Curriculum

for

Master of Technology

in

Energy Systems and Management

(ESM)

under

Centre for Energy and Environment

Department of Mechanical Engineering

Delhi Technological University

Shahbad-Daulatpur, Delhi-110042

M.Tech. (Energy Systems and Management) course is meant for those aspiring for higher education in the area of Energy Systems and Management.

The basic purpose of the course is to serve society and the nation through teaching, research and development in the area of Energy System and Management. Our aim is to build a center of excellence to give interdisciplinary exposure to energy system science, engineering, technology, and management to improve overall efficiency and effectiveness.

The primary research interests fall into three broad themed areas:

- Renewable/Non-Renewable Energy Systems
- Energy Conservation and Management
- Sustainable Development

The overall purpose of the proposed M.Tech. Programme is to establish a cohesive and expanding base of research in Energy Systems and Management. It will help in the energy industry's sustainable growth, excellence in integrated research and education, and increase in national and international stature.

Energy is the essence of human existence and a catalyst for the economic development of a country. The energy need is increasing at a fast rate in the developing countries compared to developed countries. The existing reserves of conventional resources are likely to be scarce resources and negatively impact the environment. Hence, it is time to look ahead and work in the right direction to use the present sources judiciously, find viable alternatives, and protect our environment for the next generation. This is also a transition period of fuel substitution. The emphasis is to supplement the carbon fuel to non-carbon ones to prolong the existing stock of the former, that too without environmental degradation.

Nowadays, Energy Systems and Management has attracted the attention of the researchers and practitioners to solve the energy conservation problems considering the sustainability and inclusive growth. Energy demand has been increasing day by day, but the availability of resources is limited. Thus, It becomes important to improve the way of operations and design of the energy systems so that the resources can be conserved for future generation. It is important for the industry, society and nation to fulfil the need of the people without harming the ecological systems. The professional must be given proper exposure to the sustainable growth of the economy. Considering these points, the Energy System and Management curriculum has

been designed, including the recent development in technology, industrial constraints, and need of society. Many recent topics are included in the curriculum.

The students who graduated in this course will handle the difficult situation by proper decision making. They will get exposure to all the major energy systems related to energy management, economics and planning, energy storage, energy analysis, energy materials etc.

University Vision

"To be a world class university through education, innovation and research for the service of humanity "

University Mission

1. To establish centres of excellence in emerging areas of science, engineering, technology, management and allied areas.
2. To foster an ecosystem for incubation, product development, transfer of technology and entrepreneurship.
3. To create environment of collaboration, experimentation, imagination and creativity.
4. To develop human potential with analytical abilities, ethics and integrity.
5. To provide environment friendly, reasonable and sustainable solutions for local & global needs.

Centre Vision

"CEE aims to be a Premier Observatory and Intelligence Unit of Global energy systems and energy policies"

Centre Mission

1. *The Centre for Energy and Environment conducts cutting-edge research and development activities as well as pioneer new alternative energy technology.*
2. *The Centre focuses on energy research and provides a platform for developing a conceptual and operational policy framework for sustainable renewable energy technology transfer.*
3. *It engages and facilitates avant-garde research and development initiative across disciplinary boundaries in Solar energy, Wind energy, Bioenergy, Ocean energy, Geothermal energy production, and Environmental Management supported by technology transfer in order to full energy access and clean environment to every citizen on the globe and ultimately aims to fulfils the demand of inclusive development.*

Program Educational Objectives (PEO)

PEO 1: To develop the capability to understand the fundamentals of Science and Energy Technology, the engineering problems with a futuristic approach.

PEO 2: To foster a confident and competent post graduate capable of solving real-life practical engineering problems fulfilling society's obligation.

PEO 3: To inculcate an aptitude for identifying and undertaking developmental work both in industry and in an academic environment with emphasis on continuous learning, enabling to excel in competitive participation at a global level.

PEO 4: To nurture and nourish effective communication and interpersonal skill to work in a team with a sense of ethics and moral responsibility for achieving a goal.

Program Outcomes (PO)

PO1: An ability to independently carry out research/investigation and development work to solve practical problems.

PO2: An ability to write and present a substantial technical report/document.

PO3: An ability to demonstrate a degree of command over the area as per the specialization of the program.

Programme Specific Outcomes (PSOs)

PSO 1: Apply software skills in the field of modeling, analysis and system simulation such as MATLAB, ANSYS- CFX, Fluent for performance evaluation and optimization of non-renewable/ renewable energy systems like bio, wind, solar and hybrid systems.

PSO 2: Recognize the need for lifelong learning independently, with a high level of enthusiasm and commitment to improve knowledge and competence continuously.

PSO 3: The student will be employable, able to develop entrepreneurship and be equipped in applying knowledge of energy systems in solving various real time problems and also pursue higher studies.

Graduate Attributes

1. **Scholarship of Knowledge:** Acquire in-depth knowledge of a specific discipline or professional area, including wider and global perspective, with an ability to discriminate, evaluate, analyse and synthesise existing and new knowledge, and integration of the same for enhancement of knowledge.
2. **Critical Thinking:** Analyse complex engineering problems critically, apply independent judgment for synthesising information to make intellectual and/or creative advances for conducting research in a broader theoretical, practical and policy context.

3. **Problem Solving:** Think laterally and originally, conceptualise and solve engineering problems, evaluate a wide range of potential solutions for those problems and arrive at feasible, optimal solutions after considering public health and safety, cultural, societal and environmental factors in the core areas of expertise.
4. **Research Skill:** Extract information pertinent to unfamiliar problems through literature survey and experiments, apply appropriate research methodologies, techniques and tools, design, conduct experiments, analyse and interpret data, demonstrate higher order skill and view things in a broader perspective, contribute individually/in group(s) to the development of scientific/technological knowledge in one or more domains of engineering.
5. **Usage of modern tools:** Create, select, learn and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities to understand the limitations.
6. **Collaborative and Multidisciplinary work:** Possess knowledge and understanding of group dynamics, recognise opportunities and contribute positively to collaborative-multidisciplinary scientific research, demonstrate a capacity for self-management and teamwork, decision-making based on open-mindedness, objectivity and rational analysis to achieve common goals and further the learning of themselves as well as others.
7. **Project Management and Finance:** Demonstrate knowledge and understanding of engineering and management principles and apply the same to one's own work; as a member and leader in a team, manage projects efficiently in respective disciplines and multidisciplinary environments after considering economic and financial factors.
8. **Communication:** Communicate with the engineering community, and with society at large, regarding complex engineering activities confidently and effectively, such as, being able to comprehend and write effective reports and design documentation by adhering to appropriate standards, make effective presentations, and give and receive clear instructions.
9. **Life-long Learning:** Recognise the need for, and have the preparation and ability to engage in life-long learning independently, with a high level of enthusiasm and commitment to improving knowledge and competence continuously.

10. **Ethical Practices and Social Responsibility:** Acquire professional and intellectual integrity, professional code of conduct, ethics of research and scholarship, consideration of the impact of research outcomes on professional practices and an understanding of responsibility to contribute to the community for sustainable development of society.
11. **Independent and Reflective Learning:** Observe and critically examine the outcomes of one's actions, make corrective measures subsequently, and learn from mistakes without depending on external feedback.

With these objectives in mind, Centre for Energy and Environment (CEE) designed the M.Tech. Programme to include courses of study, practicals/seminars and project/thesis through which a student may develop his/her concepts and intellectual skills. The procedures and requirements stated in this proposal embody the philosophy and regulations of the M.Tech. education and ensure a high standard of performance at the university and industries.

This will certainly expand the demonstrated capability of the University in the area of energy systems and management applications and to explore research activities that broaden and expand research expertise in this field. It will find appropriate educational outreach activities and training courses for other institutes and universities near Delhi to create awareness and stimulate interest in energy generation and conservation.

Energy is the essence of human existence and a catalyst for the economic development of a country. The need for energy is increasing at a very fast rate in developing countries compared to developed countries. The existing reserves of conventional resources are likely to be scarce resources and negatively impact the environment. Hence, it is time to look ahead and work in the right direction to use the present sources judiciously, find viable alternatives, and protect our environment for the next generation. This is also a transition period of fuel substitution. The emphasis is to supplement the carbon fuel to non-carbon ones to prolong the existing stock of the former, that too, without environmental degradation.

Centre for Energy and Environment (CEE) started in 2020, intending to produce a manpower pool in energy, develop new and efficient energy conversion technologies, and R & D and extension activities in diverse areas of energy. The CEE is proposing to start a two-year (four semesters) AICTE approved M.Tech. programme in Energy System and Management. The thrust

areas of research are Solar energy, Biomass energy, Hydro-energy, Energy-Environment interaction and Energy Conservation and Management. Apart from the teaching and research, the department also organizes training programs, workshops, and seminars in the relevant areas of energy.

Eligibility Criteria: Students with a Bachelor degree (4-years degree Programs; B.Tech./B.E/B.Sc.Engg., and equivalent degree) in any engineering branch will be eligible to take admission in this program. This program (M.Tech. in Energy System and Management) is interdisciplinary. For scholarship a valid GATE Score is mandatory.

Intake: 25

M. Tech. (Energy Systems and Management) Scheme

Semester -I

	Courses	Credits	Type	L-T-P	Total Credits
Group A	ESM-501: Energy Systems	4	Core	3-0-2	
	ESM- 503: Energy Management and Auditing	4	Core	4-0-0	17
Group B	ESM-54XX: Elective Type 1	4	Elective	4-0-0	
	ESM-53XX: Elective Type 2	3	Elective	3-0-0	
	ESM-52XX: Elective Type 3	2	Elective	2-0-0	

Semester -II

Courses		Credits	Type	L-T-P	Total Credits
Group C	ESM- 502: Energy Storage Technology	4	Core	3-0-2	
	ESM- 504:: Energy Analysis	4	Core	4-0-0	17
Group D	ESM-54XX: Elective Type 4	4	Elective	3-0-2	
	ESM-53XX: Elective Type 5	3	Elective	3-0-0	
	ESM-52XX: Elective Type 6	2	Elective	2-0-0	

Semester -III

Courses		Credits	Type	L-T-P	Total Credits
Group E	ESM- 651 -1: Track 1* Research Project	12			12
	OR				
	Track 2				
	ESM- 601: Project-1	3	Core		
	ESM-64XX: Elective Type 7	4	Elective	3-0-2	
	ESM-63XX: Elective Type 8	3	Elective	3-0-0	
	ESM-62XX: Elective Type 9	2	Elective	2-0-0	

Semester -IV

Courses		Credits	Type	L-T-P	Total Credits
Group F	Track 1* ESM-652: Research Project	12	Core	12	
	OR				
	Track 2 ESM-602: Project-2	12	Core		

Marks Distribution

S.No	Type of Course	Credit	L	T	P	CWS	PRS	MTE	ETE	PRE	Total
1.	Core	4	3	0	2	15	25	20	40	-	100
2.	Elective	4	3/4	0	2/0	15/20	25/0	20/30	40/50	-	100
3.	Elective	3	3	0	0	20	-	30	50	-	100
4.	Elective	2	2	0	0	20	-	30	50	-	100

List of Electives

Semester -I		**Credits & L-T-P**
Group C		
Elective Type 1	ESM- 5401: Foundations in Thermal Engineering (for non-Mechanical students) ESM- 5403: Foundations in Electrical and Electronics Engineering (for non-Electrical students)	4(4-0-0)
Elective Type 2	ESM-5301: Measurement and Control Engineering ESM-5303: Economics and Planning of Energy Systems ESM-5305: Nuclear Energy Technology	3(3-0-0)
Elective Type 3	ESM- 5201: Exergy Analysis ESM- 5203: Materials and Devices for Energy Applications ESM- 5205: Fundamentals of Sustainable Development	2(2-0-0)
Semester -II		
Group D		
Elective Type 4	ESM- 5402: Solar Energy Engineering and Applications ESM- 5404: Alternative Fuels for Transportation ESM- 5406: Hydrogen Energy and Fuel Cells	4(3-0-2)
Elective Type 5	ESM- 5302: Waste to Energy Conversion Technology ESM- 5304: Wind and Hydro Energy ESM- 5306: Energy Efficient Buildings	3(3-0-0)
Elective Type 6	ESM- 5202: Cogeneration and Energy Efficiency ESM- 5204: Integrated Energy System ESM- 5206: Energy, Climate Change and Carbon Trade	2(2-0-0)
Semester -III		

Group E		
Elective Type 7	ESM- 6401: Numerical Simulation and Modelling of Energy Systems ESM- 6403: Modern Refrigeration and Air Conditioning Systems ESM- 6405: Solar Thermal Power Generation	4(3-0-2)
Elective Type 8	ESM- 6301: Fuel Technology ESM- 6303: Life Cycle and Reliability of Energy Systems ESM- 6305: Direct Energy Conversion Technology	3(3-0-0)
Elective Type 9	ESM- 6201: Zero Emission Vehicles ESM- 6203: Electricity Regulations and Reforms in India ESM- 6205: Carbon Capture and Storage Systems	2(2-0-0)

ESM- 501: Energy Systems

Energy Scenario and Resources: Energy and Development, Global and Indian Energy scenario, Energy for sustainable development, Review of Conventional Energy systems, like, Thermal power plants, Hydel Power Plants, Nuclear Power Plants, Potential of renewable energy sources, Need & development of renewable energy sources, Concept of Hybrid systems, Economics and demand side management, Energy wheeling, Energy banking concepts.

Solar Energy Systems: Solar energy system, Solar Radiation, Availability, Measurement and Estimation, Solar Photovoltaic systems, Design considerations & Classification, Solar Thermal Systems, Design considerations & Classification, Other applications of solar energy systems like Solar ponds, Drying, Distillation, STEG, Space Heating, Passive Heating/cooling Building Architecture etc. Energy Storage, Sensible, Latent Heat and Thermo Chemical Storage, Pebble Bed etc.

Wind Energy Systems: Wind Energy Systems, Wind energy resource assessment, Site selection criterion, Wind Generation and Control, Nature of the wind, Power in the wind, Factors influencing wind, Wind data and energy estimation, Wind speed monitoring, Types of wind turbines, Characteristics, Wind mill component design, Applications of wind turbines, Offshore wind energy, Hybrid systems & Wind farms, Safety and environmental aspects, Wind energy potential and installation in India.

Bio Energy Systems: Bio energy systems, Classification, Design and constructional features, Biomass resources and their classification, Biomass conversion processes, Thermo chemical conversion, Direct combustion, biomass gasification, pyrolysis and liquefaction, biochemical conversion anaerobic digestion, Properties of Biogas, Calorific value and composition, Biogas plant technology and status, Types of biogas Plants, Other Applications of Bio mass energy systems like, Alcohol production from biomass, Bio diesel production, Urban waste to energy conversion, Cogeneration using bagasse, Biomass energy programme in India – its potential and future scope.

Fuel Cells and New Energy Systems: Fuel cells system, Principle of operation, components of fuel cell, types of fuel cell, low and high temperature fuel cells, fuel cell stacks, Electrochemistry of fuel cell. Ocean wave energy system, Principle of Ocean Thermal Energy Conversion (OTEC), Ocean thermal power plants, Tidal energy conversion, Tidal and wave energy its scope and development, Earth as source of heat energy, stored heat and renewability of earth's heat, Nature and occurrence of geo thermal field, Classification of thermal fields, Geothermal power plants, classification & Working, Waste to Heat Energy Systems, Direct Energy Conversion Systems, Hydrogen Energy Systems, Hydrogen Energy Production, Hydrogen economy, Hydrogen separation and purification, Hydrogen storage systems, Hydrogen Safety.

Decentralized energy Systems: Need and advantage of decentralized energy systems, Decentralized generation technologies, Costs and choice of technology, Decentralized versus Centralized generation, Optimal design of hybrid energy systems, energy economics and cost optimization of integrated energy systems, Scope and challenges in implementing off grid decentralized solutions.

Books:

1. G.D Rai Non-Conventional Energy Sources

2. S. P. Sukhatme and JK Nayak Solar Energy - Principles of thermal collection and storage, TMH
3. Kishore VVN, Renewable Energy Engineering and Technology, Teri Press, New Delhi
4. V. S. Bagotsky, Fuel Cell Problems and Solutions, John Wiley & Sons.
5. O'Hayre R. P., Cha S. W., Colella W., and Prinz F. B., Fuel cell fundamentals, John Wiley.
6. Bollen M. H. and Hassan F. Integration of Distributed Generation in the Power System, Wiley-IEEE Press.
7. J. A. Duffie and W. A. Beckman Solar Engineering of Thermal Processes
8. Twidell, J.W. and Weir, A. Renewable Energy Sources, EFN Spon Ltd.
9. Peter Gevorkian, Sustainable Energy Systems Engineering, McGraw Hill
10. Kreith, F and Kreider, J. F., Principles of Solar Engineering, McGraw-Hill
11. Godfrey Boyle, Renewable Energy, Power for a Sustainable Future, Oxford University Press, U.K
12. Bent Sorensen, Renewable Energy, Elsevier, Academic Press

ESM- 503: Energy Management and Auditing

Introduction: Energy and Sources of energy, Energy consumption and GDP, Costs of exploration and utilization of resources, Energy pricing, Energy demand and supply, National energy plan, Need for Energy Policy, National and State level Energy Policies. Basic concepts of Energy Conservation and its importance, Energy Strategy for the Future, The Energy Conservation Act and its Features, Energy conservation in household, Transportation, Agricultural, Service and Industrial sectors, Lighting, HVAC Systems.

Energy Management: History of Energy Management, Definition and Objective of Energy Management and its importance. Need of energy management, General Principles of Energy Management, Energy Management Skills, and Energy Management Strategy. Energy Management Approach. Understanding Energy Costs, Benchmarking, Energy performance, Matching energy usage to requirements, Maximizing system efficiency, Optimizing the input energy requirements, Fuel and Energy substitution. Organizing, Initiating and Managing an energy management program. Roles, responsibilities and accountability of Energy Management

Energy Audit: Energy audit concepts, Definition, Need and Types of energy audit. Energy Audit Approach and Methodology. Systematic procedure for technical audit. Understanding energy audit costs, Benchmarking and Energy Performance. Energy audit based on First law and Second law of thermodynamics, Mass and Energy balances, Availability analysis, Evaluation of energy conserving opportunities, Economic analysis and life cycle costing. Duties and responsibilities of energy auditors. Energy audit instruments and their usage for auditing. Report-writing, preparations and presentations of energy audit reports.

Energy Conservation and Environmental Control: Energy conservation areas, Energy transmission and storage, Plant Lecture wise energy optimization Models, Data base for energy management, Energy conservation through controls, Computer aided energy management, Program organization and methodology. Energy environment interaction, Environmental issues, Global Warming, Climate Change Problem and Response, Carbon dioxide emissions, Depletion of ozone layer, Governments Regulations, Energy Economy interaction. Energy Conservation in Buildings, Energy Efficiency Ratings & ECBC (Energy Conservation Building Code)

Case Studies: Study of 4 to 6 cases of Energy Audit & Management in Industries (Boilers, Steam System, Furnaces, Insulation and Refractories, Refrigeration and Air conditioning, Cogeneration, Waste Heat recovery etc.)

Books:

1. Anil Kumar, Om Prakash, Prashant Singh Chauhan, Samsher, Energy Management: Conservation and Audits, 1st Edition, CRC Press, Taylor & Francis.
2. Amlan Chakrabarti, Energy Engineering and Management, PHI, Eastern Economy Edition.
3. Smith CB, Energy Management Principles, Pergamon Press, New York.
4. Hamies, Energy Auditing and Conservation; Methods, Measurements, Management & Case study, Hemisphere, Washington
5. L. C. Witte, P. S. Schmidt and D. R. Brown, Industrial Energy Management and Utilization, Hemisphere Publications, Washington.
6. W.R.Murphy, G.Mckay, Energy Management, Butterworths.
7. C.B.Smith Energy Management Principles, Pergamon Press.

8. L.C. Witte, P.S. Schmidt, D.R. Brown, Industrial Energy Management and Utilization, Hemisphere Publication, Washington
9. Archie, W Culp, Principles of Energy Conservation, McGraw Hill
10. Munasinghe, Mohan Desai, Ashok V, Energy Demand: Analysis, Management and Conservation, Wiley Eastern Ltd., New Delhi.

ESM- 502: Energy Storage Technology

Energy Storage: Need of energy storage, Different modes of Energy Storage. Potential energy: Pumped hydro storage; KE and Compressed gas system: Flywheel storage, compressed air energy storage; Electrical and magnetic energy storage: Capacitors, electromagnets; Chemical Energy storage: Thermo-chemical, photo-chemical, bio-chemical, electro-chemical, fossil fuels and synthetic fuels. Hydrogen for energy storage. Solar Ponds for energy storage.

Electrochemical Energy Storage Systems: Batteries: Primary, Secondary, Lithium, Solid-state and molten solvent batteries; Lead acid batteries; Nickel Cadmium Batteries; Advanced Batteries. Role of carbon Nano-tubes in electrodes.

Magnetic and Electric Energy Storage Systems: Superconducting Magnet Energy Storage (SMES) systems; Capacitor and Batteries: Comparison and application; Super capacitor: Electrochemical Double Layer Capacitor (EDLC), principle of working, structure, performance and application, role of activated carbon and carbon Nano-tube.

Sensible Heat Thermal Energy Storage: SHS mediums; Stratified storage systems; Rock-bed storage systems; Thermal storage in buildings; Earth storage; Energy storage in aquifers; Heat storage in SHS systems; Aquifers storage.

Latent Heat Thermal Energy Storage: Phase Change Materials (PCMs); Selection criteria of PCMs; Stefan problem; Solar thermal LHTES systems; Energy conservation through LHTES systems; LHTES systems in refrigeration and air-conditioning systems; Enthalpy formulation; Numerical heat transfer in melting and freezing process.

Books

1. Robert, Huggins. Energy Storage: Fundamentals, Materials and Applications. Springer Press.
2. Richard Baxter. Energy storage. PennWell Corp. Elsevier.
3. Ahmed Zobaa, Energy storage: technologies and applications. Intech Open.
4. David Elliott. Energy Storage Systems. IOP Publishing, Bristol, UK

ESM- 504: Energy Analysis

Energy theory of value: Principles and systems of energy flows, Methods of energy analysis, Energy intensity method, Process analysis input-output method based energy accounting,
Energy cost of goods and services energy to produce fuels: Coal, Oil, Natural Gas, Energy to produce electricity, Energy cost of various modes of passenger & freight transportation, Industrial energy analysis: Aluminium, Steel, Cement, Fertilizers,
Energetics of materials recycling, Energetics of renewable energy utilization (case studies), General energy equation, Energy loss, Reversibility & irreversibility, Pictorial representation of energy,
Energy analysis of simple processes, Expansion, Compression, Mixing and separation, Heat transfer, Combustion, Energy analysis of thermal and chemical plants, Thermo economic applications of energy analysis and national energy balance.

Books

Blok K., Nieuwlaar E., Introduction to Energy Analysis, 2nd Edition, Routledge
Bousted I. and Hancock G.F., Handbook of Industrial Energy Analysis, Ellis Horwood
Thomas A.G., Energy Analysis, IPC Science and Technology Press Ltd.

ESM-5401: Foundations in Thermal Engineering

(for non-Mechanical students)

Thermal Engineering:

Review of basics of thermodynamics: System, properties, equilibrium, laws of thermodynamics, work and heat transfer, Laws of Thermodynamics for open and closed systems, entropy, properties of steam

Applied thermodynamics: Thermodynamic cycles and their analysis (Power and refrigeration cycles), Nozzles, compressors, steam and gas turbines, I. C. engines

Fluid Mechanics:

Review of basics of fluid mechanics: properties of fluids, pressure measurement, kinematics and dynamics of fluid flow, Boundary layer

Fluid Machines: Euler's equation of fluid machines, hydraulic turbines, centrifugal pump.

Heat Transfer:

Conduction and convection: Modes of heat transfer, Fourier's conduction equation (1 D and 3 D) for plane wall, cylinder, sphere, Heat generation in wall, cylinder, sphere, Fins.

Velocity and thermal boundary layer, continuity, momentum and energy equation significance and their solution for simple geometries flat plate and tube flow, simple correlations for laminar and turbulent flow, natural convection

Heat exchanger: Types, Idea of LMTD and effectiveness methods of design of heat exchangers

Radiation: Basic concepts related and laws related to radiation, concept of shape factor, heat exchange between black surfaces, heat exchange between gray surfaces.

Books:

1. Nag P. K. (2014); Basic and Applied Thermodynamics, McGraw Hill.
2. Zemansky M. and Dittman R. (2011); Heat and Thermodynamics, McGraw Hill, India
3. Incropera F. P., DeWitt D. P., Bergman T. L. and Lavine A. S. (2006); Introduction to Heat Transfer, 5th Edition, Wiley
4. Holman J. P. (2009); Heat Transfer, Tenth Edition, McGraw Hill
5. Balachandran P. (2010); Engineering Fluid Mechanics, Prentice Hall India

ESM- 5403: Foundations in Electrical and Electronics Engineering
(for non-Electrical students)

Basics of Electrical Engineering: Fundamentals of Electricity: Concepts of different electrical parameters like voltage, current, frequency, D.C and A.C circuits, Electrical power and energy. Electrical loads – Resistive, Inductive and Capacitive. Phasor Notation, Power in A.C. Circuits, Single and Three Phase A.C. Power, Star and Delta connections, Voltage levels. Transformers, Generators, Alternators etc. Conversion of Thermal, Chemical, Electromagnetic and Mechanical energy into electricity.
Electrical and Mechanical Energy Utility Systems: Transmission and Distribution losses, Pilferage, Transformer losses. Electricity tariff, Load management and maximum demand control, power factor improvement and its benefits, Selection and location of capacitors etc. Conversion of Electrical Energy to Mechanical Energy (Electric Motors). Energy efficient electric motors, Compressed Air System, Fans and blowers, Pumps and Pumping Systems, Cooling Towers, Illumination / Lighting Systems, Diesel generating systems.
Power Electronics Converters for various applications: Power Electronics for Solar, Wind and Electric Vehicles
Energy Audit Instruments: Basic measurements – Electrical measurements, Light, Pressure, Temperature and heat flux, Velocity and Flow rate, Vibrations, etc. Instruments Used in Energy systems: Load and power factor measuring equipments, Wattmeter, flue gas analysis, Temperature and thermal loss measurements, air quality analysis etc.
Energy Measurement & Verification Electrical Energy Measurements, Thermal Energy Measurements, Mechanical & Utility System Measurements, Measurement & Verification, M & V Protocol,

Books:

1. Principles of Energy Conversion: A.W. Culp.
2. Direct Energy Conversion: M.A. Kettani
3. Energy Conversion systems: Begamudre, Rakoshdas
4. Direct Energy Conversion: W.R.Corliss
5. Alternative Liquid fuels: B.V. Desai
6. TEDDY year book published by TERI.
7. The Watt Committee on Energy (Reports)
8. Energy Management Workbook –
9. NIFES Report -Computers in Energy Audits.
10. Efficient Use of Energy: I.E.C.Dryden (Butterworths)
11. Instrument Engineers handbook (VolI,II,III)– B.G. Liptak Chintan Book Comp/CRC Publication
12. Analysis and design of Energy Systems - Hogde B.K. (Prentice hall 1988)
13. Energy management and control system –Vol-I, II –M.C.Macedo (John Willy)
14. Energy Conservation guide book Patrick/Patrick/Fardo (Prentice hall1993)
15. Handbook on Energy efficiency – .
16. ASHRAEE Energy Use (4 Volumes),
17. CIBSI –guide –Users Manual (U.K.)

ESM- 5402: Solar Energy Engineering and Applications

Introduction: Solar radiation: Extra-terrestrial and terrestrial radiation; Earth-Sun relation: Solar angles, Sun path diagram; Shadow determination, Solar spectrum, Effect of earth atmosphere on solar radiation, Measurement and estimation of solar radiation on horizontal and tilted surfaces, Solar radiation measurement devices, Solar radiation data analysis

Solar Thermal Conversion: Theory and Basics; Introduction to different solar thermal energy systems: Solar flat plate collector, Concentrating collector, Design and components and flat plat collector; Flat plate collectors-liquid and air type; Development of solar thermal collectors; Concentrating solar collector: optical design of concentrators

Solar Thermal Applications: Solar cooker, Solar pond, Solar passive heating and cooling system; Solar cooling and refrigeration; solar water heaters, solar dryers; Solar thermal power generation and economics

Solar Energy Mission Photovoltaic: Principle of photovoltaic conversion; Solar cell basics and materials; Different solar cell technologies: Crystalline silicon solar cell, Thin Film solar cell, Tandem solar cell; Photovoltaic system: Component and configurations; off grid and grid connected PV systems, PV system design and economics

Solar Photo-catalysis: Solar photo-catalysis mechanism, kinetics and application

Books:

1. Duffie J. A. and Beckman W. A.; Solar Engineering of Thermal Processes, John Wiley
2. Solanki C. S.; Solar Photovoltaics: Fundamentals, Technologies and Applications, Prentice Hall India
3. HP Garg and J Prakash: Solar Energy: Fundamentals and Applications, Tata McGraw Hill.
4. Tom P. Hough, Trends in Solar Energy Research, Nova Publishers.
5. S Sukhatme and J Nayak: Solar Energy: Principles of Thermal Collection and Storage, Third Edition, Tata McGraw Hill.
6. Tiwari G. N.; Solar Energy: Fundamentals, Design, Modeling and Applications,
7. Goswami D. Y.; Principles of Solar Engineering, Taylor and Francis
8. Green M., Solar Cells: Operating Principles, Technology and System Applications Springer Narosa

ESM- 5404: Alternative Fuels for Transportation

Transportation Fuel Basics: Desired properties of IC Engine Fuels (various ratings, volatility, SIT, Calorific value etc.), fuel economy, carbon foot print, factors affecting fuel economy, Engine performance and emission characteristics, engine efficiency, engine life etc. Sources of transportation fuel, scope of availability in future.

Alcohol: Sources of Methanol and Ethanol, methods of production. Compatibility of methanol & ethanol as engine fuels, performance of blending alcohol with gasoline. Emulsification of alcohol and diesel. Dual fuel systems. Improvement/Change in performance and emission characteristics with respect to % blending of Alcohol. Synthetic Alternative Fuels: Di-Methyl Ether (DME), P-Series, Eco Friendly Plastic fuels (EPF).

Vegetable oils and Biodiesel: Vegetable Oils: Various Vegetable oils (Karanji oil, Neem oil, Thumba oil, Palm oil, Algae, Jatropha oil etc.), availability of vegetable oils, methods of use like direct, blended and pre-heated. Biodiesel Concept and production methods, various factors affecting yield: Catalyst, Molar ratio, FFA, temperature etc.– Esterification– Properties, Performance and emission characteristics

Gaseous Fuel: LPG & CNG: Properties of LPG & CNG as engine fuels, fuel metering systems, combustion characteristics, effect on performance, emission, cost and safety.

Biogas: Introduction to Biogas system, Process during gas formation, Factors affecting biogas formation, Enrichment Usage of Biogas in SI engine & CI engine.

Hydrogen as a transportation fuel. Sources and methods of Production of Hydrogen, Storage and Transportation of hydrogen. Economics of Application and Advantages of hydrogen (Liquid hydrogen) as fuel for IC engine/hydrogen car. Working performance and safety considerations of a hydrogen car.

Electric & Hybrid Vehicles: Layout of electric vehicles, advantages & limitations. Systems components, storage batteries merits and demerits of different type of batteries, battery wear, battery management. Electronic controlled systems, high energy and power density batteries. Study of various Types of hybrid vehicles and different drive train topologies

Fuel Cells and Solar Power: Fuel Cells: Concept of fuel cells based on usage of Hydrogen and Methanol. Power rating, and performance. Heat dissipation, Layout of fuel cell vehicle. Solar cells for energy collection. Layout of solar powered automobiles. Economics of Application Advantages and limitations.

Books:

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

ESM- 5406: Hydrogen Energy and Fuel Cells

Hydrogen Properties and Production Processes: Physical and Chemical properties of hydrogen. Production from fossil fuels, Steam, water. Advanced production methods- production using nuclear energy and renewable, photochemical, photocatalytic, hybrid, etc.

Hydrogen Storage, Handling & Transportation: Storage Technologies, Compressed hydrogen, Cryo-adsorption, Liquid hydrogen, Slush hydrogen, Underground hydrogen storage, Hydrogen tank, Automotive Onboard hydrogen storage, Hydrogen transportation methods, Challenges associated with hydrogen transport.

Hydrogen Utilization: I.C. Engines, power plant, gas turbines, hydrogen burners, domestic and marine applications, durability studies, field trials and effect on environment, Current use scenario, eco-friendly nature.

Fuel Cells: Introduction and overview, operating principle, polarization curves, components, types of fuel cell, low and high temperature fuel cells, fuel cell stacks. Thermodynamics of fuel cell: application of the first and second law to fuel cells, significance of the Gibbs free energy, concept of electrochemical potential and emf, Nernst equation, thermodynamic efficiencies of fuel cell in comparison to Carnot efficiencies, thermodynamic advantage of electrochemical energy conversion.

Electrochemistry of Fuel Cell: electrochemical cells, oxidation and reduction processes, halfcell potentials and the electrochemical series, Faraday's law, faradaic and nonfaradaic processes, current and reaction rate, Butler–Volmer theory for electrode kinetics, exchange current, polarization and over potential, cell resistance, mass transport in electrochemical cells.

Books:

1. M. Ball and M. Wietschel, The Hydrogen Economy Opportunities and Challenges, Cambridge University Press.
2. Ram B. Gupta, Hydrogen Fuel: Production, Transport, and Storage, CRC Press-Taylor & Francis.
3. Peschka, Walter, Liquid hydrogen: fuel of the future, Springer-Verlag Wien, 1992.
4. Kenneth D., Jr.; Edeskuty, F. J. Williamson, Recent Developments in Hydrogen Technology, CRC Press.
5. M.K.G. Babu, K.A. Subramanian, Alternative Transportation Fuels: Utilization in Combustion Engines, CRC Press.
6. Kazunari Sasaki et al. Hydrogen Energy Engineering: A Japanese Perspective- Springer.
7. David Anthony James Rand, Ronald Dell, Hydrogen Energy: Challenges and Prospects, RSC Publishers.

ESM- 5301: Measurement and Control Engineering

Introduction to measurements, Measurement categories-primary and derived quantities, intrusive and non-intrusive methods; Analysis of experimental data- types of errors, uncertainty analysis, propagation of uncertainty; Statistical analysis of experimental data- normal error distributions Chi-square test of goodness of fit, method of least squares (regression analysis, correlation coefficient), multivariable regression, graphical analysis and curve fitting.

Measurement of temperature- thermoelectric thermometry, resistance thermometry, pyrometry, liquid in glass, bimetallic and liquid crystal thermometer, temperature sensors for measurement of transient temperature; thermocouple compensation, temperature measurements in high- speed flow.

Measurement of pressure- U-tube manometer, Bourdon gage, pressure transducers, measurement of transient and vacuum pressures.

Measurement of volume flow rate- variable area type flow meter-orifice plate meter, flow nozzle, venture meter, rotameter. Measurement of velocity-Pitot static and impact probes, velocity measurement based on thermal effect, Doppler velocimeter, Time of flight velocimeter.

Thermal conductivity measurement of solids, liquids, and gases, measurement of gas diffusion, convection heat transfer measurements, humidity measurements, heat-flux meters. measurement of emissivity, reflectivity and transmissivity, solar radiation measurement. Dynamic response considerations, Bridgman gauge, McLeod gauge, Pirani thermal conductivity gauge, Knudsen gauge, Alphatron, Various transducers.

Review of open and closed loop control systems and servo mechanisms, Transfer functions of Mechanical Systems, input and output systems. General Data Acquisition system - Signal conditioning - Data transmission - A/D & D/A conversion - Data storage and Display - Computer aided experimentation.

Books

1. S P Venkateshan, Mechanical Measurements, Anne Books Pvt. Ltd.
2. J P Holman, Experimental Methods for Engineers, McGraw-Hill
3. Raman C S, Sharma G R, Mani V S N, Instrumentation Devices and System, McGraw Hill

ESM- 5302: Waste to Energy Conversion Technology

Introduction: An overview of world energy reservoirs. Waste Collection and Transportation. Transfer stations. Waste minimization and recycling of municipal waste, Segregation of waste, Size Reduction, Managing Waste. Status of technologies for generation of Energy from Waste Treatment and Disposal. IPCC concepts. Kyoto Protocol, Montreal Protocol etc.

Waste Characterization and Disposal: Characterization and classification of waste as fuel; agro waste, forest residues, industrial waste, Municipal solid waste. Organic Waste Sources, types, composition, Properties. Industrial & Municipal Solid Waste: Physical, chemical and biological properties. Aerobic composting, incineration, Furnace type and design, Medical waste /Pharmaceutical waste treatment Technologies, Measures to mitigate environmental effects due to incineration.

Technology for Waste to Energy: Introduction to different technologies for waste to energy– Gasification, Plasma arc gasification, Pyrolysis, Hydrolysis/fermentation (waste-to-ethanol), Anaerobic digestion, Autoclave/mechanical processing. Land Fill method of Solid waste disposal Land fill classification, methods and Sitting consideration, Layout and preliminary design of landfills: Composition, characteristics, generation, movement and control of landfill leachate and gases, Environmental monitoring system for land fill gases. Power generation using waste to energy technologies: Biogas Production: various processes and plants, use in IC engines, IGCC concepts.

MSW: Energy Generation from Waste Bio-chemical Conversion: Anaerobic digestion of sewage and municipal wastes, direct combustion of MSW-refuse derived solid fuel, Industrial waste, agro residues. Biogas production. Gasification of waste using Gasifiers, Briquetting, Utilization and advantages of briquetting, Environmental benefits of Bio-chemical and Thermo- chemical conversion. Comparison of properties with conventional fuels

Books

1. Rogoff, M.J. and Screve, F., "Waste-to-Energy: Technologies and Project Implementation", Elsevier Store.
2. Young G.C., "Municipal Solid Waste to Energy Conversion processes", John Wiley and Sons.
3. Harker, J.H. and Backhusrt, J.R., "Fuel and Energy", Academic Press Inc.
4. EL-Halwagi, M.M., "Biogas Technology- Transfer and Diffusion", Elsevier Applied Science.
5. Hall, D.O. and Overeed, R.P.," Biomass - Renewable Energy", John Willy and Sons.
6. Mondal, P. and Dalai, A.K. eds. Sustainable Utilization of Natural Resources. CRC Press.
7. Shah, Kanti L., Basics of Solid & Hazardous Waste Management Technology, Printice Hall
8. Nicholas P. Cheremisinoff. Handbook of Solid Waste Management and Waste Minimization Technologies. An Imprint of Elsevier, New Delhi
9. P. Aarne Vesilind, William A. Worrell and Debra R. Reinhart. Solid Waste Engineering. Thomson Asia Pte Ltd. Singapore
10. M. Dutta, B. P. Parida, B. K. Guha and T. R. Surkrishnan. Industrial Solid Waste Management and Landfilling practice. Narosa Publishing House, New Delhi.

ESM- 5303: Economics and Planning of Energy Systems

Energy economics: Basic concepts, energy data, energy cost, energy balance.
Energy accounting framework; Economic theory of demand, production and cost market structure; National energy map of India, Energy subsidy – National and international perspectives
Concepts of economic attributes involving renewable energy, Calculation of unit cost of power generation from different sources with examples, different models and methods
Application of econometrics; input and output optimization; energy planning and forecasting- different methods
Concepts of economic attributes involving renewable energy, Calculation of unit cost of power generation from different sources with examples, different models and methods
Application of econometrics; input and output optimization; energy planning and forecasting - different methods
Evaluation of National and Regional energy policies; oil import, energy conservation, rural energy economics, integrated energy planning
Conflict between energy consumption and environmental pollution, Economic approach to environmental protection and management, Energy-Environment interactions at different levels, energy efficiency, cost-benefit risk analysis; Project planning and implementation, Planning for energy security and renewable energy innovations; Regional, National and
Global aspirations and requirements; Role of Governments, Societies and NGOs.

Books

1. Bhattacharyya S. C.; Energy Economics, Springer
2. Ferdinand E. B.; Energy Economics: A Modern Introduction, First Edition, Kluwer
3. Kandpal T. C. and Garg H. P.; Financial Evaluation of Renewable Energy Technology, Macmilan
4. Stoft S.; Power Systems Economics, Willey-Inter Science
5. Munasinghe M. and Meier P.; Energy Policy Analysis and Modeling, Cambridge University Press
6. Samuelson P. A. and William D. N.; Economics, 14th edition, McGraw Hill
7. Thuesen G. J. and Fabrycky W. J.; Engineering Economy, Ninth Edition, Prentice Hall India

ESM- 5304: Wind and Hydro Energy

Atmospheric circulations, classification, factors influencing wind, wind shear, turbulence, wind speed monitoring, Wind resource assessment, Weibull distribution; Betz limit, Wind energy conversion systems: classification, applications, power, torque and speed characteristics

Aerodynamic design principles; Aerodynamic theories: Axial momentum, Blade element and combine theory, Rotor characteristics, Maximum power coefficient, Tip loss correction, Wind turbine design considerations: methodology, theoretical simulation of wind turbine characteristics.

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

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

Hydraulic Turbines: types and operational aspects, classification of turbines, elements of turbine, selection and design criteria, geometric similarity operating characteristic curves; Speed and voltage regulation

Selection of site for hydroelectric plant, Essential elements of hydroelectric power plant, Economics: cost structure, Initial and operation cost, environmental issues related to large hydro projects, Potential of hydro power in North East India

Books

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

ESM- 5305: Nuclear Energy Technology

Basics: Basic nuclear physics concepts, properties of nuclei. nuclear forces, nuclear models. nuclear decay, introduction to physics of fission process, chain reaction; four factor formula; definitions of k-infinity, k-effective, definition of reactivity; criticality.

Types of nuclear reactors: Brief history. Pressurized Water Reactors (PWR), Boiling Water Reactor (BWR), Pressurised Heavy Water Reactor (PHWR), Development of Gas Cooled Reactors (GCR), Fast Reactors

Components of a Nuclear Reactor: Overview of core components, major primary and secondary system components, choice of core materials, heat transport systems including decay heat transport

Advanced Reactors and Direct Energy Conversion: Different generation of nuclear reactors. Evolutionary improvements and revolutionary improvements. High Temperature Reactor (HTR) and Advanced Heavy Water Reactor (AHWR), Next Generation of Reactors

Nuclear Emergency management: Nuclear accidents, emergency preparedness and management: reasons for accidents, classification of accidents, International Nuclear Event Scale, types of emergency, emergency preparedness, countermeasures.

Defence in depth approach in design, redundancies, diversity, independence. Shutdown systems, decay heat removal, physical protection.

Books:

1. G. Vaidyanathan, Nuclear reactor engineering (principles and concepts), S. Chand and company Pvt Ltd, Delhi.
2. Samuel Glasstone, Principles of nuclear reactor engineering, D. Van Nostrand Company, INC, Princeton, New Jersey.

ESM- 5306: Energy Efficient Buildings

Energy Management Concept in Building: Energy auditing in buildings, Bioclimatic classification of India; Climate Analysis for Nat-Vent Buildings, Mixed Mode Buildings and Conditioned building; Passive design concepts for various climatic zones; Case studies on typical design of selected buildings in various climatic zones

Vernacular Architecture: Vernacular architecture in Indian Context, Factors which shape the architecture, building material and construction techniques; Case studies on vernacular architecture of Rajasthan, North-East India; Low cost buildings, climate responsive buildings, energy efficient buildings, green buildings, intelligent buildings, Building Integrated Photovoltaics (BIPV), Green Buildings in India; Case studies

Building codes and Rating systems: LEED, GRIHA, ECBC, Thermal properties and energy content of building materials; Building energy simulation, Simulation tool like TRANSYS, eQuest; Building management systems/automation, Artificial and daylighting in buildings

Thermal Performance: Studies, concept of comfort and neutral temperatures, Thermal comfort, PMV-PPD models, Thermal comfort models, Adaptive thermal comfort models, case studies, Heat flow calculations in buildings: Unsteady heat flows through walls, roof, windows etc. Concept of sol-air temperature and its significance; heat gain through building envelope; building orientation; shading and overhangs; Ventilation and Air-conditioning systems

Passive and Low Energy Concepts and Applications: Passive heating concepts: Direct heat gain, indirect heat gain, isolated gain and sunspaces; Passive cooling concepts: Evaporative cooling, radiative cooling; Application of wind, water and earth for cooling; Shading, paints and cavity walls for cooling; Roof radiation traps; Earth air-tunnel.

Books

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

ESM- 5201: Exergy Analysis

Review of Second Law of thermodynamics and entropy principles: Definition, Carnot's cycle, Carnot theorem, Concept of Reversibility and irreversibility, Clausius Theorem, Clausius inequality, Property entropy, Principle of increase of entropy, Applications of entropy Principle, Entropy generation equation for closed and open systems

Exergy Analysis: Difference between high and low grade energy, Available energy or Exergy refereed to a cycle, Decrease in available energy through finite temperature difference heat transfer, Law of degradation of energy, Maximum work in a reversible process, reversible work by an open system exchanging, Heat only with the surroundings, reversible work in a steady flow process, reversible work in a closed system, useful work, maximum useful work obtainable when the system exchanges heat with a Thermal Reservoir in Addition to the Atmosphere, Dead state and availability, Availability in open and closed systems, Gouy stodala theorem, Exergy balance equation, Second law efficiency, Components of exergy.

Exergy Analysis of simple processes: Exergy analysis of simple processes, Expansion Processes, Compression Processes, Heat transfer processes, Mixing and separation Processes, Combustion processes.

Exergy analysis of cycles: Exergy Analysis of power, refrigeration, heating systems and combined CHP systems

Book

1. T.J. Kotas, The Exergy Method of Thermal Plant Analysis, Butterworth-Heinemann

ESM- 5202: Cogeneration and Energy Efficiency

Cogeneration concept, Basics of Energy efficiency improvement in heat engines, Design parameters for cogeneration, Concept of tri-generation and polygeneration, Cogeneration alternatives, Cogeneration efficiency.
Steam turbine plants: (a) Introduction (b) Boiler, Turbine, Condenser, Economizer, Super heater (c) Reheating, Methods to improve power output and efficiency
Gas turbine plants: (a) Introduction, (b) Compressor, Combustors, Turbine, Closed and Open type gas turbine system, (c) NOx emission reduction techniques, Sequential combustion in multi combustors
Spark Ignition engines and compression ignition power plants:(a) Introduction, (b) Indicated power, Brake power (c) Supercharger, Turbocharger, Exhaust Recirculation

Books:

2. Gupta M. K., Power Plant Engineering, Prentice Hall India.
3. Kolanowski B. F., Small-Scale Cogeneration Handbook, 4th Edition, The Fairmont Press.
4. Meherwan P., Boyce, Handbook for Cogeneration and Combined Cycle Power Plants, Second Edition, ASME.
5. Nag P. K., Power Plant Engineering, Tata McGraw-Hill Education.
6. EI-WakilM. M., Power Plant Technology, McGraw Hill.
7. PolimerosG., Energy Cogeneration Hand Book for Central Plant Design, Industrial Press Inc.,

ESM- 5203: Materials and Devices for Energy Applications

Device fabrication technologies: diffusion, oxidation, photolithography, sputtering, physical vapor deposition, chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), hot wire CVD (HWCVD) High efficiency solar cells, PERL Si solar cell, III-V high efficiency solar cells, GaAs solar cells, tandem and multi-junction solar cells, solar PV concentrator cells and systems, III-V, II-VI
thin-film solar cells; Amorphous silicon thin-film (and/or flexible) technologies, multijunction (tandem) solar cells, organic/flexible solar cells, polymer composites for solar cells,
Spectral response of solar cells, quantum efficiency analysis, dark conductivity, I-V characterization Introduction to material characterization: Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), X-ray diffraction (XRD), Raman spectroscopy, Atomic force microscopy (AFM); device fabrication and characterization; Materials and devices for energy storage; Batteries, Carbon Nano-Tubes (CNT), fabrication of CNTs, CNTs for hydrogen storage, CNT-polymer composites, ultra-capacitor; Polymer membranes for fuel cells, PEM fuel cell, Acid/alkaline fuel cells

Books

1. Robert F. P. . Advanced Semiconductor Fundamentals, 2nd Edition, Pearson
2. Duncan W. B., Dermot O., and Richard I. W. (2011). Energy Materials, 1st Edition, Wiley Reference Books
3. Fahrenbruch A. L. and Bube R. H.; Fundamentals of Solar Cells: PV Solar Energy Conversion, Academic Press
4. Tom M. and Luis C. Solar Cells: Materials, Manufacture and Operation, 1st Edition, Elsevier Science
5. Christoph B. Ullrich S. and Vladimir D.. Organic Photovoltaics: Materials, Device Physics, and Manufacturing Technologies, 2nd Edition, Wiley-VCH
6. San P. J. and Pei K. S. Nanostructured and Advanced Materials for Fuel Cells, 1st Edition, CRC Press
7. Daniel C. and Besenhard J. O. Handbook of Battery Materials, 1st Edition WileyVCH

ESM- 5204: Integrated Energy System

Projection of energy demands, Potential of solar, wind, biogas, natural gas, forest produce, tidal, geothermal, mini-hydro and other modern applications, Hybrid and integrated energy systems.
Introduction on electric grid, Supply guarantees, power quality and Stability, Introduction to renewable energy grid integration, concept of mini/micro grids and smart grids; Wind, Solar, Biomass power generation profiles, generation electric features, Load scheduling
Introduction to basic analysis and operation techniques on power electronic systems; Functional analysis of power converters, Power conversion schemes between electric machines and the grid, Power systems control using power converters; Power control and management systems for grid integration, island detection systems, synchronizing with the grid; Issues in integration of converter based sources; Network voltage management; Power quality management and Frequency management;

Books:

1. Laurie Barrtom, Renewable Energy Sources for fuels and Electricity.
2. R. Hunter and G. Elliot, Wind-Diesel Systems Cambridge University Press.
3. Vittal V. and Ayyanar R.; Grid Integration and Dynamic Impact of Wind Energy, Springer
4. Bollen M. H. and Hassan F.; Integration of Distributed Generation in the Power System, Wiley-IEEE Press
5. Muhannad H. R.; Power Electronics: Circuits, Devices and Applications, Pearson Prentice Hall
6. Teodorescu R. Liserre M. Rodriguez P.; Grid Converters for Photovoltaic and Wind Power Systems, First Edition, Wiley-IEEE Press
7. P. Kundur , Power system stability and control, McGraw-Hill.
8. Dragan Maksimovic, Robert Warren Erickson, Springer.

ESM- 5205: Fundamentals of Sustainable Development

Concept of Sustainable Development: Definition of sustainability - History and emergence of the concept of sustainable development – Our Common Future - Objectives of Sustainable Development - Millennium Development Goals - Environment and Development linkages – Globalization and environment - Population, Poverty and Pollution – Global, Regional and Local environmental issues – Resource Degradation – Greenhouse gases and climate Change – Desertification – Industrialization – Social insecurity.

Sustainability and The Triple Bottom Line: Components of sustainability – Complexity of growth and equity - Social, economic and environmental dimensions of sustainable development – Environment – Biodiversity – Natural Resources – Ecosystem integrity – Clean air and water – Carrying capacity –Equity, Quality of Life, Prevention, Precaution, Preservation and Public participation. - Structural and functional linking of developmental dimensions – Sustainability in national and regional context

Sustainable Development and International Response: Role of developed countries in the development of developing countries – International summits –Stockholm to Johanesburg – Rio Principles – Agenda 21 - Conventions –Agreements – Tokyo Declaration-Doubling Statement-Transboundary issues –Integrated approach for resource protection and management

Sustainable Development of Socio-Economic Systems: Demographic dynamics of sustainability – Policies for socio-economic development – Strategies for implementing eco-development programmes – Sustainable development through trade – Economic growth – Action plan for implementing sustainable development – Urbanization and Sustainable Cities – Sustainable Energy and Agriculture – Sustainable Livelihoods – Ecotourism

Framework for Achieving Sustainability: Sustainability indicators - Hurdles to Sustainability - Operational guidelines –Interconnected prerequisites for sustainable development – Empowerment of Women, Children, Youth, Indigenous People, Non-Governmental Organizations, Local Authorities, Business and Industry - Science and Technology for sustainable development –Performance indicators of sustainability and Assessment mechanism – Constraints and barriers for sustainable development.

Books

1. Austin, James and Tomas Kohn. Strategic Management in Developing Countries. The Free Press.
2. Berger. "The Environment and the Economy." In Smelser and Swedberg (eds.)
3. The Handbook of Economic Sociology. Russel Sage Foundation. D'Arcy, David. Transcript of broadcast, "In Houston, a Treasure of Exiled Afghan Art," National Public Radio,
4. Elkington, John. Cannibals with Forks: The Triple Bottom Line for 21st Century Business Oxford: Capstone Publishing.
5. Guillen, Mauro and Sandra L. Suarez. "The Institutional Context of Multinational Activity." In Organization Theory and the Multinational Corporation. 2nd edition. New York: St. Martin's Press

ESM- 5206: Energy, Climate Change and Carbon Trade

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

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

New Industrial Emissions Directive, Categorization of Scope 3 Emissions for Streamlined Enterprise Carbon Foot printing, Calculating Scope 3 Emissions Carbon dioxide (CO_2) emissions due to energy conversion; combustion physics; case studies and comparison of (i) different technologies and (ii) different resources used for energy conversion;

Role of technology up-gradation and alternative resources on reduction of CO_2 emission; Methodology for CO_2 assessment; UNFCCC baseline methodologies for different conversion process, estimation of emission from fossil fuel combustion;

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

Books

1. Mathez E. A.; Climate Change: The Science of Global Warming and Our Energy Future, First edition, Columbia University Press
2. Dessler A.; Introduction to Modern Climate Change, Cambridge University Press
3. Stern N.; The Economics of Climate Change. The Stern Review. Cambridge University Press
4. IPCC (Intergovernmental for Climate Change). Climate Change (2007): Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press
5. Yamin F. (ed); Climate Change and Carbon Markets: A Handbook of Emissions Reduction Mechanisms, Earthscan
6. Clean Development Mechanism, UNFCC Website; http://cdm.unfccc.int/

ESM- 6401: Numerical Simulation and Modelling of Energy Systems

Introduction: Conservation equation, Mass Momentum and Energy equations, Convective form of the equation and general description.
Basic Aspects of Discretization: Taylor series expansion, Introduction to Finite Difference, Finite Elements and Finite Volume Methods. Detailed treatment of Finite Difference method, explicit and implicit methods, errors and stability analysis.
Grids with Appropriate Transformations: Adaptive grids and unstructured meshes. Lift reduction, down force generation and drag reduction. An introduction to the aerodynamics of airflows for cooling.
Analysis of energy systems: power flow analysis, modelling and solution by Newton Raphson method, continuation power flow analysis, modelling and solution by homotopy methods, optimal power flow analysis, modelling and solution by gradient method.
Commercial codes (e.g. ANSYS FLUENT) application. Numerical simulation of heat exchanger.

Books

1. John Anderson, Computational Fluid Dynamics", " McGraw- Hill Ltd
2. Ferziger Joel H, Computational Methods for Fluid Dynamics Springer-Verlog
3. L.P. Singh, "Advanced Power System Analysis and Dynamics", New Age International.
4. Subhes C. Bhattacharyya, "Energy Economics: Concepts, Issues, Markets and Governance", Springer Science & Business Media.
5. Jizhong Zhu, "Optimization of Power System Operation", IEEE Press Series on Power Engineering, John Wiley & Sons.

ESM- 6403: Modern Refrigeration and Air Conditioning Systems

Review of conventional vapour compression systems and alternative refrigerants: Review of conventional vapour compression systems: VCR systems single stage, multistage and cascade systems. Refrigerants and its types, ODP and GWP of important refrigerants, Montreal & Kyoto Protocol, Alternatives to important CFCs, HCFCs and HFCs, Modern trends in Refrigeration and Air conditioning industry. Retrofitting, Recovery, Recycling and Reclaim.

Novel Trends for efficiency improvement in VCR systems and Novel cycles: Performance enhancement of VCR system using novel methods of subcooling: Integrated and dedicated subcooling VCR cycles, Ejector Refrigeration system, Trans-critical vapour compression system. Integration of Vortex tube in Trans-critical vapour system, Morar and Keller Models. Waste Heat recovery from refrigeration systems. Methods of improving efficiency at component level.

Vapour absorption refrigeration systems: Vapor absorption systems single, double and triple effect, GAX Vapour Absorption systems. New trends in vapour absorption systems.

Solar refrigeration systems: Solar operation of refrigeration systems, Rankine and sterling cycle based solar cooling systems.

Solar Airconditioning systems: Solar desiccant cooling systems, Open cycle absorption/desorption solar cooling alternatives, Advanced solar cooling systems, Computer simulation of refrigeration and air-conditioning systems including solar systems.

Novel Technologies for refrigeration and Airconditioning: Thermoelectric refrigeration, Thermo acoustic cooling and hybrid cooling systems, Magnetic and Optical refrigeration systems.

Books

1. S.C. Kaushik, Solar Refrigeration and space conditioning, Divyajyoti Publications.
2. Kaushik, Arora and Bilga, I.K. Publications Alternatives in refrigeration and Air-conditioning.

ESM- 6405: Solar Thermal Power Generation

Solar Thermal Power Systems, Components and Solar Field: Electricity demand in the country, Challenges with conventional power generation option, Need and relevance of renewable energy based power generation, suitability of solar thermal power generation for India , Concentrating Collectors types and classification, Fresnel and Parabolic trough as linear focussing Collectors, Optical Analysis of PTC, Thermal Losses from PTC., Thermal Performance of PTC, Design of Parabolic Trough–Based Power Plants., Sizing and Layout of the Solar Field, Pressure Drop in the Solar Field., Expansion Tank, Examples of PTC Solar Thermal Power Plants Collector Central-Receiver and dish type as point focus Collectors, Collector Configurations, Concentration Ratio, solar concentrator mountings, Tracking of solar concentrators.

Thermal Performance of Concentrating Collectors: Optical Performance of Concentrating Collectors, Cylindrical Absorber Arrays, Optical Characteristics of Non-imaging Concentrators, Orientation and Absorbed Energy for CPC Collectors , Tracking requirements, Performance of CPC Collectors, Linear Imaging Concentrators: Geometry, Images Formed by Perfect Linear Concentrators, Images from Imperfect Linear Concentrators , Ray-Trace Methods for Evaluating Concentrators , Incidence Angle Modifiers and Energy Balances ,materials for concentrators, materials for reflecting and refracting surfaces, for absorber cover and surface coating. Receiver designs, Thermal performance characterization

Energy Storage Field: Need of thermal energy storage, size and duration of storage, sensible, latent and phase change material, Design of Storage System. Selection of Storage Material, heat transfer fluid HTF system, Nitrate Molten Salt type, Heat Storage, Options developed, Molten Salt- Most Accepted; research going for single tank storage with two sections, Phase Change Materials-, Steam Accumulator- Less Duration; large area, Concrete Materials-

Power Generation Block: Power generation block of solar thermal power plants, Oil-Indirect steam generation, Organic Rankine cycle, Brayton cycle, Stirling, water-steam cycle, auxiliary systems (bop), steam turbines, Electric generators, High voltage system, Solar thermal power plants engineering, Solar thermal power plants construction, Solar thermal power plants cooling systems, Wet cooling, Dry cooling and Hybrid cooling,

Operation and maintenance of solar thermal power plants: Solar thermal power plants maintenance, Occupational risk/hazard prevention, Environmental management, Maintenance management, Explosive atmospheres, Chemical control, boiler operator, Cooling towers maintenance, Case studies Andasol 1, 2 & 3. Location: Granada Province, Southern Spain, India one solar thermal plant at Mount Abu

Books

1. John A. Duffie and William A. Beckman, Solar Engineering of Thermal Processes Fourth Edition, Solar Energy Laboratory University of Wisconsin-Madison
2. H P Garg and J Prakash, Solar Energy fundamentals and Applications
3. D Yogi Goswami Principles of Solar Engineering
4. Patricia Palenzuela, Diego-Ce´sar Alarcon-Padilla Guillermo Zaragoza, Concentrating Solar Power and Desalination Plants Engineering and Economics of Coupling Multi-Effect Distillation and Solar Plants
5. Nikolai V. Khartchenko, Green Power: The Eco-Friendly Energy Engineering-Fundamentals and Design, Tech Books International Publishers New Delhi

ESM- 6301: Fuel Technology

Introduction to fuel: Different fuel energy resources, it's Indian and global perspective, Classification of Solid, liquid and gaseous fuels, Combustion appliances for solid, liquid and gaseous fuels

Origin and formation of coal: Different theories on coal formation, Coal as a source of energy and chemicals in India, Coal preparation, Carbonization, Gasification and liquefaction of coal and lignite, Fundamentals of coal combustion, combustion stoichiometry, Flue gas composition, Fundamentals of coal gasification, producer gas, water gas.

Extraction of liquid fuels: Petroleum and its derived products, Petroleum refining processes, Interconversion of fuels, Liquid fuel resources, world and Indian statistics, methods for characterization of crude oil and its products, refinery operations, testing of liquid fuels, industrial process design, utilization of petroleum products, synthetic liquid fuels.

Production of gaseous fuels: Natural gases and its derivatives, sources, potential, Gas hydrates Different types of gaseous fuels and its resources and their characteristics, principles of manufacturing of gaseous fuels from coal and oil, kinetics and mechanism of gasification, production of industrial fuel gases, rich gases such as SNG, purification, storage and transportation of gaseous fuels.

Nuclear fuels: Oxide fuel, Metal fuel, Ceramic fuel, liquid fuel, Refused-derived fuel, Bio-fuels: Biomass, Algae, biodiesel, Alcohol Fuels: Methanol, Ethanol, Butanol, Propane, etc.

Book

1. J.G. Speight and B. Ozum, Petroleum Refining Process, CRC Press, 2009.
2. J. G. Speight, The Chemistry and Technology of Coal, CRC Press, 2013.
3. F. Peter, Fuels and Fuel Technology, Wheaten & Co. Ltd., 1st edition, 1965.
4. S. Sarkar, Fuels and Combustion, Orient Longman, 2nd edition, 1990.
5. J. G. Speight, The chemistry & Technology of Petroleum, 4th edition, CRC Press, 2006.
6. Ke Liu, C. Song and V. Subramani, Hydrogen and Syngas Production and Purification Technologies, John Wiley & Sons, 2010.

ESM- 6303: Life Cycle and Reliability of Energy Systems

Energy and environment correlations, Environmental degradation due to energy production and utilization.
Environmental Impact Assessment, Life cycle analysis and sustainability issues of various systems, technologies and products based on their environmental properties.
Elements of probability theory. Elements of statistical theory. Some general stochastic processes. Statistical failure models.
System reliability. Reliability improvement. Maintainability and availability. Fault tree analysis, Failure mode effect analysis.
Reliability physics models, Testing reliability hypotheses

Books

1. Dessler A. Introduction to Modern Climate Change, Cambridge University Press
2. N.R. Mann, R.E. Schafer & N.D. Singpurwalla, Methods for Statistical Analysis of Reliability and Life Data, John Wiley & Sons.
3. L.S. Srinath, Concepts of Reliability Engg., Affiliated East-Wast Press (P) Ltd.
4. A.K. Govil, Reliability Engineering, Tata McGraw-Hill Publishing Co. Ltd.
5. E. Balagurusmy, Reliability Engineering, Tata McGraw-Hill Publishing Co. Ltd.
6. B.S. Dhillion, C. Singh, Engineering Reliability, John Wiley & Sons.
7. M.L. Shooman, Probabilistic, Reliability, McGraw-Hill Book Co.
8. P.D.T. Conor, Practical Reliability Engg., John Wiley & Sons.
9. K.C. Kapur, L.R. Lamberson, Reliability in Engineering Design, John Wiley & Sons.
10. S.K. Sinha, Reliability and Life Testing, Wiley Eastern Ltd.

ESM- 6305: Direct Energy Conversion Technology

Basic science of energy conversion, Indirect verses direct conversion
Physics of semiconductor junctions for photovoltaic and photo-electrochemical conversion of solar energy, Fabrication and evaluation of various solar cells in photovoltaic power generation systems
Technology of thermo-electric generations, Thermal-electric materials and optimization studies
Basic concepts and design considerations of MHD generators, Cycle analysis of MHD systems,
Thermonic power conversion and plasma diodes, Thermo dynamics and performance of fuel cells and their applications.

Books

1. S. S. L. Chang, Energy Conversion, Prentice Hall.
2. S. W. Angrist, Direct Energy Conversion, Pearson.
3. R. J. Rosa, Magneto hydrodynamic Energy Conversion, Springer.
4. V. S. Bagotsky, Fuel Cell Problems and Solutions, John Wiley & Sons.

ESM- 6201: Zero Emission Vehicles

Transportation Basics: Requirement of transportation, Global trends in growth of Transportation vehicles, Vehicular exhaust emissions effect on human health, Factors affecting the exhaust emission (A/F Ratio, combustion chamber design, Advances in IC engine).
Mitigation IC Engine Exhaust Emissions: MPFI, CRDI, GDI, EGR, Alternative fuels, After Exhaust Treatment devices, OBD, Evolution and development of Emission Standard.
Environment Friendly Fuel: CNG, LPG, DEE, DME, Hydrogen, Bio-CNG etc., arrangement for their use in IC engines, case studies on performance and emissions. Well to wheel analysis of various alternative fuels.
Fuel Cell & Solar Power: Fuel Cells concept and types, fuel cells based on usage of Hydrogen and Methanol, Power rating, and performance. Heat dissipation, Layout of fuel cell vehicle. Solar cells for energy collection. Storage batteries, Charge controllers. Layout of solar powered automobiles. Advantages and limitations.
Electric & Hybrid Vehicles: Layout of electric vehicles, advantages & limitations. Systems components, storage batteries merits and demerits of different type of batteries, battery wear, battery management. Electronic controlled systems, high energy and power density batteries. Study of various Types of hybrid vehicles and different drive train topologies, charging stations, charging protocols, BMS, Battery swapping stations.

Books

1. Rogoff, M.J. and Screve, F., "Waste-to-Energy: Technologies and Project Implementation", Elsevier Store.
2. Young G.C., "Municipal Solid Waste to Energy Conversion processes", John Wiley and Sons.
3. Harker, J.H. and Backhusrt, J.R., "Fuel and Energy", Academic Press Inc.
4. EL-Halwagi, M.M., "Biogas Technology- Transfer and Diffusion", Elsevier Applied Science.
5. Hall, D.O. and Overeed, R.P.," Biomass - Renewable Energy", John Willy and Sons.
6. Mondal, P. and Dalai, A.K. eds., 2017. Sustainable Utilization of Natural Resources. CRC Press.
7. Shah, Kanti L., Basics of Solid & Hazardous Waste Management Technology, Printice Hall
8. Nicholas P. Cheremisinoff. Handbook of Solid Waste Management and Waste Minimization Technologies. An Imprint of Elsevier, New Delhi.
9. P. Aarne Vesilind, William A. Worrell and Debra R. Reinhart. Solid Waste Engineering. Thomson Asia Pte Ltd. Singapore.
10. M. Dutta, B. P. Parida, B. K. Guha and T. R. Surkrishnan. Industrial Solid Waste Management and Landfilling practice. Narosa Publishing House, New Delhi.
11. Modern electric, hybrid electric, and fuel cell vehicles, Ebrahimi, Kambiz M., Ehsani, Mehrdad, Gao, Yimin, Longo, Stefano, CRC Press
12. Electric and Hybrid Vehicles, Tom Denton, Routledge

ESM- 6203: Electricity Regulations and Reforms in India

Overview of Indian Power Sector & Phase wise Sectoral Reforms: Power sector structure in Country, Significance of Regulatory Overview, Indian Electricity Act 1910, Electricity Supply Act 1948,

Electricity Regulatory Commission Act 2003: Salient features & Regulatory provisions, Electricity Amendment Act 2007, Electricity Amendment Bill 2014, National Electricity Policy & National Tariff Policy Regulatory Institutions in Indian Power Sector & their functioning: Objectives, Constitution & Function of CERC & SERC's, Role of APTEL & Forum of Regulators (FOR), Regulatory initiatives undertaken by CERC & respective SERC's

Tariff determination methodology: Regulatory norms for computation of Tariff of Thermal and Hydro, Comparison of CERC & SERC Tariff norms, Tariff determination exercise on Computer for Thermal Power Plant and Renewable Energy, Tariff based bidding for Power Projects Regulatory framework for Renewable Energy (RE),

RE policy prescriptions: Central and State; CERC guidelines on RE development, Regulatory issues and challenges; Comparative state regulations and RE

Power Market transactions: Concept of Power Trading, Power Exchange mechanism in India, Availability Based Tariff & Concept of UI, Open access in Power sector, Multi Year Tariff (MYT) framework

Text Books

1. Kumar A., and Chatterjee S. K. ; Electricity Sector in India: Policy and Regulation, Oxford University Press
2. Daniel S. K., and Goran S. ; Fundamentals of Power System Economics, Wiley
3. Suggested Reading NPTEL E-Learning; Restructured Power Systems, http://nptel.ac.in/syllabus/108101005/
4. Rao S L. (Ed); Powering India, Academic Foundation
5. Bhattacharya K., Bollen M., Daalder J. E; Operation of Restructured Power Systems, Springer
6. Ruet J., and Kaushik P. D.; Privatising Power Cuts? Ownership and Reform of State Electricity Boards in India, Academic Foundation
7. Lai L L. (editor); Power System Restructuring and Deregulation: Trading, Performance and Information Technology, Wiley.

ESM- 6205: Carbon Capture and Storage Systems

Introduction to source of CO_2 (Greenhouse gas) from thermal energy systems and their Global warming potential (GWP), carbon and CO_2 cycle, Scenario of CO_2 concentration in atmosphere, Relationship between radiative forcing and greenhouse gas concentration, Estimation of the equilibrium surface temperature change, and global warming and climate change.

Mechanism of CO_2 emission formation during combustion in power plants (steam turbine, gas turbine and internal combustion engines), CO_2 emission reduction by use of alternative fuels and energy efficiency improvement in thermal energy system, Measurement and analysis of CO_2 emission in heat engines/power plants/thermal energy system.

Carbon capture: different methods (physical/chemical/biological) of Carbon capture from power plants, CO_2 capture through precombustion methods, Oxygen-combustion method, Post-combustion methods (physical solvents/sorbents, membranes, cryogenic fractionation), and Chemical-looping combustion, and algae species.

Carbon storage under empty oil well, Ocean storage, etc. Carbon sequestration: mineral carbonation, Photosynthesis of plants, Fuel production, refrigerant, Dry ice, Fertilizer, Working fluid for power plants, Industrial applications (textile, paint, mining, oil etc.) and Case studies/numerical calculations for energy input requirement for CCS system.

Books

1. Steve Rackley, Carbon Capture and Storage, Elsevier Publisher.
2. Rao.Y, Surampalli, Tian.C.Zhang, et al, Carbon Capture and Storage: Physical, Chemical and Biological methods, American Society of Civil Engineer (ASCE).
3. Ibrahim Dincer, Calin Zamfirescu, Sustainable Energy Systems and Applications, Springer.