2 Years M. Tech. Program on "Energy Science and Engineering"

Intake 2020-2021: 5 MHRD + 5 sponsored

Total: 48 + 3 Lab = 51 credits

The goal of the program is to impart and foster knowledge in energy research and development and state-of-the art approaches to shape the future of energy.

EST participating departments

- Chemistry (Coordinating)
- Chemical Engineering
- Electrical Engineering
- Materials Science and Metallurgical Engineering
- Physics

Industry participants

- PURE EV, Hyderabad
- NED Energy Ltd., Hyderabad
- HBL Power Systems Limited, Hyderabad
- Renewable energy systems, Hyderabad
- Reliance Power

Semester wise credit requirements:

Semester	**Theory**		**Lab**	**Total**
	Core	Elective		
I	8	4	Lab-1 Material Synthesis and Characterization (1.0)	13
II	6	6	Lab-2 Energy conversion and storage devices (2.0)	14
III	12 (Thesis- Stage 1)			12
IV	12 (Thesis- Stage 2)			12
Total (I-IV)				51

Semester I

Course Code	**Semester I**	**Credits**	**Core/Elective**
ET5010	Fundamentals of Electrochemistry	2.0	Department core
ET 5020	Electrochemical Energy Storage Systems: Batteries, Fuel Cells and Supercapacitors	2.0	Department core
ET5030	Non-conventional energy sources and environment	2.0	Department Core
ET5040	Energy Management	1.0	Department core
ET5053	Material synthesis and characterization (including lab 1.0)	3.0	Department core
ET5060	Bio-energy	2.0	Department Core
LAXXXX	1-English communication	1.0	Soft skill (Core)
Semester-I	Total	13.0	

Extra Electives Semester I:

Course Code	**Semester I**	**Credits**	**Core/Elective**
CH5010	Computational Methods for Chemical Engineers	3.0	Elective
CH6310	Introduction to statistical hypothesis	2.0	Elective

Semester II

Course Code	Semester II	Credits	Core/Elective
ET5210	Power systems engineering and converters for renewable applications	3.0	Department core
ET 5220	Photovoltaic (PV) Technology	2.0	Department core
ET5230	Energy Audit	1.0	Department core
ET5211	Energy conversion and storage devices Lab-2	2.0	Department core-Lab
ET52XX	Elective-1	2.0	Department elective
	Elective-2	2.0	Elective
ET52XX	Elective -3	1.0	Department Elective
IDXXXX	Industrial lecture series	1.0	Soft skill
Semester-II	Total	14.0	

Semester II Electives

Course Code	Semester II	Credits	Core/Elective
CH6690	Energy Storage Systems	2.0	Department Elective
ET 5240	Hydrogen economy	2.0	Department Elective
ET5250	Energy Systems Analysis	2.0	Department core
ET5260	Electric vehicles	1.0	Department Elective
ET5270	Nuclear Energy	1.0	Department elective
CH6400	Bio Refinery	1.0	Elective
EEXXXX	Control and instrumentation	2.0	Elective
CH6020	Sustainable and Energy Options	1.0	Elective
CH5080	Advanced Transport Phenomena	3.0	Elective
CH5030	Molecular Thermodynamics	2.0	Elective
CH6610	Fuel Cell Technology	1	Elective
CH6140	Petroleum Refinery	1	Elective
CH6860	Data analysis tools for experimental research	1	Elective
CH6180	Statistical design and analysis	1	Elective
CH6640	Optimization Techniques-I	2	Elective

Semester III

	Semester III	
ET6015	Thesis stage -1	12

Semester IV

	Semester IV	
ET6015	Thesis stage -2	12

Note:

- Project will be mostly Industry based or few may be academic research
- Currently 3 industries PURE EV, Hyderabad, NED Energy Ltd., Hyderabad, HBL Power Systems Limited, Hyderabad has given their consent.
- Industry selection at the end of 2nd semester
- Each faculty will supervise 1-2 students
- Project should be focused on developing energy storage and conversion devices
- Electives should be taken in consultation with EST coordinator

EST Core courses (Aug-Nov 2020)

1. **ET5010: Fundamentals of Electrochemistry Credit 2.0**

Galvanic cells, redox potential, electromotive force, electrochemical series, Nernst equation, thermodynamics of reversible electrodes/cells, concentration cells reversible to electrode/electrolyte, liquid junction potential, Faraday's laws, Electrical double layer: Helmholtz-Perrin, Guoy-Chapman and Stern models, polarization and overpotential, diffusion, electrolytic conductance and transport number, electrolytes for electrochemical cells, electroanalytical methods (cyclic voltammetry and chronoamperometry).

References:
1. Modern Electrochemistry 1: Ionics, by J.M. Bockris and A.K.N. Reddy
2. Principles of Physical Chemistry, by B.R. Puri, L.R. Sharma, M.S. Pathania.
3. Physical Chemistry by P Atkins & J De Paula
4. Electrochemical Methods: Fundamentals and Applications, by Allen J. Bard and Larry R. Faulkner
5. Solid State Chemistry and its Applications, by A. R. West

2. **ET5020: Electrochemical Energy Storage Systems: Batteries, Fuel Cells and Supercapacitors Credit 2:0**

Principles of Operation of Cells and Batteries; Electrochemical Principles and Reactions; Factors Affecting Battery Performance; Battery Design; Primary Batteries; Secondary Batteries: Advanced Lead-acid, Ni-based and lithium ion batteries (Fundamentals, Materials, Electrode preparation, Battery Assembly, Testing, Failure Analysis, Safety issues); Flow Batteries; Next Generation Batteries; Fuel cells, Supercapacitors, Selection and Application of energy storage systems for UPS, Solar, Telecom, Aerospace, Grid and Electric Vehicle Systems.

References

1. Kirby W. Beard. Linden's Handbook of Batteries, Fifth Edition (McGraw-Hill Education: New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto, 2019).
2. Vladimir S. Bagotsky, Alexander M. Skundin and Yury M. Volfkovich (A.N. Frumkin Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Science, Russia) Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors" By, John Wiley & Sons Inc, New Jersey, USA, 2015, 372 pages, ISBN: 978-1-118-46023-6.
3. Ying-Pin Chen, Sajid Bashir, Jingbo Louise Liu, Nanostructured Materials for Next-Generation Energy Storage and Conversion: Advanced Battery and Supercapacitors, Springer Nature, 10-Oct-2019 - Technology & Engineering - 472 pages.
4. D. Pavlov, Lead-Acid Batteries: Science and Technology, Elsevier 31-May-2011 - Technology & Engineering - 656 pages.
5. C. Vincent, Bruno Scrosati, Modern batteries, Elsevier, 26-Sep-1997 - Technology & Engineering - 368 pages.

3. ET5030 Non-Conventional Energy Resources and Environment Credit 2.0

- Green energy resources: Introduction to non- conventional energy resources, overview of current developments. overview solar cell technology, solar thermal energy, geothermal energy, wind energy, wave energy/tidal energy, hydrogen production, biomass and biofuel production.
- Solar cells: overview of solar cell technology, principles of solar cell technology, Silicon based solar cells, fabrications and latest development, Non-Si solar cells i.e. chalcogenide solar cells, dye sensitized solar cells and organic solar cells
- Concentrated solar thermal energy and geothermal energy: introduction to working principles of concentrated solar thermal energy systems, type of solar concentrators and their components, types of heat storage systems and mechanisms of heat storage, thermodynamics aspect of heat exchange systems and steam generators. Overview of geothermal technology
- Wind Energy: advantages and challenges of wind energy, fundamentals mechanisms of electricity generation from wind energy, geographical estimation and prediction of wind energy potential, type of wind energy systems, life cycle analysis and economical aspects of wind energy systems

References

1) *Handbook of Photovoltaic Science and Engineering,* Antonio Luque, Steven Hegedus, John Wiley & Sons, 2011, 1162 pages
2) *Advances in Concentrating Solar Thermal Research and Technology*, Manuel Blanco, Lourdes Ramirez Santigosa, woodhead publishing/ Elsevier – 2016- 461 pages
3) *Wind Energy: Fundamentals, Resource Analysis and Economics,* Mathew Sathyajith, Springer – 2006, 241 page

4. ET5040 Energy Management Credit 1.0

Energy generation, Energy storage, Generation-side management, Network operation, Demand-side management, Design example of the autonomous power supply using solar PV and battery to study energy management, Energy management smart parking lot with EVs.

References: selected papers from literature

5. MS5030/ET5053 Materials Synthesis and Characterization Credits: 3

Crystal Structure: Crystalline solids, crystal systems point groups: methods of characterizing crystal structure - Powder x-ray diffraction; types of close packing - hcp and ccp, packing efficiency, radius ratios; structure types with examples. Basics of Solid State Synthesis: Powder synthesis and compaction- precipitative reactions, sol-gel route, precursor method, ion exchange reactions, intercalation/deintercalation reactions, powder metallurgy; Bulk synthesis, Solidification from melt (amorphous and crystalline), electrodeposition, thin film preparation. Characterization Techniques: Thermal analyses (differential scanning calorimetry, thermogravimetric), microscopy (light, X-ray, electron) and spectroscopy.

References:

1. Solid State Chemistry and its Applications, by A. R. West, Wiley.
2. Solid State Chemistry, An Introduction by Lesley Smart, CRC Press
3. New Directions Solid State Chemistry, C. N. R. Rao and J. Gopalkrishnan, 2nd Edn, Cambridge University Press

6. ET5060: Bio-energy **Credit: 2.0**

Overview of Bio Energy; Biomass sources, classification and properties; Biomass pre-treatment and processing; Biomass Conversion processes; Biofuels; Biohydrogen; Biogas, Biofuels Economics, Sustainability, Environmental and Policy

References:

1. Yebo Li, Samir Kumar Khanal, Bioenergy: Principles and Applications, Wiley 2016

2.Vaughn C. Nelson, Kenneth L. Starcher, Introduction to Bioenergy, CRC press, 2017

3. Anju Dahiya, Bio Energy: Biomass to Biofuels and Waste to Energy, 2nd Ed, Academic press, 2020

4. Francesco Dalena, Angelo Basile and Claudio Rossi, Bioenergy systems for the future: Prospects for Biofuels and Biohydrogen, Woodhead publishing (Elsevier), 2017.

Other department Electives:

7. **CH5010 Computational Methods in Chemical Engineering**
   Credits 3.0

   Contents: Review of computer programming; Solutions of simultaneous linear/nonlinear equations; Newton's interpolation formula; Quadrature formula; Systems of first order ordinary differential equations (ODEs), Stability analysis; Variable step size algorithms (Gear's algorithm etc.), Finite Difference Methods for ODEs (IVPs & BVPs) and PDEs (hyperbolic, parabolic, elliptic). Numerical solutions of Chemical engineering problems e.g. separation processes, reaction engineering, fluid mechanics, process control, thermodynamics etc.

   References

1. Gupta, S. K., Numerical Methods for Engineers, 5-th Ed., New Age International (2010).
2. Pushpavanam, S. Mathematical Methods in Chemical Engineering, Prentice-Hall of India, New Delhi (2004).
3. Chapra, S. C., Canale, R. P. Numerical Methods for Engineers, Tata McGraw-Hill, New Delhi (2006).
4. Hoffman, J. D. Numerical Methods for Engineers and Scientists, Taylor and Francis, Boca Raton (2001).
5. Conte SD & de Boor C, Elementary Numerical Analysis - An Algorithmic Approach, 3rd Ed, SIAM Publishing, 2018.

8. CH6310 Introduction to statistical hypothesis testing Credit: 2.0

Measures of central tendency, some important probability distributions, Sampling distribution of the mean, Confidence intervals, Hypothesis testing, Comparison of means and variances, Analysis of variance and associated designs.

References

1. Principles of Biostatistics, Marcello Pagano and Kimberlee Gauvreau, Second edition, Brooks/Cole Cengage Learning, 2000
2. Design and Analysis of Experiments, R Panneerselvam, First edition, PHI Learning Pvt Ltd, 2012

Semester II (January-April)

Core Courses:

ET5210: Power systems engineering and converters for renewable applications Credit 3.0

Basic concept of power plants, types of power plants, thermal power stations, various components of thermal power stations, power plant cycles, fuel handling, combustion, waste disposal methodologies, economizers, turbo alternators, heat transfer/balance and efficiencies, hydroelectric power plant, various components, capacity calculation, design methodologies, operation and maintenance methodologies, elements of nuclear power stations, reactor design, fuel, moderator, coolant control and safety, waste disposal, Need for power conversion, Concept of MPPT, Introduction to Power Electronic switches, Power electronic converters - basics of dc to dc converters (non-isolated), dc to ac converters (Inverters), ac to dc converters (rectifiers). Modelling of basic dc to dc converters

ET5220: Photovoltaic (PV) Technology ` Credit: 2.0

Characteristics of the photovoltaic cell; Semiconductor Basics; Silicon solar cells; Thermodynamic limit to efficiency, Light management, electrical losses, thin-film silicon solar cells; Advanced strategies for high-efficiency solar cells; Chalcogenides & III-V Technologies; Organic Photovoltaics; Hybrid Technologies; PV modules.

References:

- The Physics of Solar Cells by Jenny Nelson, Imperial College Press-2013.
- Solar Photovoltaics: Fundamentals, Technologies and Applications, Chetan Singh Solanki, PHI Learning PVT Ltd.
- Third Generation Photovoltaics: Advanced Solar Energy Conversion, by Martin Green, Springer

ET5230: Energy Audit Credit: 1.0

Concept, types of audit, energy index, cost index, pie charts, Sankey diagrams, load profiles, Energy efficiency in thermal utilities, Energy efficiency in electrical utilities, Energy performance assessment for utility systems, building energy audit.

ET5211 Energy conversion and storage devices Credits: 2.0

Electrodeposition, Battery charge-discharge, life-cycle studies, CV, EIS, Chronoamperommetry and potentiommetry, LSV, Solar cell testing.

Semester II Electives:

1. CH6690: Energy Storage Systems Credits: 2.0

Introduction to energy storage, power density vs. energy density, electrochemical energy storage including batteries, supercapacitors and fuel cells, chemical energy storage including hydrogen storage and biofuels, thermal energy storage including phase change materials and cryogenics, mechanical energy storage including flywheels and compressed gas, discussion of viable technologies for commercialization with emphasis on environmental impact, cost and efficiency, advantages, disadvantages and applicability of various technologies.

Suggested References:

1. Energy Storage, 1st Edition by Robert A. Huggins, Springer US, 2010.
2. Energy Storage - Technologies and Applications, edited by Ahmed Faheem Zobaa, In Tech, 2013.

2. ET5240: Hydrogen Storage Credit 2.0

Hydrogen-based energy carrier and storage, Sustainable application, high-efficiency hydrogen conversion devices, Production and storage of hydrogen, Hydrogen Storage in Advanced Solid State and Liquid Materials

References:
1. Handbook of Hydrogen Storage: New Materials for Future Energy Storage 1st Edition by Michael Hirscher (Editor), Katsuhiko Hirose (Foreword), Wiley-VCH.

2. Hydrogen Storage Technology: Materials and Applications, by Lennie Klebanoff (Editor), 2012, CRC Press.
3. Nanomaterials for Solid State Hydrogen Storage, Robert A. Varin, Tomasz Czujko, Zbigniew S. Wronski, 2009, Springer

3. ET5260: Electric Vehicles: Credit 1.0

Introduction, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design, Vehicle Dynamics, drive train design methodology and control principles, Battery-fuel cell-supercapacitor requirements, BMS, Advantages and disadvantages of EVs.

References:

1. Electric and Hybrid Vehicles: Design Fundamentals, Iqbal Husain (Author), Second Edition, 16 August 2010, CRC Press.
2. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design, by Mehrdad Ehsani (Author), Yimin Gao (Author), Ali Emadi (Author), Second Edition (Power Electronics and Applications Series) 2009, CRC Press.
3. Electric Vehicle Technology Explained, James Larminie (Author), John Lowry (Author), 2012, Wiley.

4. **ET5270: Nuclear Energy** **Credit 1.0**

Nuclear reactions, Fusion-Fission Reactions, nuclear power systems, basic principles of radiation detection and Protection, advanced nuclear reactor systems, the sustainable development of innovative nuclear energy technologies, Nuclear Waste Disposal, Nuclear Fuel Cycles, Economy of Nuclear Energy.

References:

1. Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes by Raymond Murray (Author), Keith E. Holbert (Author), 2014, Butterworth-Heinemann
2. Nuclear Energy, An Introduction to the Concepts, Systems, and Applications of Nuclear Processes, By, Raymond Murray, Keith Holb, 8th Edition, 2019, Elsevier.

5. **CH5080 Advanced Transport Phenomena** **Credit: 3.0**

Course content: Vectors and tensor analysis, Momentum transport, Governing equations & Boundary conditions: equations of continuity and motion, Steady, Unidirectional flows, Non-dimensionalisation (Reynolds number, Schmidt number, Prandtl number etc), Time dependent flows, method of similarity solutions (combination of variables), Sturm-Liouville problems (separation of variables, infinite series), Two-dimensional flows: Stream function, limiting cases: creeping flow, inviscid flow, potential flow, velocity potential, Boundary layer theory, Turbulent flow, transition to turbulence, turbulence models, Analogy of Energy & Mass transport with Momentum transport (with examples).

References

1.Bird RB, Stewart WE, Lightfoot EN, Transport Phenomena (Revised 2nd Edition), John Wiley & Sons, 2007.
2.Deen WM. Analysis of Transport Phenomena (2nd Edition), Oxford University Press, New York, 1998.
3.Leal LG, Advanced Transport Phenomena, Cambridge University Press, Cambridge, 2010.
4.White FM, Fluid Mechanics, 7th Edition, McGraw Hill, New York, 2011.

6. **CH5030 Molecular Thermodynamics** **Credits: 2.0**

Course content: Quick Recap of Basic Thermodynamics, Introductory Probability, Extremum Conditions, Statistical Interpretations of Free Energy & Entropy, 3rd Law & Boltzmann Distribution, Simple Gases, Temperature & Heat Capacity, Solutions, Different Ensembles, Fluctuations, Example Applications.

References

1.Chemical, Biochemical, and Engineering Thermodynamics by Sandler, Wiley, 4th or 5th Edition.
2.Thermodynamics & Statistical Mechanics, M. Scott Shell, 2015, Cambridge University Press.

7. **CH6640 Optimization Techniques** **Credit:2.0**

Course content: Concepts of optimization, formulation of optimization problems, unconstrained optimization, necessary and sufficient conditions, convexity, single and multi-variable optimization, constrained optimization, KKT conditions, numerical optimization, one dimensional area elimination and interpolation based methods, multi-dimensional

Newton's / Quasi - newton methods, evolutionary optimization, genetic algorithms, solving practical problems.

References:

1. S. S. Rao, Engineering Optimization: Theory and Practice, New Age Intl. Publishers, New Delhi, 3rd Enlarged Ed., 2011.
2. T. F. Edger, D. M. Himmelblau, L S Lasdon, Optimization of Chemical Processes, McGrawHill, 2nd Edition, 2001.

8. **CH6610 Fuel Cell Technology** **Credit: 1.0**

Course Content: Types of fuel cells, advantages and disadvantages of different fuel cell types, fuel cell thermodynamics, electrode kinetics, charge transport, fuel cell characterization, modelling of electrochemical processes.

"

9. **CH6860 Data analysis tools for Experimental Research** **Credit:1.0**

Course content: Probability density function, analysis of variance: One way and Two-way ANOVA, Non-parametric testing, correlation, regression, computation of distances, clustering and validation, introduction to principal component analysis**.**

10. **CH6180 Statistical design and analysis** **Credit: 1.0**

Course content: Factorial Experiments, Full Factorial Designs, Blocking and Confounding in Factorial Designs, Fractional Factorial Designs, Introduction to Multivariate Analysis

References:

1. Design and Analysis of Experiments, Douglas C Montgomery, Eighth edition, Wiley, 2017
2. Design and Analysis of Experiment, R Panneerselvam, PHI Learning Pvt Ltd, 2012

11. **CH6140 Petroleum Refinery** **Credit:1.0**

Course Content: Evaluation and characterization of crude oil: TBP and other distillation tests. Petroleum products, their properties, specification and testing different properties like flash point, fire point, smoke point, aniline point, carbon residue, kinematic viscosity, pour point, freezing point etc. Petroleum refinery distillation-pre- fractionation and atmospheric distillation of crude. Stabilization of naphtha. Vacuum distillation of RCO. Reforming of naphtha. Other secondary processes like Vis-breaking, FCC unit. Hydrotreatment processes in refining: hydro-desulfurisation, hydrofinishing, Hydrocracking. Production of lube oil base stock.

References:

1. C.E. Dryden, Dryden's outlines of Chemical Technology for the 21st century, (Edited and revised by M.G. Rao and M. Sitting) 2006.
2. James H. Gary, Glenn E. Handwerk, Mark J. Kaiser, Petroleum Refining: Technology and Economics. CRC Press, 5th edition, 2007.

12. **CH6400 Bio-refinery** **Credit: 1.0**

Course Content: Overview of petroleum refinery and petrochemicals, Scenario of energy and chemicals and need for renewable feedstock; introduction and overview of bio-refinery, fuels and chemicals from vegetable oils; bio-alcohol as feedstock for fuels and chemicals; synthesis gas from biomass, overview of gasification, pyrolysis, and reforming; fuels and chemicals from synthesis gas; fuels and chemicals from biomass.

References:

1. James H. Gary, Glenn E. Handwerk, Mark J. Kaiser, Petroleum Refining: Technology and Economics. CRC Press, 5th
edition, 2007.

2. Birgit Kamm, Patrick R. Gruber, Michael Kamm, Bio-refineries - industrial processes and products: status quo and
future directions. Volume 1&2, Wiley-VCH, 2006.