team	10 marks
IV	Proper Documentation and Technical Writing	20 marks
V	Presentation and Response to questions	30 marks

Evaluation Criteria-CO Mapping

CO / **Criteria**	**CO-1**	**CO-2**	**CO-3**	**CO-4**
I	X			
II	X			
III		X	X	
IV				X
V				X

3rd Semester

CH27089 **0-0-0 (2)**

Seminar and Technical Writing

Pre-Requisites: None

Course Outcomes:

CO-1	Consolidate ideas based on expert talks attended
CO-2	Prepare a well-organized report employing elements of critical thinking and technical writing
CO-3	Demonstrate the ability to describe, interpret and analyze the subject matter and develop competence in presenting

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	-	2	-	-	-	-
CO-2	2	3	-	-	3	2
CO-3	2	3	-	-	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Seminar and Technical Writing, every student is expected to prepare a well-organized report based on one / all of the following:

- by attending at least 5 expert lectures/ invited talks/ Seminar/ Popular lectures etc. organized by the institute/any of the departments, ideally in a specific domain or with the same theme.
- prepare a business or marketing plan based on patent search

The student is expected to consolidate the ideas from these lectures/patent searches and may even include material from other sources to strengthen the content of the report. The student should prepare a well-organized report based on the above and present it to the panel constituted by the department, for evaluation.

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria.

Criteria	Description	Weightages
I	Clarity on the topic	15 marks
II	List of lectures attended	15 marks
III	Report	15 marks
IV	Presentation	30 marks
V	Response to questions	25 marks

Evaluation Criteria-CO Mapping

CO / Criteria	CO-1	CO-2	CO-3
I	X		
II	X		
III		X	
IV			X
V			X

CH27091 **0-0-0 (2)**

Summer Internship / Research Experience

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world problems, gaining practical experience
CO-2	Plan, manage and execute the work with ethical consideration
CO-3	Review the social and environmental impact of the work
CO-4	Communicate the learnings through report and presentation

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	-	2	2	-	-
CO-2	3	-	2	2	3	3
CO-3	3	-	2	2	-	3
CO-4	-	3	-	-	2	-

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Description:

Every student has to undergo either a Summer Internship / Research project. The summer internship may be undergone in an Industry/Research organization or any premier academic Institution, including NIT Warangal for 6-8 weeks. The research project shall be registered under the guidance of any faculty member in the institute. The student is required to submit a report and present the work before an evaluation committee, nominated by the Head of the Department.

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria.

Criteria	**Description**	**Weightages**
I	Relevance of the area of work	25 marks
II	Performance of the Task	20 marks
III	Crucial learnings from the work	20 marks
IV	Report Preparation	15 marks
V	Presentation and Response to questions	20 marks

Evaluation Criteria-CO Mapping

CO / **Criteria**	**CO-1**	**CO-2**	**CO-3**	**CO-4**
I	X			
II		X		
III			X	
IV				X
V				X

CH27093 **0-0-0 (2)**

Comprehensive Viva-voce

Pre-Requisites: **None**

Course Outcomes:

CO-1	Comprehend the knowledge gained in the course work
CO-2	Demonstrate the ability in problem solving
CO-3	Communicate effectively using engineering terminology

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	-	2	3	3	-	3
CO-2	3	-	3	3	-	-
CO-3	-	2	3	3	-	-

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Description:

In Comprehensive viva-voce each student will be evaluated for their overall comprehension of the course work and laboratory training that they have undergone. The students will be expected to answer questions orally, write down simple equations, draw plots, schematics, write simple code etc. as questioned by the panel. Assessment will be done by the panel based on the student response.

CH27097 **0-0-0 (8)**

Dissertation: Part A

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify a topic in advanced areas of Chemical Engineering
CO-2	Review literature to identify gaps and define objectives and scope of the work
CO-3	Employ the ideas from literature and develop research methodology
CO-4	Develop a model, experimental set-up and / or computational techniques necessary to meet the objectives

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	-	3	-	-	-
CO-2	-	3	3	-	3	3
CO-3	-	-	2	2	3	-
CO-4	-	-	3	3	-	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – A will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria

The student will be evaluated by the panel based on the below criteria.

Criteria	**Description**	**Weightages (%)**
I	Selection of Topic	20
II	Literature Survey	20
III	Defining the Objectives and Solution Methodology	30
IV	Performance of the Task	30

Evaluation Criteria - CO Mapping:

CO / Criteria	CO-1	CO-2	CO-3	CO-4
I	X			
II		X		
III			X	
IV				X

Refer to M.Tech. – Regulations for any further information regarding Mid-term review, End Sem evaluation.

4th Semester

CH27098 **0-0-0 (12)**

Dissertation: Part B

Pre-Requisites: **CH2797**

Course Outcomes:

CO-1	Identify the materials and methods for carrying out experiments/develop a code
CO-2	Execute the research methodology with a concern for society, environment and ethics
CO-3	Analyse, discuss and justify the results/trends and draw valid conclusions
CO-4	Prepare the report as per recommended format and present the work orally adhering to stipulated time
CO-5	Explore the possibility to publish/present a paper in peer reviewed journals/conference proceedings without plagiarism

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	3	2	3
CO-2	-	-	3	2	3	3
CO-3	3	-	3	3	2	3
CO-4	-	3	3	-	-	-
CO-5	-	3	3	-	-	-

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – B will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria as a continuation of Dissertation Part A.

Task	Description	Weightages (%)
IV	Performance of the Task	20
V	Dissertation Preparation	25
VI	Review (Presentation & Understanding)	30
VII	Viva-Voce	15
VIII	Publications /Possibility of publication	10

Evaluation Criteria-CO Mapping:

CO / Criteria	CO-1	CO-2	CO-3	CO-4	CO-5
IV	X	X			
V				X	
VI			X		
VII				X	
VIII					X

Refer to M.Tech. – Regulations for any further information regarding Mid-term review, End Sem evaluation, Template for report preparation and plagiarism.

Professional Electives – I & II

CH26021 **3-0-0 (3)**

Fuel Cell Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand working principle of fuel cell
CO-2	Analyse the performance of fuel cell systems
CO-3	Identify the intricacies in the operation of fuel cell stack and fuel cell system
CO-4	Analyse the fuel cell system design and integration

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	2	2	2
CO-2	2	1	2	2	2	1
CO-3	2	1	2	3	3	1
CO-4	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 Theoretical Voltage, Fuel Cell Efficiency; Electrode Kinetics; Butler-Volmer Equation; Overpotentials; Tafel Equation; 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; Membrane Electrode Assembly Components; Fuel Cell Stack; Bi-Polar Plate; Humidifiers and Cooling Plates.

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 Testing: Performance Testing and Measurement Techniques; Electrochemical and Physical Characterization Techniques; Thermal Management and Water Management; Hydrogen Production from Renewable Sources and Storage; Safety Issues; Cost Analysis.

Learning Resources:

Text Books:

1. Hoogers G ,Fuel Cell Technology Hand Book, CRC Press, 2003, 1st Edition.
2. Mathew M. Mench, Fuel Cell Engines, Wiley, 2008, 1st Edition.
3. O'Hayre, R. P., Cha, S., Colella, W., Prinz, F. B., Fuel Cell Fundamentals, Wiley, 2016, 3rd Edition.
4. Barbir, F., PEM Fuel Cells: Theory and Practice, Elsevier, 2013, 2nd Edition.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/103/102/103102015/

CH26023 **3-0-0 (3)**

Nuclear Power Technology

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand nuclear fission and nuclear fusion techniques
CO-2	Analyse the interaction of alpha, beta particles and neutrons with matter
CO-3	Evaluate the neutron diffusion theory, fuel depletion, and neutron transport equations
CO-4	Apply engineering aspects to reactor kinetics and control, radiation shielding, and reactor material selection

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	-	-	2	3	-	1
CO-2	-	-	2	3	-	1
CO-3	-	-	2	3	-	1
CO-4	-	-	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 BetaParticles 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 ofReactor 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. Glasstone Samuel, Sesonske Alexander, Nuclear Reactor Engineering Reactor Systems Engineering, Springer, 1994, 4th Edition.
2. Manson Benedict, Thomas H. Pigford, Hans WolfgangLevi, Nuclear Chemical Engineering, McGraw-Hill, 1981, 2nd Edition.
3. A. J., Lamarsh, J. R., Baratta, Introduction to Nuclear Engineering, Pearson, 2001, 3rd Edition.

Reference Books:

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

CH26025 **3-0-0 (3)**

Energy Resources, Economics and Environment

Pre-Requisites: **None**

Course Outcomes:

CO-1	Describe renewable and non-renewable energy sources and their availability
CO-2	Assess the interdependencies and trade-offs between energy resources, economics, and the environment
CO-3	Perform data analysis and energy balance calculations
CO-4	Evaluate financial and economic aspects of energy projects
CO-5	Evaluate the environmental impacts associated with energy production and utilization

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	1	1	3	3	2	1
CO-2	1	2	2	3	3	1
CO-3	1	2	1	3	3	1
CO-4	1	3	2	2	2	1
CO-5	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 and Environment: Air pollution, global atmospheric change, the economics of environmental protection, introduction to Life Cycle Assessment (LCA), LCA framework methods and standards, future energy scenarios and elements of sustainability.

Learning Resources:

Text Books:

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

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

Reference Books:

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

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc22_hs43/preview

CH26027 **3-0-0 (3)**

Waste to Energy

Pre-Requisites: **None**

Course Outcomes:

CO-1	Demonstrate technologies for generation of energy from solid waste
CO-2	Select thermochemical conversion methods
CO-3	Identify sources of energy from biochemical conversion
CO-4	Analyse the environmental and health impact of waste to energy conversion

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	1	1	1
CO-2	2	2	-	2	2	1
CO-3	2	2	2	2	-	1
CO-4	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. Robert C. Brown, Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, John Wiley and Sons, 2019.
2. Sergio Capareda, Introduction to Biomass Energy Conversions, CRC Press, 2013.
3. Krzysztof J Ptasinski, Efficiency of Biomass Energy: An Exergy Approach to Biofuels, Power, and Biorefineries, John Wiley & Sons, 2016.
4. Vesilind, P. A., Worrell W. A., Solid Waste Engineering, Cengage India, 2016, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/103/107/103107125/

CH16005 **3-0-0 (3)**

Data Analytics and Machine Learning

Pre-Requisites: **None**

Course Outcomes:

CO-1	Demonstrate proficiency with statistical analysis of data
CO-2	Use inferential statistics for decision making
CO-3	Apply supervised learning for classification and regression problems
CO-4	Apply unsupervised learning for clustering

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	2	2	2	2
CO-2	3	-	2	2	2	2
CO-3	3	-	2	2	2	2
CO-4	3	-	2	2	2	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

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, barchart, 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 andpruning, support vector machines, random forest, Naive Bayes, Introduction to Neural networksand deep learning.

Unsupervised learning: Cluster analysis – K Means, hierarchical, DBSCAN.

Time series analysis: Auto-Regressive (AR), Moving Average (MA), Auto Regressive Moving Average (ARMA), Auto-Regressive Integrated Moving Average (ARIMA).

Practical applications to different engineering systems.

Learning Resources:

Text Books:

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

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/106/107/106107220/
2. https://nptel.ac.in/courses/110/106/110106072/

CH16021 **3-0-0 (3)**

Circular Economy for Sustainable Development

Pre-Requisites: **None**

Course Outcomes:

CO-1	Explain the concept of circular economy and its core principles compared to the traditional linear economy
CO-2	Analyze different circular economy models (e.g., product-service systems, resource recovery, industrial symbiosis) and their applications in specific industries
CO-3	Apply circular design principles to products, processes, and systems for extending their lifespan and value retention
CO-4	Evaluate the role of policy instruments and regulations in promoting circular economy practices
CO-5	Analyze the social, economic, and environmental benefits of transitioning to a circular economy

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	-	-	2	1
CO-2	1	2	-	-	2	1
CO-3	1	2	-	-	2	1
CO-4	3	3	-	-	2	1
CO-5	1	3	-	-	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction to Circular Economy: Definition and Core Principles-The concept of circular economy and its core principles (reduce, reuse, recycle, recover); Comparison of the linear and circular economy models. Drivers and Challenges- Environmental implications of the linear economy, Drivers for transitioning to a circular economy, Challenges of implementing circular economy practices. Circular Economy and SDGs: Links between circular economy and the UN Sustainable Development Goals (SDGs).

Circular Economy Models and Applications: Circular Economy Models- Analysis of different models (e.g., circular product design, closed-loop recycling, sharing economy). Real-world examples of circular economy practices across various industries; Case Studies- Development of a case study on a company successfully implementing circular economy principles; Evaluation of the potential economic and environmental benefits of circular economy models.

Design for Circularity: Circular Design Principles- Explanation of principles (e.g., design for disassembly, durability, material selection); Application of design thinking tools for developing circular product concepts; Life Cycle Analysis- Analysis of the life cycle of a product, Identification of opportunities for circular design interventions, Comparison of Design Approaches- Comparison of traditional product design with design for circularity principles.

Policy and Governance for Circular Economy: Policy Instruments- Evaluation of the role of government policies and regulations in promoting circular economy practices; Analysis of various policy instruments used to support circularity (e.g., extended producer responsibility, eco-design regulations, taxation); Governance and Collaboration- Importance of stakeholder collaboration and multi-level governance for a

successful circular economy transition- Identification and analysis of international initiatives and frameworks promoting circular economy.

Benefits and Future of Circular Economy: Social, Economic, and Environmental Benefits- Analysis of the social, economic, and environmental benefits of a circular economy; Emerging Trends and Innovations- Discussion of emerging trends and innovations in circular economy practices; The Future of Circular Economy-Exploring the potential of circular economy for achieving sustainable development.

Learning Resources:

Text Books:

1. Walter R Stahel, The Circular Economy A User's Guide, CRC Press, 2019.
2. Peter Lacy, Jessica Long, Wesley Spindler, The Circular Economy Handbook: Realizing The Circular Advantage, Palgrave Macmillan, 2020.
3. Peter Lacy, Jakob Rutqvist, Waste to Wealth: The Circular Economy Advantage, Palgrave Macmillan, 2015.

Reference Books:

1. María-Laura Franco-García, Jorge Carlos Carpio-Aguilar, Hans Bressers. Towards Zero Waste: Circular Economy Boost, Waste to Resources, Springer International Publishing, 2019.
2. Marcello Tonelli, Nicolo Cristoni, Strategic Management and the Circular Economy, Routledge, 2018.
3. Sadhan Kumar Ghosh, Circular Economy: Global Perspective, Springer, 2020.
4. Stahel, Walter R., The Circular Economy: A User's Guide, Routledge, 2019
5. Lerwen Liu, Seeram Ramakrishna, An Introduction to Circular Economy, Springer, 2021.

Other Suggested Readings:

1. https://online-learning.harvard.edu/course/introduction-circular-economy?delta=0

CH16023 **3-0-0 (3)**

Advanced Mass Transfer

Pre-Requisites: **None**

Course Outcomes:

CO-1	Design multicomponent columns using equilibrium-based approach
CO-2	Analyse separations involving energy and mass separating agents
CO-3	Select advanced separation technique for a given process
CO-4	Design reactive separation processes

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	-	3	2	1
CO-2	3	-	-	3	2	1
CO-3	3	-	-	3	2	1
CO-4	3	-	-	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Multi-component system fractionation: Preliminary calculations, feed condition, column pressure, design procedure, number of equilibrium stages, feed location, estimation of number of theoretical plates – shortcut methods and rigorous calculation methods.

Enhanced Distillation and Supercritical Extraction: extractive distillation, distillation, pressure-swing distillation, azeotropic distillation, reactive distillation, supercritical fluid extraction.

Membrane Separations: transport in membranes, dialysis, electrodialysis, reverse osmosis, gas permeation, pervaporation.

Adsorption, Ion Exchange, Chromatography: sorbents, equilibrium considerations, kinetic and transport considerations, equipment for sorption operations, Ion-exchange cycle.

Leaching and Washing: equipment for leaching, equilibrium-stage model for leaching and washing, rate-based model for leaching.

Reactive Separation processes: reactive distillation, extraction with reaction, absorption with reaction, adsorption with reaction, reactive membrane separation, reactive crystallization.

Learning Resources:

Text Books:

1. J.D. Seader, Ernest J. Henley, D. Keith Roper, Separation Processes Principles, John Wiley& Sons, 2011, 3rd Edition.
2. King C. J., Separation Processes, Tata McGraw Hill Book Company,1983, 2nd Edition.
3. Geankoplis C. J., Transport Processes and Unit Operations, Prentice Hall of India Pvt. Ltd., 2004, 4th Edition.
4. Santi Kulprathipanja, Reactive Separation Processes, Taylor & Francis, 2002.

Other Suggested Readings:

1. https://nptel.ac.in/courses/103/105/103105060/

PH18025 **3-0-0 (3)**

Solar Energy Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Outline the technologies that are used to harness the power of solar energy
CO-2	Understanding of the available solar energy and the current solar energy conversion and utilization processes
CO-3	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
CO-4	Understand the manufacturing processes involved, environmental challenges that need to be solved, economic aspects, and future potential
CO-5	Illustrate the concepts of direct energy conversion systems and their applications

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	1	1	1	1
CO-2	1	1	1	2	2	1
CO-3	1	1	2	3	3	1
CO-4	1	1	2	2	2	1
CO-5	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. Martin A. Green, Solar Cells: Operating Principles, Technology and System Applications, Published by the University of New South Wales, 1998, 1st Edition.
2. D. Yogi Goswami, Principles of Solar Engineering, Taylor and Francis, 2000, 1st Edition.

Reference Books:

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

Other Suggested Readings:

1. https://energyeducation.ca/encyclopedia/Photovoltaic_system

EE16025 **3-0-0 (3)**

Electric Vehicles

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the concepts of electric vehicles, hybrid electric vehicles and their impact on environment
CO-2	Analyze the drive-train topologies and advanced propulsion techniques
CO-3	Analyze hybrid energy storage methodologies
CO-4	Identify the suitable power converter topologies for motor control and hybrid energy storage

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	2	3	3	2
CO-2	1	2	2	3	3	2
CO-3	1	2	3	3	3	2
CO-4	2	2	3	3	3	2

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 drive- trains on energy supplies.

Hybrid Electric Vehicles: Micro hybrid vehicles, mild hybrid vehicles, full hybrid vehicles, configuration of hybrid electric Vehicles -Parallel hybrid, series Hybrid, Series-Parallel Hybrid, Complex Configuration. Power flow diagrams Hybrid electric vehicle configurations 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, Electric Hybrid electric vehicles-configurations, Solar powered vehicles.

Electric drive-trains: Basic concept of electric traction, introduction to various electric drive- train topologies, power flow control in electric drive-train topologies, fuel efficiency analysis.

Electric propulsion unit: Electric components used in electric vehicles, Configuration and control schemes of DC Motor drives, Induction Motor drives, BLDC motor drives, Permanent Magnet Motor drives, Switch Reluctance Motor drives.

Energy Storage: Storage requirements for Electric Vehicles, Battery energy storage, Fuel Cell based energy storage, Super Capacitor based energy storage and Super Magnetic Energy storage (SMES). Power pack management systems, Active and passive Cell balancing techniques. Hybridization of different energy storage devices, Flywheel based energy storage, compressed air storage systems, super magnetic storage 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, coupled inductor based configurations.

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. Ali Emadi, Advanced Electric Drive Vehicles, CRC Press, 2015.
2. Iqbal Hussein, Electric and Hybrid Vehicles: Design Fundamentals, CRC Press, 2021, 3rd Edition.

Reference Books:

1. Mehrdad Ehsani, Yimi Gao, Sebastian E. Gay, Ali Emadi, Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, CRC Press, 2023, 3rd Edition.
2. James D. Halderman, Curt Ward, Pear Son, Electric and Hybrid Electric Vehicles, 2023, 1st Edition.
3. Aunpam Singh, Electric Vehicles and the end of ICE Age, 2022, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/106/108106170/
2. https://nptel.ac.in/courses/108/102/108102121/

EE16026 **3-0-0 (3)**

Control and Integration of Renewable Energy Sources

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand different renewable energy sources and storage devices
CO-2	Model and simulate renewable energy sources
CO-3	Analyze and simulate control strategies for grid-connected and off-grid systems
CO-4	Develop converters to comply with grid standards to obtain grid integration

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	2	3	3	2
CO-2	3	3	3	3	3	2
CO-3	3	3	3	3	3	2
CO-4	3	3	3	3	3	2

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. G. Masters, Renewable and Efficient Electric Power Systems, IEEE-John Wiley and Sons Ltd., 2013, 2nd Edition.

2. A. MahaboobSubahani, G. R. Kanagachidambaresan, M. Kathiresh, Integration of Renewable Energy Sources with Smart Grid, Willey, 2021.
3. Felix A. Farret, M. Godoy Simoes, Integration of Renewable Sources of Energy, Wiley, 2017, 2nd Edition.

Reference Books:

1. Chetan Singh Solanki, Fundamentals, Technologies & Applications, Solar Photovoltaic, PHI Publishers, 2019, 3rd Edition.
2. Quing-Chang Zhong, Control of Power Inverters in Renewable Energy and Smart Grid Integration, IEEE-John Wiley and Sons Ltd. Publishers, 2013, 1st Edition.
3. Bin Wu, Yongqiang Lang, Navid Zargari, Power Conversion and Control of Wind Energy Systems, IEEE- John Wiley and Sons Ltd. Publishers, 2011, 1st Edition.
4. S. Chowdhury, S. P. Chowdhury, P. Crossley, Microgrids and Active Distribution Networks, IET Power Electronics Series, 2012.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/102/108102145/
2. https://nptel.ac.in/courses/103/103/103103206/

ME56025 **3-0-0 (3)**

Alternate Fuels and Emissions

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the need of alternate fuels
CO-2	Evaluate the performance of the engine with alternate fuels and blends with petroleum derived fuels
CO-3	Examine the viable production and storage methods of alternate fuels
CO-4	Measure the pollutant emissions as per standards and describe emission control methods

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	2	1	1	1
CO-2	1	1	2	3	2	1
CO-3	1	1	2	3	3	1
CO-4	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 Hydrogenand Aldehydes.

Emission Measurement and Control Methods: Measurement of Pollutants Using Flame Ionization

Detection, NDIR, Chemiluminescent Analyzer and Particulate Matter (Soot/Smoke),mission Norms-EURO and Bharat Stage Engine Emission, Control Methods: in Cylinder andAfter Treatment Methods.

Learning Resources:

Text Books:

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

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/112/104/112104033/

ME16023 **3-0-0 (3)**

Power Plant Engineering

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply the principles of thermodynamics to analyse the performance of steam, gas, combined and nuclear power plants
CO-2	Design and develop power plant components for optimum performance
CO-3	Select appropriate site and technology for power plants
CO-4	Evaluate economic and environmental implications on power plants

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	3	3	3	3
CO-2	3	3	3	3	3	2
CO-3	3	3	3	3	3	2
CO-4	3	3	3	3	3	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Energy Resources and Their Availability, Types of Power Plants, Selection of thePlants, 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-Poweringof Thermal Power Plant.

Nuclear Power Plants: Principles of Nuclear Energy, Basic Nuclear Reactions, Nuclear Crosssection, 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. Nag, P. K., Power Plant Engineering, McGraw Hill Education, 2017, 4th Edition.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/112/107/112107291/

ME16025 **3-0-0 (3)**

Renewable Sources of Energy

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify the renewable energy sources, their utilization and storage
CO-2	Understand the basic concepts of the solar radiation and analyze the solar thermal systems for their utilization
CO-3	Understand the principle of working of solar cells and their modern manufacturing techniques
CO-4	Analyze wind energy, biomass and Fuel cell systems and their applications
CO-5	Design of solar thermal and energy storage systems for specific applications
CO-6	Evaluate the energy conversion from ocean thermal energy, geothermal energy, biomass and magneto hydrodynamic power generation

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	1	1	2	3	3
CO-2	3	2	2	3	3	2
CO-3	2	2	3	3	3	2
CO-4	2	2	2	1	3	2
CO-5	3	3	3	2	3	2
CO-6	2	2	2	1	3	2

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. Indianand 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 HybridSystem, Environmental Aspects, Wind Energy Storage, Wind Energy Program 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 CycleOTEC 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. Khan, B. H., Non-conventional Energy Resources, Tata McGraw Hill, 2017, 3rd edition.
2. Rao, S.,Parulekar, Energy Technology: Non-Conventional, Renewable and Conventional, B. B., Khanna Publishers, 2010, 1st Edition.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/121/106/121106014/

Professional Electives – III, IV & V

CH26022 **3-0-0 (3)**

Energy Management and Life Cycle Assessment

Pre-Requisites: **None**

Course Outcomes:

CO-1	Demonstrate the goals, scope and industrial standards of LCA & energy management
CO-2	Interpret the results of inventory analysis and life cycle impact assessment
CO-3	Compare the environmental performance of different renewable energy options
CO-4	Apply various approaches to optimize energy use and reduce energy consumption
CO-5	Apply LCA as a decision-making tool to create sustainable and environmentally friendly energy systems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	2	2	1	1
CO-2	3	3	2	3	1	1
CO-3	3	2	2	2	2	1
CO-4	3	2	2	2	3	2
CO-5	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 ImpactAssessment (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 andProduct 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 EnergyManagement, 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. Curran, M. A., Life Cycle Assessment Student Handbook, John Wiley & Sons, 2015.
2. David Allen, David R. Shonnar, Sustainable Engineering: Concepts, Design, and Case Studies, Prentice Hall, 2011.
3. Stephen A. Roosa, Steve Doty, Wayne C. Turner, Energy Management Handbook, River Publishers, 2000, 9th Edition.

Reference Books:

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

CH26024 **3-0-0 (3)**

Energy, Water and Food Nexus

Pre-Requisites: None

Course Outcomes:

CO-1	Understand the concept of the Energy-Water-Food Nexus and its importance
CO-2	Analyse the interactions within the Energy-Water-Food Nexus and investigate the emerging paradigm
CO-3	Evaluate the energy and water use in agriculture for food production and security
CO-4	Explore the models and tools used to operationalize the Energy-Water-Food Nexus
CO-5	Assess water, energy, and carbon footprints using relevant case studies

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	1	1	1	1
CO-2	1	1	2	2	2	1
CO-3	1	1	2	2	2	1
CO-4	1	1	2	2	3	1
CO-5	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, Evolutionof the Nexus as a Policy and Development Discourse, The Nexus Contribution to Better WaterManagement and Its Limitations, Dynamic and Cross Sectoral Analyses of the Water-Energy-Food Nexus, Investigating an Emerging Paradigm, Importance and Relevance of the Nexus inAddressing 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 AfricanPerspective, 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. Salam, P. A., Shrestha, S., Pandey, V. P., Anal, A. K., Water-Energy-Food nexus: Principles and Practices, John Wiley & Sons, 2017.
2. Ahuja, S., Food, Energy, and Water: The Chemistry Connection, Elsevier, 2015.
3. Allouche, J., Middleton,C., Gyawali, D., Routledge, The Water–Food–Energy Nexus: Power, Politics, and Justice, Taylor & Francis, 2019.

Reference Books:

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

CH26026 **3-0-0 (3)**

Modelling and Analysis of Process and Energy Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the fundamental concepts of linear algebra
CO-2	Analyze and solve ordinary and partial differential equations using suitable techniques and approaches
CO-3	Develop mathematical models and perform analysis for process and energy systems
CO-4	Utilize computer-aided tools and techniques to solve mathematical models

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	1	1	1	1
CO-2	1	1	2	1	2	1
CO-3	1	1	3	3	3	1
CO-4	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, Battery Modelling: Battery Boot Camp, Equivalent-Circuit Cell Models, Microscale Cell Models, Continuum (Porous-Electrode) Cell Models.

Learning Resources:

Text Books:

1. Gilbert Strang, Introduction to Applied Mathematics, Wellesley Cambridge Press. 2009.
2. Gilbert Strang, Linear Algebra and Its Applications, Wellesley Cambridge Press, 2009, 4th Edition.
3. Gourdin, A., Boumhrat, M., Applied Numerical Methods, Prentice Hall India, 2000.
4. Sayyaadi, H., Modeling, assessment, and optimization of Energy Systems, AcademicPress, 2020.
5. Knopf, F. C., Modeling, analysis and optimization of process and energy systems, John Wiley & Sons, 2011.
6. Gregory L. Plett, Battery Management Systems, Volume 1: Battery Modeling, Artech House, 2015.

Reference Books:

1. Lund, H., Renewable Energy Systems: The Choice and Modeling of 100% Renewable Solutions Academic Press, 2009.
2. Frangopoulos, C. A., Exergy, Energy System Analysis and Optimization-Volume III: Artificial Intelligence andExpert Systems in Energy Systems Analysis Sustainability Considerations in the Modeling of Energy Systems (Vol. 3), EOLSS Publications, 2009.
3. Energy Systems Engineering: Evaluation and Implementation, Vanek, F. M., Albright, L. D., Angenent, L. T., McGraw Hill Education, 2016.

CH26028 **3-0-0 (3)**

Sustainable Recycling of Energy Materials

Pre-Requisites: None

Course Outcomes:

CO-1	Understand the importance of recycling in the context of energy materials and their impact on sustainable energy systems
CO-2	Analyze the composition, recyclability, and challenges associated with energy materials
CO-3	Select material recovery techniques and recycling technologies specific to energy materials
CO-4	Gain knowledge of policy frameworks, regulations, economic considerations, and market opportunities relevant to energy material recycling

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	2	1	1
CO-2	2	2	2	2	1	1
CO-3	2	2	2	2	2	1
CO-4	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 EnergyMaterials 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, EnvironmentalImpacts 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. Worrell, E., Reuter, M. A., Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists, Newnes, 2014.
2. Guangjin Zhao, Reuse and Recycling of Lithium-Ion Power Batteries, Wiley Online Library, 2017.

Reference Books:

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

CH26030 **3-0-0 (3)**

Bioenergy and Biofuels

Pre-Requisites: None

Course Outcomes:

CO-1	Describe the nature and principle of different biomass energy extraction systems
CO-2	Choose suitable biomass fuels for different energy applications
CO-3	Address the desirable features of biomass energy sources and their advantages over traditional fuels such as petroleum and coal
CO-4	Identify suitable bioenergy sources in terms of suitable sites, composition and cost-effectiveness

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	2	3	1	3
CO-2	3	3	2	3	1	3
CO-3	3	3	2	3	1	3
CO-4	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, SizeReduction, 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 ofThermal 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. Filemon A. Uriarte Jr., Biofuels from Plant Oils, ASIAN Foundation, 2010.
2. Anuj Dahiya, Bioenergy: Biomass to Biofuels, Elsevier, 2015.
3. Sunggyu Lee, Y. T. Shah, Biofuels and Bioenergy Processes and Technology, CRC Press, 2013.

4. Pandey, A., Larroche, C.,Ricke, S. C., Dussap, C. G., Gnansounou, E,.Biofuels: Alternative Feedstocks and Conversion Processes, Academic Press, 2011.
5. Brown, R. C., Thermochemical Processing of Biomass into Fuels, Chemicals and Power, Wiley, 2011.

Reference Books:

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

CH16002 **3-0-0 (3)**

Computational Fluid Dynamics

Pre-Requisites: **None**

Course Outcomes:

CO-1	Develop governing equations of fluid flow and heat transfer
CO-2	Discretize the equations using finite difference and finite volume formulation
CO-3	Solve the discretized equations
CO-4	Implement pressure velocity coupling algorithms
CO-5	Generate grid for a given geometry

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	3	3	1
CO-2	2	1	1	3	3	1
CO-3	2	1	1	3	3	1
CO-4	2	1	1	3	3	1
CO-5	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. H.K. Versteeg, Malalasekera, W., An Introduction to Computational Fluid Dynamics – the Finite Volume Method, Prentice Hall, 2007, 2nd Edition.
2. John D. Anderson, Jr.,Computational Fluid Dynamics – the Basics with Applications, McGraw Hill Education, 2017.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/103/106/103106119/
2. https://www.cfd-online.com

CH16004 **3-0-0 (3)**

Steady State Process Simulation

Pre-Requisites: **None**

Course Outcomes:

CO-1	Analyse the role and importance of property estimation methods in process simulation
CO-2	Determine the degrees of freedom for a given stream, process unit and flowsheet
CO-3	Apply suitable mathematical methods for solving sparse sets of equations, partitioning & precedence ordering and tear stream sets
CO-4	Carry out steady state process simulation using sequential modular approach and equation-oriented approach
CO-5	Apply convergence promotion techniques for both sequential and simultaneous convergence loops

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	1	3	3	1
CO-2	2	-	-	3	2	1
CO-3	3	-	-	3	3	1
CO-4	3	-	-	3	2	1
CO-5	3	-	-	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Steady-state flowsheeting and the design process, the total design project.

Flowsheeting on the computer: Motivation for development, Developing a simulation model, Approaches to flowsheeting systems-examples.

Solving linear and nonlinear algebraic equations: Solving one equation in one unknown, Solution methods for linear equations, General approaches to solving sets of nonlinear equations, Solving sets of sparse nonlinear equations.

Physical property service facilities: The data cycle, Computerized physical property systems, Physical property calculations.

Degrees of freedom in a flowsheet: Degrees of freedom, Independent stream variables, Degrees of freedom for a stream and a unit, Degrees of freedom for a flowsheet.

The sequential modular approach to flowsheeting: The solution of an example flowsheeting problem, Other features: Handling design specifications, information streams and control blocks.

Convergence of tear streams: Sequential convergence and simultaneous convergence, Partitioning and precedence ordering set of equations and a flowsheet, tearing a flowsheet, Finding the best tear set family or tear set with minimum number of tears.

Flowsheeting by equation solving methods based on tearing: An example system based on equation solving, A complex example of selecting decision and tear variables for a flowsheet, Handling the iterated variables.

Simulation by linear methods: Introduction to linear simulation, Application to staged operations, Application to management problem.

Learning Resources:

Text Books:

1. Westerberg A. W., Hutchison H. P., Motard R. L. and Winter P., Process Flowsheeting, Cambridge University Press, 2011.

Reference Books:

1. Ivan Dano Gill Chaves, Javier Ricardo Guevara Lopez, Jpose Luis Garcia Zapata, Alexander Leguizamon Robayo and Gerardo Rodrigue Nino, Process Analysis and Simulation in Chemical Engineering, Springer, 2016.
2. Babu B. V., Process Plant Simulation, Oxford University Press, 2004.
3. Mariano Martin Martin, Introduction to Software for Chemical Engineers, CRC Press, 2015.

CH16022 **3-0-0 (3)**

Wastewater Treatment

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the principles and operation of wastewater treatment systems
CO-2	Identify suitable treatment processes
CO-3	Evaluate process operations and performance
CO-4	Differentiate coagulation, flocculation, sedimentation, filtration and disinfection

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	-	1	-	1
CO-2	2	2	-	2	-	1
CO-3	2	2	-	3	-	1
CO-4	2	1	-	3	-	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Sources of wastewater; Necessity of treatment; Critical wastewater quality parameters; Water quality guidelines and standards for various water uses; Wastewater flowrates and constituent loadings.

Wastewater microbiology: Bacteria; Cell composition and structure; Bacterial growth curve; Classification by carbon and energy requirement; Classification by oxygen requirement; Classification by temperature, Bacteria of significance – Archaea, Protozoa, Algae, Fungi, Virus.

Classification of wastewater treatment methods: Physical treatment; Chemical treatment; Biological treatment; Levels of wastewater treatment: Preliminary treatment, Primary treatment, Enhanced primary treatment, Conventional secondary treatment, Secondary treatment with nutrient removal, Tertiary treatment, Advanced treatment.

Preliminary treatment: Screens; Shredder/grinder; Grit chambers; Primary treatment - Types of settling/sedimentation, Primary sedimentation, Chemically enhanced primary treatment.

Secondary treatment (Suspended growth processes): Microbial growth kinetics; Activated sludge process; Aeration requirements; Types of aerators; Types of suspended growth processes; Staged activated sludge process; Extended aeration process; Oxidation ditch; Sequencing batch reactor (SBR); Membrane biological reactor (MBR); Stabilization ponds and lagoons.

Secondary treatment (Attached growth and combined processes): System microbiology and biofilms; Stone media trickling filter; Rotating biological contactor; Hybrid processes; Moving bed biofilm reactor (MBBR); Integrated fixed-film activated sludge (IFAS); Fluidized bed bioreactor (FBBR); Combined processes.

Secondary Clarification: Secondary clarifier for attached growth processes and suspended growth processes.

Anaerobic wastewater treatment: Anaerobic growth kinetics; Anaerobic attached and suspended growth processes.

Solids processing and disposal: Characteristics of municipal sludge; Sludge thickening and stabilization; Biosolids dewatering.

Introduction to advanced treatment processes: Membrane processes; Ceramic and polymeric membrane processes; Microfiltration; Ultrafiltration, Reverse osmosis.

Learning Resources:

Text Books:

1. MetCalf, Eddy, Wastewater engineering, Treatment and Reuse, Tata McGraw Hill, 2003, 3rd Edition.
2. Rumana Riffat, Fundamentals of wastewater treatment and engineering, CRC Press, 2013.

Reference Books:

1. S.J. Arceivala, S.R. Asolekar, Wastewater Treatment for Pollution Control and Reuse, Tata McGraw Hill, 2007, 3rd Edition.
2. Fair, G.M., Geyer J.C, Okun, Water and Wastewater Engineering, John Wiley Publications, 2010, 3rd Edition.
3. Tchobanoglous G., Burton F. L., Stensel H.D., Wastewater Engineering: Treatment and Reuse, Tata McGraw Hill, 2002, 4th Edition.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc19_ce32/preview

CH16024 **3-0-0 (3)**

Engineering Optimization

Pre-Requisites: **None**

Course Outcomes:

CO-1	Formulate objective function for a given problem
CO-2	Solve unconstrained single and multi-variable optimization problems
CO-3	Apply linear programming and nonlinear programming techniques
CO-4	Use dynamic programming for optimization

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	-	-	-	2	1
CO-2	3	-	-	-	2	1
CO-3	3	-	-	-	2	1
CO-4	3	-	-	-	2	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).

Learning Resources:

Text Books:

1. Edgar T.F., D. M. Himmelblau, Optimization of Chemical Processes, McGraw Hill, 2001, 2nd Edition.
2. Stoecker W. F., Design of Thermal Systems, McGraw Hill, 2011, 3rd Edition.

Reference Books:

1. Singiresu S Rao, Engineering Optimization: Theory and Practice, John Wiley & Sons Ltd., 2019, 5th Edition.
2. Stephen Boyd, Lieven Vandenberghe, Convex optimization, Cambridge University Press, 2004.
3. P. Venkataraman, Applied Optimization with MATLAB Programming, Wiley, 2009, 2nd Edition

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/103/105/103105139/

CH16026 **3-0-0 (3)**

CO_2 Capture, Sequestration and Utilization

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify the necessity of CO_2 capture, storage and utilization
CO-2	Distinguish the CO_2 capture techniques
CO-3	Evaluate CO_2 storage and sequestration methods
CO-4	Assess environmental impact of CO_2 capture and utilization

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	1	2	3
CO-2	3	2	3	1	2	3
CO-3	3	2	3	1	2	3
CO-4	3	2	3	1	2	3

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. Peter Styring, Elsje Alessandra Quadrelli, Katy Armstrong, Carbon dioxide utilization: Closing the Carbon Cycle, Elsevier, 2015.
2. Goel, M., Sudhakar, M., Shahi, R. V., Carbon Capture, Storage and, Utilization: A Possible Climate Change Solution for Energy Industry, TERI, Energy and Resources Institute, 2015.
3. Amitava Bandyopadhyay, Carbon Capture and Storage, CO_2 Management Technologies, CRC Press, 2014.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/103/107/103107157/
2. https://climate.mit.edu/explainers/carbon-capture

CH16028 **3-0-0 (3)**

Energy Audit and Conservation

Pre-Requisites: **None**

Course Outcomes:

CO-1	Implement energy audit for a process plant
CO-2	Plan energy conservation strategies
CO-3	Evaluate the suitability of renewable energy resources
CO-4	Analyze the energy utilization of a process equipment

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	1	3	3	1
CO-2	3	2	2	3	3	-
CO-3	3	1	1	3	3	-
CO-4	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. W. R., Mckay, G., Energy Management, Murphy, Elsevier, 2007.
2. Hinrichs, R. A., Kleinbach, M. H., Energy: Its Use and the Environment, Cengage Learning, 2012.
3. Capehart, B. L., Turner, W. C., Kennedy, W. J., Keinnedu, Guide to Energy Management, Fairmant press, 2011, 7th Edition.

Reference Books:

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

Other Suggested Readings:

1. https://nptel.ac.in/courses/112/105/112105221/

CH16030 **3-0-0 (3)**

Novel Separation Techniques

Pre-Requisites: **None**

Course Outcomes:

CO-1	Select a membrane and membrane process for a given application
CO-2	Evaluate the flux of solvent and solute through membrane
CO-3	Differentiate surfactant based separation
CO-4	Design centrifugal separation processes

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	1	-	1
CO-2	1	-	2	3	-	1
CO-3	1	-	2	3	-	1
CO-4	1	-	2	2	-	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Fundamentals of separation processes, Basic definitions of relevant terms.

Membrane separation process: Definition of Membrane, Membrane types, Advantages and limitations of membrane technology compared to other separation processes, Membrane materials and properties.

Preparation of synthetic membranes: Phase inversion membranes, Preparation techniques for immersion precipitation, Synthesis of asymmetric and composite membranes and Synthesis of inorganic membranes.

Transport in membranes: Introduction, Driving forces, Non-equilibrium thermodynamics, Transport through porous membranes, transport through non- porous membranes, Transport through ion-exchange membranes.

Membrane processes: Pressure driven membrane processes, Concentration as driving force, electrically driven membrane processes.

Polarization phenomena and fouling: Concentration polarization, Pressure drop, Membrane fouling, methods to reduce fouling.

Modules: Introduction, membrane modules, Comparison of the module configurations.

Gas separation: Basic Principles, Membranes for gas separations, membrane modules, gas transport mechanisms, factors affecting gas permeation, complete mixing model, cross flow model, counter current model.

Surfactant based separation processes: Liquid membranes: Fundamentals and modelling, Micellar enhanced separation processes, Cloud point extraction.

Other separation processes: Centrifugal Separation processes and their calculations. Ion exchange and chromatographic separation processes. Supercritical fluid extraction.

Learning Resources:

Text Books:

1. Mulder M., Basic Principles of Membrane Technology, Kluwer Academic Publishers, 1996.
2. Baker R. W., Membrane Technology and Research, Inc. (MTR), 2004.
3. Nath K., Membrane Separation Processes, Prentice-Hall Publications, 2008.
4. R. W. Rousseau, Handbook of Separation Process Technology, John Wiley & Sons, 1987.
5. M. A. Mchugh, V. J. Krukonis, Supercritical Fluid Extraction: Principles and Practice, Butterworth Heinmann, 2013, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/103105060

CH16050 **3-0-0 (3)**

Heat Integration and Process Scheduling

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify the objectives of heat integration and process scheduling
CO-2	Apply the concepts of pinch technology and retrofitting
CO-3	Develop models for batch process scheduling
CO-4	Analyze heat exchanger networks and process scheduling models

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	2	1	1	1	1	1
CO-2	2	1	2	3	3	1
CO-3	2	1	2	3	3	1
CO-4	2	3	2	3	3	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Heat Integration:

Introduction: Heat integration fundamentals; History and industrial experience; Why does pinch analysis work; The concept of process synthesis; The role of thermodynamics in process design.

Key concepts of Pinch analysis: Heat recovery and heat exchange; The pinch and its significance; Heat exchanger network design; Choosing ΔT_{min}; Methodology of pinch analysis.

Data extraction and energy targeting: Data extraction; Case study: Organics distillation plant, Energy targeting, Multiple utilities, Targeting heat exchanger units, Area and shells, Super targeting, Targeting organics distillation plant case study.

HEN Design Utilities: Heat exchange equipment; Stream splitting and cyclic matching; Network relaxation; More complex designs; Multiple pinches and near pinches; Retrofit design.

Process Scheduling:

Short-Term Scheduling: Effective technique for scheduling of multipurpose and multi product batch plants; Different storage policies for intermediate and final products; Evolution of multiple time grid models in batch process scheduling; Short-term scheduling of multipurpose plants; Planning and scheduling in chemical and biopharmaceutical industry.

Heat integration in multipurpose batch plants: Direct and indirect heat integration; Simultaneous optimization of energy and water use in multipurpose batch plants.

Design and Synthesis: Design and synthesis of multipurpose batch plants; Process synthesis approaches for enhancing sustainability of batch process plants; Scheduling and design of multipurpose batch facilities.

Learning Resources:

Text Books:

1. Ian C Kemp, Pinch Analysis and Process Integration, Elsevier Publication, 2007, 2nd Edition.
2. Thokozani Majozi, Esmael Reshid Seid, Jui-Yuan Lee, Synthesis, Design, and Resource Optimization in Batch Chemical Plants, CRC Press, 2015.

Reference Books:

1. Thokozani Majozi, Batch Chemical Process Integration - Analysis, Synthesis and Optimization, Spinger, 2010.
2. Mohmoud Bahy Noureddin, Pinch Technology and Beyond Pinch, New Vistas on Energy Efficiency Optimization, Booktopia, 2011.
3. Gintaras V. Reklaitis, Aydin K. Sunol, David W. T. Rippin, Oner Hortacsu, Batch Processing Systems Engineering, Spinger, 1996.
4. Mariano Martin, Introduction to Software for Chemical Engineers, CRC Press, 2015.

CH16060 **3-0-0 (3)**

Advanced Process Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify controlled and manipulated variables
CO-2	Design regulatory control schemes for a given process
CO-3	Analyse the multivariable process control schemes
CO-4	Evaluate linear and nonlinear model predictive control strategies

Course Articulation Matrix:

	PO-1	**PO-2**	**PO-3**	**PO-4**	**PO-5**	**PO-6**
CO-1	3	1	-	1	2	2
CO-2	3	1	-	1	2	2
CO-3	3	1	-	1	2	2
CO-4	3	1	-	1	2	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Hierarchy of control layers, review of basics, system linearization, state space and transfer function models.

Advanced regulatory control schemes: Cascade control, feed-forward control, ratio control, split-range control, time delay compensator, and inverse response compensator.

Multivariable control: Challenges, Control pairing; Interactions in closed-loop systems; Relative Gain Array (RGA) and variants. Centralized, decentralized, decoupled control schemes.

Model Predictive Control (MPC): MPC control formulation: simple unconstrained optimal control formulation, general characteristics of MPC formulation, translation of MPC problem into quadratic programming optimization problem, Practical MPC implementation considerations: empirical model development, usage of design/tuning parameters, design of MPC control for typical systems.

Extensions of MPC: Theory: Economic MPC, Nonlinear Model Predictive Control (NMPC), Robust MPC, Data-driven MPC.

Learning Resources:

Text Books:

1. Seborg, D. E., Edgar, T. F., Millechamp, D. A., Doyle III, F. J., Process Dynamics and Control, Wiley, 2014, 3rd Edition.
2. Raghunathan Rengaswamy, Babji Srinivasan, Nirav Pravinbhai Bhatt, Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, CRC Press, 2020.
3. Liuping Wang, Model Predictive Control System Design and Implementation using MATLAB, Springer, 2009.

Reference Books:

1. Francesco Borrelli, Alberto Bemporad, Manfred Morari, Predictive Control for Linear and Hybrid Systems, Cambridge University Press, 2017.
2. Jean-Pierre Corriou, Process Control: Theory and Applications, Springer, 2018, 2nd Edition.
3. B. Roffel, B. Betlem, Process Dynamics and Control, Wiley, 2006.
4. Cecil L. Smith, Advanced Process Control, Wiley, 2010.
5. Surekha Bhanot, Process Control: Principles and Applications, Oxford, 2008.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc21_ge01/preview

EE36024 **3-0-0 (3)**

Transactive Energy Markets

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand Transactive Energy (TE) and Transactive Energy resources
CO-2	Analyze Transactive Energy as a Grid Support service
CO-3	Model Transactive Control for Stable and economic operation of Smart Grid
CO-4	Develop TEM models and understand its application

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	-	-	1	1	1	-
CO-2	-	-	1	1	1	-
CO-3	-	-	1	2	2	-
CO-4	-	-	1	2	3	-

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction to Transactive Energy (TE): Transactive Energy Definition, Transactive Energy Products, Transactive Energy Market Participants, Transactive Energy Classification scheme for renewable market participants.

Transactive Energy Market Models: Transactive Energy Market Models: Transactive Node based Energy Management model, Hierarchical Energy Management Model. Conceptual View of Distributed Power Generation and Management, Centralized and Decentralized Transactive Energy, Transactive energy vs. demand response, TE market management.

Transactive Energy as Grid Support Services: Ancillary Services from TEM, Characterization of Residential Distributed Energy Resource Potential to Provide Ancillary Services, New Emerging ASs to Be Offered by DRESs, Synthetic Inertia from TEM, Inertia response from wind turbines, Voltage control and reactive power supply from solar PV and Battery Energy Storage System, Harmonic mitigation as ancillary service from DERs, Ancillary Service Transactive Energy Market design.

Transactive Control: Transactive control (TC) in Smart Grid, Time scale for TC, TC implanting methodologies, Transactive Control for HVAC systems, Transactive Control model for distribution congestion management, Transactive Control for EV chargers, TE based Auction mechanism, Price- based resource scheduling and dispatch, Congestion management, Market-clearing and pricing in TEM.

Transactive Energy Applications: Concept of Prosumers and Peer-to-peer (P2P) market, P2P and P2G Energy Trading, Energy Management under uncertainties in P2P Market, Game Theory in TEM, Concept of Blockchain techniques, Multi-agent Transactive energy management, Challenges in Transactive Electricity Market.

Learning Resources:

Text Books:

1. MohammadrezaDaneshvar, Behnam Mohammadi-Ivatloo and Kazem Zare, Emerging Transactive

Energy Technology for Future Modern Energy Networks‖, Academic Press, 2022, 1st Edition.
2. S. Barrager, E. Cazalet, —Transactive Energy: A Sustainable Business and Regulatory Model for Electricity‖, Baker Street Publishing, 2014, 1st Edition.

Reference Books:

1. Aisultan Alimkhan, Ileskhan Kalysh, Ilyas Temirtayev, Transactive Energy Management System‖, Lambert Academic Publishing, 2019, 1st Edition.
2. Meng Song, Ciwei Gao, Integration of Distributed Resources in Smart Grids for Demand Response and Transactive Energy: A Case Study of TCLs‖, Springer Verlag, 2022, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/129105004

EE36005 **3-0-0 (3)**

Challenges and Solutions in Renewable Integration

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the importance of grid codes for renewable integration
CO-2	Understand challenges due to uncertainties in renewable energies
CO-3	Assess power quality and inertia issues with increased penetration of RES in electric grids
CO-4	Evaluate solutions and apply for renewable energy issues

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	-	-	1	1	1	-
CO-2	-	-	1	1	1	-
CO-3	-	-	1	2	2	-
CO-4	-	-	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.

Photovoltaic Penetration in Distribution Network: Mathematical model of grid connected PV system, performance evaluation with conventional MPPT, application of adaptive neuro fuzzy inference system (ANFIS) for DC-DC convertor for PV system. 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.

Solution for RES Uncertainties: Storage Technologies for Overcoming Uncertainty and Variability With Renewable Resources, Managing Operational Uncertainty Through Improved Visualization Tools in Control Centers with Reference to Renewable Energy Providers, SynchroPhasors 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, Dynamic response with Fuel cell and Microturbine combination, virtual inertia concept with PV and Diesel generator combination.

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,

Renewable Generation Integration and Long Term Power Purchase Agreements (PPA).

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, 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. Concept of grid forming and grid following.

Learning Resources:

Text Books:

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

Reference Books:

1. Ali Keyhani, Mohammad N. Marwali, Min Dai, Integration of Green and Renewable Energy in Electric Power Systems, Wiley publisher, 2009.
2. John Twidell, Renewable Energy Resources, Routledge Taylor and Francis Group publishers, 2021, 4th Edition.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc23_ge47/preview
2. https://iitk.ac.in/smartcity/qip/download/ppt/Day2/Sandeep_Anand_Renewable%20Integration%20and%20Microgrid_shared.pdf