Department of Sustainable Energy Engineering
Indian Institute of Technology Kanpur

Proposal for a New Course

Course Title	Carbon Capture, Utilization, and Storage (CCUS)
Course Number	SEE XXX
Credits (L-T-P-C)	3-0-0-0 [9]
Department Proposing the Course	Sustainable Energy Engineering
Name of the Proposer	Soumyabrata Roy
Offered For	PG students
Prerequisite(s)	None
Faculty Members Interested in Teaching	Soumyabrata Roy, Sheo Shankar Rai, Raju Kumar Gupta
Other Departments/Programs who may be interested in the course	CHE, ES, KSS, CHM, MSE, CE, ME, CESE, DoMS

Course Objectives: This course will provide an in-depth understanding of Carbon Capture, Utilization, and Storage (CCUS) technologies as a critical pillar of sustainable energy transitions. It will address CO_2 emissions mitigation across sectors such as power generation, industry (hard-to-abate sectors), and transportation. The course will cover scientific principles, technological approaches, system integration, and policy/regulatory frameworks associated with the CCUS value-chain. Emphasis will be placed on emerging research directions, Indian and Global case studies, and techno-economic evaluations for large-scale deployment. The following will be the key objectives of this course:

1. Develop a strong foundational understanding of carbon emissions and the need for CCUS in achieving net-zero targets.
2. Explore fundamental principles of thermodynamics, reaction engineering, materials science, and system integration in CCUS technologies.
3. Provide a systematic overview of CO_2 capture techniques (solvent-based, solid sorbent, membrane-based, and cryogenic), transport logistics, and storage options (geological, mineral, and deep-sea).

4. Evaluate utilization technologies, including catalytic, electrochemical, biochemical, and mineralization routes for conversion to value-added products.
5. Assess techno-economic parameters, life-cycle assessments (LCA), and integration strategies with power plants, cement & steel industry, bioenergy systems, and other relevant industrial sectors.
6. Review current policy frameworks, carbon trading mechanisms, and regulatory aspects relevant to India and globally.
7. Encourage innovation and research thinking by connecting emerging trends such as AI/ML for CCUS system optimization and novel materials development.

Expected Learning Outcomes

On completion of this course, students are expected to develop the ability to analyze and compare various CO_2 capture technologies and understand their integration potential within relevant industrial systems. They will acquire a strong grasp of the underlying thermodynamics and kinetics of CO_2 capture and conversion processes, along with familiarity with a wide range of capture technologies, including solvent-based systems, solid sorbents, membranes, and cryogenic approaches. They will gain insights into CO_2 transport mechanisms and strategies for long-term geological storage, as well as understand the technical and economic potential of CO_2 utilization pathways such as fuels, chemicals, building materials, and biological fixation. The course will also prepare students to identify and navigate the regulatory, policy, and societal acceptance challenges surrounding CCUS deployment. They will develop understanding of the feasibility, cost, and environmental implications of implementing CCUS projects and will gain proficiency in designing conceptual flowsheets tailored to site or sector-specific applications. Lastly, students will be trained to critically assess current literature, evaluate emerging research trends and development efforts, and develop the necessary skills to design and optimize CCUS systems, particularly in the context of Indian industrial and energy sectors.

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Course outline

S. No.	Broad Title	Topics	Lectures
1	**Introduction to CCUS and Global Context**	-Climate change and global carbon budget -Role of CCUS in Net Zero transitions and SDG goals - Global and Indian emissions scenario - Types of CO_2 sources and Sectoral emissions profiles (power, cement, steel, chemical, bioenergy) - Technology readiness and sectoral applicability - Life-cycle assessment of CCUS pathways - CCUS roadmap: Global and Indian perspective (IEA, NITI Aayog)	4
2	**Fundamentals of CO_2 Capture**	- Separation thermodynamics and driving forces -Post-combustion vs. pre-combustion vs. oxy-combustion - Mass transfer and reaction engineering basics - Energy penalties and process intensification strategies -Solvent-based capture (amine systems, challenges, regeneration) - Solid sorbents (zeolites, activated carbon, MOFs) - Membrane separations (types, transport mechanisms, limitations, permeability/selectivity trade-offs, energy penalties) - Cryogenic, Chemical looping and oxy-combustion approaches - Emerging materials: ionic liquids, phase-change solvents	8
5	**CO_2 Transport Systems**	- CO_2 compression, liquefaction, and conditioning - Pipeline design: codes, safety, monitoring - CO_2 shipping and logistics for remote storage - Infrastructure and cost assessment models	2
6	**CO_2 Storage Mechanisms**	- Geological storage: saline aquifers, depleted oil/gas fields - Well drilling and injection techniques - Geomechanics, Caprock integrity and leakage risks - Long-term monitoring and MRV (Measurement, Reporting, Verification) - Mineralization, in-situ reactions, solid-storage - Environmental and risk assessment frameworks	6
7	**CO_2 Utilization Pathways**	- Thermocatalytic, electrocatalytic and solar conversion: CO_2 to fuels, methanol, syngas - CO_2 to polymers, CO_2 mineralization to building materials (carbonates) - Biological conversion: algae, microbial fermentation - Techno-economic analysis of utilization pathways, Industrial symbiosis and circular carbon economy	6

8	**Integration with Industrial and Bioenergy Systems**	- CCUS in cement, steel, and refineries- BECCS (Bioenergy with Carbon Capture and Storage): scope, challenges, Indian context - Coupling CCUS with green hydrogen and waste-to-energy plants - Case studies: NTPC, Indian Oil, and global benchmarks	4
9	**Techno-Economics, LCA, and Evaluation**	- Cost of CO_2 avoided vs. captured vs. utilized - Key CAPEX and OPEX components - Life cycle assessment: GHG reduction potential - TEA tools and scenario analysis using open-source models	4
10	**Policy, Regulatory, and Public Engagement Dimensions**	- CCUS in national and international climate policies - Carbon markets, tax incentives, and subsidies - Indian regulatory landscape: MoEFCC, MNRE, NITI Aayog - Legal frameworks for liability and permanence - Social license to operate and community engagement	3
11	**Outlook and Emerging Frontiers**	- Emerging materials and digital tools (AI/ML) for CCUS optimization - Hybrid energy systems and CCUS coupling - Direct Air Capture (DAC) vs. Point Source Capture- - Role of CCUS in hard-to-abate sectors - Summary, project presentations, and open discussions	3

Textbooks, reference books, suggested readings and any other references

- *Carbon Capture, Storage and, Utilization: A Possible Climate Change Solution for Energy Industry" by Malti Goel*
- *Carbon Capture by Jennifer Wilcox*
- *Carbon Dioxide to Chemicals and Fuels by M. Aulice Scibioh and B. Viswanathan*
- *CO_2 Capture, Utilization, and Sequestration Strategies by Yatish T. Shah (https://doi.org/10.1201/9781003229575)*
- *Carbon Capture-Utilization and Storage: Climate Change Mitigation by Jayarama Reddy Puthalpet*
- *Carbon Capture: Sequestration and Storage: 29 (Issues in Environmental Science and Technology) by Vassilis Kitidis and Klaus Lackner*
- *Climate Change and Carbon Recycling: Surface Chemistry Applications* by K. S. Birdi
- Introduction to Carbon Capture and Sequestration (Berkeley Lectures on Energy) (The Berkeley Lectures on Energy) by Smit
- Carbon Capture, Utilization, and Storage (CCUS) Resources: CCUS Handbook for Policymakers
- Carbon Capture and Storage, IPCC Special Report, 2005
- IEA CCUS Reports (2020–2024), International Energy Agency

- Carbon Capture and Storage in Developing Countries: A Perspective from the Global South, Routledge
- CO_2 Utilization: From Fundamentals to Applications, Elsevier
- Government of India Reports: NTPC, MNRE, NITI Aayog – Reports on CCUS

Course proposed by	**Forwarded by**	**This course is approved/ not approved**
(Soumyabrata Roy)	Convener, DPGC (SEE)	Chairman, SPGC