CCS/CCUS Academic Curriculum

This product was supported by the CCUS CONSENSUS Program, a cooperative agreement with the United States Department of Energy, to address the need for global public outreach and consensus building on carbon capture, utilization and storage and clean energy systems.

USA

Arizona State University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Capture	SOS 598	3	Fall	2016	Klaus Lackner

Managing carbon dioxide emissions resulting from the use of fossil fuels is a major concern for the development of sustainable energy infrastructures in the future. It is a transdisciplinary challenge involving engineering, physical and social science as well as policy and legal issues. Carbon capture and storage has been widely recognized as an important set of technologies for managing carbon. This class will introduce major new technologies to capture carbon dioxide from new or retro--¿fitted power plants, from other emissions occurring in industrial processes, and ultimately the capture of carbon dioxide from ambient air, to deal with emissions that have no other solution. In addition to basic science and engineering challenges of each technology, the full spectrum of economic, environmental, regulatory, and political/policy aspects, and their implication for regional and global carbon management strategies of the future will be discussed.

USA

Carnegie Mellon University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Energy Conversion and Supply	39-610	6	Fall	2016	Karmalidis Noack

This is the first course in the ESTP core mini-course sequence where master?s students learn the basic workings of the systems that supply, distribute, and utilize energy. This class will consider fossil energy, nuclear energy, and renewable energy resources. The course will provide some basic thermodynamics and will cover both conventional and emerging energy conversion technologies. Specific technology examples may vary from semester to semester selected from such important topics as photovoltaics, fuel cells, carbon sequestration and biofuels.

Special Topics: Climate Change Mitigation	19-653	6	Spring		Jay Apt
Special Topics: Seminar in Low-Carbon Electric Power I/II	19-881/19-882	6	Spring		Allen Robinson
Water Resources Chemistry	12-720	12	Fall		Yoosuf Picard

A rigorous yet practical basis for applying the principles of physical chemistry to understanding the composition of natural waters and to the engineering of water and wastewater treatment processes. Topics covered include chemical equilibrium and kinetics; computer-aided problem solving; solid precipitation and dissolution; acid-base equilibria and buffering; oxidation and reduction reactions; sorption on solids; and coagulation and softening. Two laboratory sessions illustrate chemical principles of dilute aqueous systems.

USA

Clemson University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Environmental and Exploration Geophysics	GEOL 4090/6090	3			Stephen Moysey

Students develop an understanding of the principles and methods used to acquire, analyze, and interpret geophysical data. Emphasis on seismic/radar, gravimetric, and electromagnetic methods. Applications to hydrogeology, environmental engineering and science, soil science, contaminant transport and remediation, near surface geology, geotechnical problems, oil and gas exploration, and carbon sequestration. Includes Honors sections

USA

Colorado School of Mines

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Clean Coal Technology	MNGN540	3			Kazemi Hossien

Clean Energy - Gasification of Carbonaceous Materials - including coal, oil, gas, plastics, rubber, municipal waste and other substances. This course also covers the process of feedstock preparation, gasification, cleaning systems, and the output energy blocks along with an educational segment on CO products. These output energy blocks include feedstock to electrical power, feedstock to petroleum liquids, feedstock to pipeline quality gas. The course covers co- product development including urea, fertilizers, CO2 extraction/sequestration and chemical manufacturing.

Compositional Modeling-Application to Enhanced Oil Recovery	PEGN624	3			Benjamin Hoffman

Efficient production of rich and volatile oils as well as enhanced oil recovery by gas injection (lean and rich natural gas, CO2, N2, air, and steam) is of great interest in the light of greater demand for hydrocarbons and the need for CO2 sequestration. This course is intended to provide technical support for engineers dealing with such issues. The course begins with a review of the primary and secondary recovery methods, and will analyze the latest worldwide enhanced oil recovery production statistics. This will be followed by presenting a simple and practical solvent flooding model to introduce the student to data preparation and code writing. Next, fundamentals of phase behavior, ternary phase diagram, and the Peng-Robinson equation of state will be presented. Finally, a detailed set of flow and thermodynamic equations for a fullfledged compositional model, using molar balance, equation of motion and the afore-mentioned equation of state, will be developed and solution strategy will be presented. Prerequisite: PEGN513 or equivalent, strong reservoir engineering background, and basic computer programming knowledge. 3 hours lecture; 3 semester hours

Enhanced Oil Recovery Methods	PEGN506	3			William Hart

Enhanced oil recovery (EOR) methods are reviewed from both the qualitative and quantitative standpoint. Recovery mechanisms and design procedures for the various EOR processes are discussed. In addition to lectures, problems on actual field design procedures will be covered. Field case histories will be reviewed. Prerequisite: PEGN424. 3 hours lecture; 3 semester hours.

USA

Columbia University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Carbon Sequestration	EAEE E6212	3	Spring	Ah-Hyung Park

New technologies for capturing carbon dioxide and disposing of it away from the atmosphere. Detailed discussion of the extent of the human modifications to the natural carbon cycle, the motivation and scope of future carbon management strategies and the role of carbon sequestration. Introduction of several carbon sequestration technologies that allow for the capture and permanent disposal of carbon dioxide. Engineering issues in their implementation, economic impacts, and the environmental issues raised by the various methods

Climate Change and Law	W3355		Spring	Michael Gerrard

The purpose of this course is to provide students with a broad introduction to the field of climate law in the United States and at the international level. The course begins with an overview of the causes and effects of global climate change and the methods available to control and adapt to it. We then examine the negotiation, implementation and current status of the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Copenhagen Accord. The focus then turns to the past and proposed actions of the U.S. Congress, the executive branch and the courts, as well as regional, state and municipal efforts. The Clean Air Act, the National Environmental Policy Act and the Endangered Species Act will receive special attention. We evaluate the various legal tools that are available to address climate change, including cap-and-trade schemes; carbon taxation; command-and-control regulation; litigation; securities disclosures; and voluntary action. The roles of energy efficiency, renewable energy sources, carbon capture and sequestration, and forestry and agriculture each receive close attention. Implications for international human rights, international trade, environmental justice, and international and intergenerational equity are discussed. The course concludes with examination of the special challenges posed by China; proposals for adaptation and geoengineering; and business opportunities and the role of lawyers. Offered in the Spring.

Energy sources and conversion	E4211	3		Vijay Modi

Energy sources such as oil, gas, coal, gas hydrates, hydrogen, solar, and wind. Energy conversion systems for electrical power generation, automobiles, propulsion and refrigeration. Engines, steam and gas turbines, wind turbines; devices such as fuel cells, thermoelectric converters, and photovoltaic cells. Specialized topics may include carbon-dioxide sequestration, cogeneration, hybrid vehicles and energy storage devices.

Intro to Carbon Management	E4300	3	Spring	Peter Schlosser

Undergraduate level mathematics and science, or instructor's permission. Introduction to natural and anthropogenic carbon cycle, and carbon & climate. Rationale and need to manage carbon and tools with which to do so (basic science, psychology, economics and policy background, negotiations & society; emphasis on interdisciplinary and inter-dependent approach). Simple carbon emission model to estimate the impacts of a specific intervention with regards to national, per capita and global emissions. Student-led case studies (e.g., reforestation, biofuels, CCS, efficiency, alternative energy) to illustrate necessary systems approach required to tackle global challenges.

USA

Cornell University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Geological Carbon Sequestration Module	CHEME 6665/ EAS 6665	1	Spring		T.E. Jordan

United Kingdom

Cranfield University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
1 week Carbon Capture Technologies modular					

To mitigate climate change while meeting energy demand, the UK and other developed countries have set ambitious targets to reduce carbon emissions through carbon capture and storage (CCS). This short course introduces to the delegates different technologies and strategies for CO2 emission reduction from power generation and energy intensive industries. The course will be delivered by a team of leading researchers working on different aspect of CO2 capture from material, process modelling through to integration (https://www.cranfield.ac.uk/Courses/training/Carbon-Capture-Technologies)

Carbon Capture and Storage MSc/PgCert/PgDip		180			Vasilije Manovic

The course consists of nine modules - eight compulsory and an optional module which is selected from a suite of three options. You will also complete an individual research project. For part-time students, who are not able to do the group project, an extra optional module will be taken in order to complete the programme.

United Kingdom

Durham University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Environment and Resources	GEOL 1111	20			Fred Worrall

A component of CCS is included in this undergraduate programme. This module aims to give students an understanding of the mode of formation, distribution and extraction of the Earth's resources and energy and of the Earth's water cycle.

United Kingdom

Heriot-Watt University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
MSc Petroleum Geoscience					

The Petroleum Geoscience programme is jointly offered by Heriot-Watt University and Edinburgh University, with external staff from Durham University, and combines the expertise available at each of these three institutions to create a unique programme in subsurface geoscience and exploration. The Petroleum Geoscience degree provides participants with a thorough training in aspects of subsurface geology, geophysics and geo-engineering, relating to the exploration, appraisal and development of subsurface resources. Although the programme mainly concentrates on exploration for hydrocarbon resources, and delineation of hydrocarbon reservoirs in the subsurface, the skills gained in this subject are applicable to all subsurface geoscience areas, including groundwater exploration, waste disposal or CO2 sequestration.

Research Masters Carbon Capture and Storage					

Researchers in the CCS Group use experimental and numerical modelling techniques to address questions about CO2 injectivity, the mechanisms of oil mobilisation during CO2-EOR, CO2 migration and trapping from pore scale to basin scale, and the security of storage over thousands of years. These activities all contribute to a better understanding of the risk assessment, management, optimisation and cost reduction in CO2 injection operations. The group draws heavily on expertise developed in petroleum engineering disciplines such as reservoir description, fluid phase behaviour, flow in porous media, geomechanics, geochemistry and flow assurance to tackle the current subsurface technical challenges facing CCS. Postgraduate students carry out research on the fundamental understanding of CO2 behaviours in the subsurface, and also on very applied studies, some of which use field data supplied by funders and partners. The tools used include core flooding equipment, micromodel visualisation cells, pore scale network models and commercial reservoir simulation suites such as CMG and ECLIPSE.

United Kingdom

Imperial College

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Capture and Clean Fossil Fuels	CE4-28				Paul Fennell

"Students taking this course will be able:- To understand how the environmental impacts of fossil fuels in general can be minimised- To understand how syngas can be generated and used- To understand issues relating to industrial CCS- To understand how a range of technologies, including more advanced power cycles and/or more efficient heat recovery and utilisation, can minimise the costs of CO2 avoidance- To understand CO2 capture from a range of processes, including how efficiency drops for power stations are calculated- To understand CO2 storage- To consider issues of media reporting of CCS"

CCS Research Program					

USA

Massachusetts Institute of Technology

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Advanced Topics in Surfactant Science	10.56				Daniel Blankschtein

Introduces fundamental advances and practical aspects of surfactant self-assembly in aqueous media. In-depth discussion of surfactant micellization, including statistical-thermodynamics of micellar solutions, models of micellar growth, molecular models for the free energy of 173 COURSE 1 0 2014–2015 micellization, and geometric packing theories. Presents an introductory examination of mixed micelle and vesicle formation, polymersurfactant complexation, biomolecule-surfactant interactions, and micellar-assisted solubilization. Discusses molecular dynamics simulations of self-assembling systems. Covers recent advances in surfactant-induced dispersion and stabilization of colloidal particles (e.g., carbon nanotubes and graphene) in aqueous media. Examines surfactant applications in consumer products, environmental and biological separations, enhanced oil recovery using surfactant flooding, mitigation of skin irritation induced by surfactant-containing cosmetic products, and enhanced transdermal drug delivery using ultrasound and surfactants.

Computational Methods for Flow in Porous Media	1.723				

Covers physical, mathematical and simulation aspects of fluid flow and transport through porous media. Conservation equations for multiphase, multicomponent flow. Upscaling of parameters in heterogeneous fields. Modeling of viscous fingering and channeling. Numerical methods for elliptic equations: finite volume methods, multipoint flux approximations, mixed finite element methods, variational multiscale methods. Numerical methods for hyperbolic equations: low-order and high-order finite volume methods, streamline/front-tracking methods. Applications to groundwater contamination, oil and gas reservoir simulation, and geological CO2 sequestration, among others. Limited to graduate students.

Energy Systems and Climate Change Mitigation	ESD 124				Jessika Trancik

Explores the contributions of energy systems to global greenhouse gas emissions and the potential levers for reducing emissions. Lectures and projects focus on decomposing contributions to greenhouse gas emissions, with emphasis on technology related variables such as per unit cost and carbon intensity of energy. Reviews other performance attributes of energy technologies. Student projects explore pathways for realizing emissions reduction scenarios.

USA

New Mexico Institute of Mining and Technology

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Advanced Topics in Enhanced Oil Recovery Methods	PETR 558				

Advanced topics may include surfactant and alkali flooding mechanisms. Polymer flooding and rheology of non-Newtonian fluids. Gas injection methods including carbon dioxide, hydrocarbons, and nitrogen. Thermal recovery.

Carbon Capture and Storage	GEOL 528				

Offered on demand. The course examines efforts to reduce the buildup of atmospheric greenhouse gases by sequestering carbon into geological reservoirs. Topics include Earth's climate history, atmospheric chemistry, sources and sinks for greenhouse gases, carbon capture technology, geological reservoirs and seals, water/rock interaction, subsurface flow modeling, site monitoring for verification, decision making rationale, and policy issues. Taught jointly with the University of Utah using Distance Education facilities. Numerous guest lectures from experts in the field.

Carbon Sequestration Science	ERTH 427			Peter Mozley

Overview of geological carbon sequestration. Topics include: Earth's changing climate, sources and sinks of greenhouse gases, carbon capture, reservoirs and caprocks, physical and aqueous chemistry of CO2. Field trip

Master of Science Teaching (MST). Climate and carbon sequestration	ST 189	2	Summer	Bruce Harrison

This class is designed for K-12 teachers, particularly those enrolled in New Mexico Tech's MST program. It will be taught on the New Mexico Tech campus.

Reservoir and Caprock Analysis	ERTH 461			

Offered on demand The class focuses on the role of sedimentary and structural heterogeneities in controlling porosity, permeability, and fluid flow in the subsurface. Topics include controls on conventional and unconventional reservoir quality and performance, evaluating caprock integrity, and the influence of faults and fracture networks on fluid flow. Applications to petroleum geology, petroleum engineering, carbon sequestration, and hydrology. There is a mandatory field trip associated with the class, which involves camping and moderately strenuous hiking on uneven ground. Shares lecture with GEOL 561, with additional expectations for graduate credit.

Reservoir and Caprock Analysis	GEOL 561			Peter Mozley

The class focuses on the role of sedimentary and structural heterogeneities in controlling porosity, permeability, and fluid flow in the subsurface. Topics include controls on conventional and unconventional reservoir quality and performance, evaluating caprock integrity, and the influence of faults and fracture networks on fluid flow. Applications to petroleum geology, petroleum engineering, carbon sequestration, and hydrology. There is a mandatory field trip associated with the class, which involves camping and moderately strenuous hiking on uneven ground. Shares lecture with ERTH 461, with additional expectations for graduate credit.

USA

Pennsylvania State University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Enhanced Oil Recovery Methods	PEGN 506	3		

Enhanced oil recovery (EOR) methods are reviewed from both the qualitative and quantitative standpoint. Recovery mechanisms and design procedures for the various EOR processes are discussed. In addition to lectures, problems on actual field design procedures will be covered. Field case histories will be reviewed

From Meteorology to Mitigation: Understanding Global Warming	METEO 469		Michael Mann

This course provides an introduction to global warming and climate change, covering the basic science, projected impacts, and approaches to mitigation.

Reactive Transport in the Subsurface	PGN 550		

This course targets graduate students from various disciplines that work with chemical and physical processes in natural subsurface. This includes, for example, petroleum and natural gas engineering, geosciences, environmental engineering, agricultural engineering, civil engineering, chemical engineering, and applied mathematics. The course teaches fundamental concepts that are important in understanding subsurface reactive transport processes, as well as their quantitative representation and application. Covered topics include, for example, (bio)geochemical thermodynamics and kinetics, contaminant transport, and reactive transport coupling. Depending on the students' interests, the course will discuss the applications of the principles in understanding and quantifying chemical weathering processes, environmental (bio)remediation, geological carbon sequestration, and reservoir souring.

The Economics of Global Climate Change	ECON 415W		

The first part of the course reviews the scientific evidence on global climate change (IPCC studies). This is followed by an analysis of market failure in the production of greenhouse gas emissions, and consideration of carbon markets as a policy response. A cost-benefit study of the control of greenhouse gases (the Stern Report) is examined, and the concluding part of the course looks at a computer model of economic activity and the environment.Students will learn about the scientific evidence on global climate change, and the associated economic implications, market failures, and policy options to mitigate those market failures. Students will develop skills to assess policy options in this area, and they will become conversant with applied cost-benefit analysis and a computer model of economic activity and the environment.e on climate change; economic models of the environment and market failure; cost-benefit analysis of policy options; carbon market

USA

Princeton University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Energy for a Greenhouse-Constrained World	MAE 328	Spring	Julia Mikhailova

Overview of technology challenges and opportunities for energy in the context of global warming. Physics of greenhouse warming, projected climate changes, and structure of US and global energy economy are reviewed. Majority of lectures emphasize understanding engineering and economics of low-carbon energy production systems, including solar, wind, nuclear fission, and capture/storage of fossil-fuel carbon. Energy storage and efficient energy use are also considered. Intersections of energy with economic development, international security, local environmental quality, and human behavior are also touched upon.

Environmental Implications of Energy Technologies	CEE 304	Fall, Spring	Catherine Peters

In our sustainable future, the world's energy needs will be met while protecting natural resources and minimizing risks to human health. The course covers the environmental and geological engineering principles relevant to the entire energy supply chain from mining and extraction of fuels, to power production, to disposal of wastes and sequestration of greenhouse gases. Both conventional and renewable energy are considered. Students will learn the engineering principles and practices to address environmental challenges and to find the best ways to utilize earth systems to our advantage.

Fundamentals of Biofuels	CBE/ENE 418	Spring	Jose Avalos

This course defines biofuels, and explains why we should make them. It presents the challenges and opportunities of sustainable biofuels, addressing issues of land use, and competition with food production. It describes production processes of first generation, and cellulosic ethanol. It covers microbial engineering to improve production, or make new advanced biofuels. It describes the use of photosynthetic organisms such as algae, which fix carbon directly from the atmosphere to make biofuels. It addresses the environmental, economic and societal impact of biofuels, and how they can fulfill their promise as a renewable source of energy.

Special Topics in Environmental Engineering and Water Resources	CEE 599		

USA

Stanford University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Carbon Capture and Sequestration	Energy 153 (253)				S. Benson

CO2 separation from syngas and flue gas for gasification and combustion processes. Transportation of CO2 in pipelines and sequestration in deep underground geological formations. Pipeline specifications, monitoring, safety engineering, and costs for long distance transport of CO2. Comparison of options for geological sequestration in oil and gas reservoirs, deep unmineable coal beds, and saline aquifers. Life cycle analysis.

USA

Texas A&M University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Capture, Utilization and Storage	ICPE 618				

Introduction to technologies for carbon capture, modeling and technoeconomic analysis and comparison of different carbon capture technologies, and economics of carbon capture, utilization, and storage statewide and nationwide.

CO2 Capture and Uses	PETE 644				

Sequestration, Enhanced Oil Recovery (EOR)including sequestration and Enhanced Oil Recovery (CCS-EOR), understanding the need and potential of CO2 captures and uses, the scientific, technological and economic aspects of identifying and implementing a CCS-EOR; overview of safety, environmental and legal aspects. Prerequisites: Graduate classification.

CO2 Sequestration	ICPE 614				

Introduction to the goals and methods of CO2 sequestration in the subsurface and of monitoring its effectiveness; discussion and explanation of current technological challenges and problems in monitoring CO2 in the subsurface and in implementing sequestration for mitigating climate change; addresses how carbon is transferred between atmosphere, hydrosphere, biosphere and geosphere by natural processes; basic geologic processes influencing sequestrati

Enhanced Oil Recovery Processes	PETE 609				

Fundamentals and theory of enhanced oil recovery; polymer flooding, surfactant flooding, miscible gas flooding and steam flooding; application of fractional flow theory; strategies and displacement performance calculations. Prerequisite: PETE 323.

Fundamentals of Reservoir Engineering	PETE 323				

Determination of reserves; material balance methods; aquifer models; fractional flow and frontal advance; displacement, pattern and vertical sweep efficiencies in waterfloods; enhanced oil recovery processes; design of optimal recovery processes; introduction and performance analysis of unconventional reservoirs

United Kingdom

UK Carbon Capture and Storage Research Centre (UKCCSRC)

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
CPD courses					

The UKCCSRC offers accredited CPD courses on aspects of CCS for Early Career Researchers and professionals working in field. Past courses have covered CCS (overview course) and CO2 Storage and Monitoring. The CCS overview CPD course provides a fundamental understanding of CCS technology, including capture, transportation, and storage. The CO2 Storage and Monitoring CPD course provides an overview of that topic, beginning with fundamentals and progressing to the present state of the technology - key topics include the UK North Sea and international state of the art in understanding of storage and monitoring - generics and specifics; target formation engineering challenges and modelling approaches; economic and environmental challenges for operators. Both courses focus on recent advances in the understanding of technological challenges in their areas and examine knowledge gaps; integral to both is insight from planned and developing demonstration projects in UK and worldwide.

USA

University of Alabama, Birmingham

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Combustion	ME 445	3		Peter Walsh

Evaluation of the impact of fuel characteristics and operating conditions on the performance of coal-fired electric utility steam-raising plant and the prospects for continued reliance on coal as fuel for electric power generation. The phenomena emphasized are the behavior of turbulent jets; ignition, devolatilization and combustion of coal particles; radiative heat transfer and the effect of ash deposits on heat transfer; formation of air pollutants and their removal from combustion products; integrated gasification combined cycle; and capture and sequestration of carbon dioxide.

USA

University of California, Berkeley

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Management and Business Strategy	NAT RES X438.1				

Study the relationship of greenhouse gases (GHGs) to environmental quality management, sustainability and GHG-offset project markets. Understand the significance of GHGs from the perspectives of climate change, sustainability, human health and social welfare. Examine technology options for controlling GHG emissions and mitigating atmospheric CO2. Learn business development and career opportunities in current GHG management markets. Learn about the California Law AB32 requirements and the status of implementation, new policies, concepts, methods and tools supporting management of greenhouse gases (GHGs) in California. Hands on exercises and in-class discussions help you gain insight into the opportunities and risks of the emerging GHG-management industry.

Climate Change Mitigation	CIV ENG 107	3	Spring	William Nazaroff

Description: Assessment of technological options for responding to climate change. Overview of climate-change science; sources, sinks, and atmospheric dynamics of greenhouse gases. Current systems for energy supply and use. Renewable energy resources, transport, storage, and transformation technologies. Technological opportunities for improving end-use energy efficiency. Recovery, sequestration, and disposal of greenhouse gases. Societal context for implementing engineered responses.

Energy Solutions: Carbon Capture and Sequestration	C295Z	3	Fall	

After a brief overview of the chemistry of carbon dioxide in the land, ocean, and atmosphere, the course will survey the capture and sequestration of CO2 from anthropogenic sources. Emphasis will be placed on the integration of materials synthesis and unit operation design, including the chemistry and engineering aspects of sequestration. The course primarily addresses scientific and engineering challenges and aims to engage students in state-of-the-art research in global energy challenges. Also listed as Earth and Planetary Science C295Z and Chemistry C236.

USA

University of California, Irvine

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Solving the Energy-Carbon-Climate Problem.	EARTHSS 178				Steven Davis

Why is climate change such a difficult problem? What can we do about it? The course will introduce the global politics of energy and climate, assess options for decreasing energy demand, generating low-carbon energy, sequestering carbon, geoengineering, and adaptation.

United Kingdom

University of Edinburgh

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Capture and Transport	PGGE 11141	20			Ondrej Masek

This course will commence by introducing the topic of power generation from fossil fuels and biomass. Students will acquire general knowledge of standard and advanced power generation technologies and understanding of their respective strengths and weaknesses. Consequently, based on this understanding, students will be introduced to a range of CO2 capture technologies, ranging from those commercially available to technologies still in the development stage. They will acquire a thorough understanding of each technology and its operating principle and will be able to associate particular CO2 capture technology to a relevant power generation process, taking into account strengths and weaknesses of each capture technology and its compatibility with different power generation processes. Following that, students will learn about the issues related to compression and transport of captured CO2 stream. They will be presented with different ways of CO2 transport and will become familiar with topics such as CO2 properties under transport conditions, impurities present in CO2 streams from different generation/capture systems and the effects of impurities on CO2 compression and transport. In addition, the risks associated with CO2 transport will be discussed.

Carbon Economics	ECNM 11034	20			Stuart Sayer

This course first introduces the concepts of carbon markets and the efficiencies (or lack of) therein. It then covers the models currently used to assess carbon performance and issues of scale in terms of time and geographical coverage. It explores the existing and proposed policy instruments for carbon management via fiscal measures and makes a critical assessment of cost-benefits analyses of these mechanisms. Finally it makes an in-depth exploration of the emission trading scheme, its mechanisms, development and barriers.

Carbon Storage and Monitoring	PGGE 11139	20		Mark Wilkinson

Hydrocarbon Reservoir Quality	EASC 11002	20		Stuart Haszeldine

To develop a critical understanding of how sandstone and carbonate reservoir porosity and permeability in the subsurface is influenced by sedimentological effects of grainsize and sorting. To develop a detailed understanding of the effects of compaction, cementation and dissolution. This knowledge will be integrated with geological setting, basin modelling, geochemical measurements and petrological measurements which are both the principal and the special skills employed to assess the quality of a reservoir. The assessment via a critical essay will enable students to showcase their detailed understanding of a specific topic and, in this exercise, they will be encouraged to offer professional level interpretations of forefront developments.

MSc Carbon Capture and Storage		180		Mark Wilkinson

The UK's first MSc on CCS. This programme provides training in reservoir geology and an overview of geological carbon storage including capture and economic aspects. It is designed for science graduates in Engineering or Geoscience-related subjects, who are seeking an advanced academic qualification as a launch pad for careers in business, industry and government, in the field of low carbon energy production and hydrocarbon production. A 12 month duration MSc by teaching and 3 month dissertation.

MSc Carbon Management		180		Simon Shackley

In this landmark collaboration between the Schools of Geosciences, Economics and the Business School at the University of Edinburgh, the MSc in Carbon Management provides high-level knowledge, skills and training in the business, economics, policy, and science of carbon management. It is designed for graduates who want an advanced academic qualification as a launch pad for a career in carbon and climate change management in business, industry and government. An A 12 month duration MSc by teaching and 3 month dissertation. The MSc Carbon Management is also available as Distance Learning from September 2017.

MSc in GeoEnergy and CCS		180		Mark Wilkinson

An international MSc in GeoEnergy and CCS is under development to commence September 2017. The course will offered jointly by the University of Edinburgh, University of Regina, and University of Calgary, with UNAM Mexico, and KwaZulu University South Africa also expected to contribute. Funded scholarships are available to study in Canada and dissertations are intended to be based in a partner country where practical CCS projects are underway. An 18-24 month duration MSc by teaching and 9-12 month dissertation.

MSc in Sustainable Energy Systems				Dimitri Mignard

The MSc in Sustainable Energy Systems provides graduates and working professionals with a broad training in, and understanding of, energy systems in the context of the sustainability of energy supply. CCS is covered.

PgCert Carbon Innovation				

The online PG Certificate in Carbon Innovation is a ground-breaking development of the award-winning MSc in Carbon Management programme at the University of Edinburgh. Building on the proven success and expert content of the established residential programme, this new online programme provides high-level knowledge and skills in the economics, policy and accounting of climate change management.

PgCert Climate Change Management				

The online PG Certificate in Climate Change Management is a ground-breaking development of the award-winning MSc in Carbon Management programme at the University of Edinburgh. Building on the proven success and expert content of the established residential programme, this new online programme provides high-level knowledge and skills in the science, business and policy of climate change management.

Seismic Reflection Interpretation	PGGE 11144	10		Anton Ziolkowski

The course introduces the seismic reflection method, including land and marine data acquisition and processing, with emphasis on the geological interpretation of seismic reflection data. The following topics are covered: the role of the seismic reflection method in exploration; basic principles of the seismic reflection method; subsurface velocities, reflection coefficient and acoustic impedance; seismic data acquisition, including sources and receivers, 2D and 3D source-receiver configurations; seismic data processing steps, including normal moveout and stack, static corrections, deconvolution and migration; sonic and density logs, check shots, well ties and vertical seismic profile (VSP); the seismic wavelet: bandwidth and resolution; seismic structural interpretation; seismic stratigraphic interpretation; Petrel interpretation software. Practicals include the interpretation of a seismic reflection dataset using Petrel interpretation software.

Separation Processes for Carbon Capture	PGGE 11045	10		Hyungwoong Ahn

The course covers the main separation processes required for carbon capture applications. These include chemical absorption using amine for post-combustion capture, physical absorption for pre-combustion capture, Solid-looping process for post-combustion capture and other advanced separation processes relating to carbon capture. The students will be given formal lectures to introduce them to the overview of various separation processes for carbon capture. The students will then be asked to develop process flowsheets for a carbon capture option and analyse this in detail as part of group project.

USA

University of Illinois Urbana-Champaign

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Seminar Energy & Sustain Engagement	ENG 471	1			John Abelson

Challenges of developing energy systems and civil infrastructure that are sustainable in terms of resource availability, security, and environmental impact. Guest lecturers focus on: (i) global challenges -- future energy demand, geologic sources of energy, climate change, energy-water nexus, energy and security; (ii) markets, policies and systems -- economic incentives, policy and law, life cycle analyses; (iii) opportunities for change -- CO2 sequestration, renewable power, bioenergy feedstocks, biofuels for transportation, energy use in buildings, advanced power conversion, the smart grid. 1 undergraduate hour. 1 graduate hour. Prerequisite: MATH 220 or MATH 221; one of CHEM 104, CHEM 204, PHYS 101, PHYS 211. Recommended: NPRE 201.

USA

University of Kentucky

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Kentucky Energy and Environment Cabinet Externship	LAW 976				

The goals of this Externship course are to develop an understanding of legal and policy issues arising from energy development and environmental protection in Kentucky; to assess the legal implications of emerging energy strategies, including carbon sequestration from coal gasification; and to increase understanding of the role played by attorneys in the Energy and Environment Cabinet

USA

University of North Carolina

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Decarbonizing Fuels	PHYS 582	3			

Assess quantitatively the feasibility of powering humanity without increasing release of climate-altering carbon dioxide and other organic greenhouse gases into the atmosphere. Can these gases be removed? Which bio-chemical-physical novelties may scale to meet growing demand and at what cost?

USA

University of Texas at Austin

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Advanced CO2 injection and Storage of Geological Forms	GEO 391	3	Fall		Susan Hovorka
Fundamentals of Enhanced Oil Recovery I	PGE 387K				

Recent innovations in the recovery of petroleum by injecting fluids miscible with the oil or by application of heat to the reservoir. Three lecture hours a week for one semester. Prerequisite: Graduate standing. PGE 387L. Fundamentals of Enhanced Oil Recovery II. Selection of candidate reservoirs; design and performance prediction of miscible and thermal processes. Three lecture hours a week for one semester. Prerequisite: Graduate standing and Petroleum and Geosystems Engineering 387K.

Fundamentals of Enhanced Oil Recovery II	PGE 387L				

USA

University of Utah

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Carbon Sequestration Engineering and Science	CVEEN 7450	3			

The goals of this course are to (1) create a broad academic foundation ofcarbon capture and sequestration (CCS), with the primary emphasis on geologic sequestration, that prepares the student for continuing education, leading to greater professional competency, and (2) provide the student with the fundamental knowledge and tools necessary to perform design of CCS systems for professional practice.

Energy Choices for the 21st Century	ENVST 3368	3			

Meets with GEOG 5368 and GEO 5368. Graduate students should enroll in GEOG 5368 or GEO 5368 and will be held to higher standards and/or more work. This class is designed to give students an introduction to the critical energy issues facing our planet, with a focus on controversial topics and issues in Utah. These will include: hydraulic fracking (fracking), offshore oil and gas development, oil shale and tar sand development, nuclear energy (with particular regard to the proposed Blue Castle nuclear plant in Green River and storage of radioactive waste in Utah), wind, solar and geothermal energy (again, with emphasis on Utah), other renewable technologies, the Smartgrid difficulties in commercializing new energy technologies, air pollution, transportation choices, energy policy development, and global issues including population dynamics, climate change, carbon management, water resources, the Law of Unintended Consequences, and tipping points. A number of outstanding guest lecturers will provide expertise in their respective fields.

Solute Transport and Subsurface Remediation	GEO 7390				

Application of principles of ground water hydrology and contaminant chemistry in the quantification and characterization of physical, chemical and biological processes influencing subsurface hazardous waste. Topics include: quantification of advective-dispersive transport of conservative and reactive solutes, transport in granular and fractured media, application of environmental regulations and toxicological parameters, design of air-stripping, carbon adsorption, soil vapor extraction, surfactant enhanced extraction, bio-venting, bio-augmentation, solidification, and capture systems. Class project involves design of remediation system for a hypothetical site.

USA

University of Virginia

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)

Energy & Environmental Products Trading and Commodities Regulation	LAW 7712				Athena Eastwood

This class will provide a comprehensive overview of energy trading and commodities regulation by the Commodity Futures Trading Commission (CFTC), including with respect to traditional energy products (such as natural gas, power, crude oil and coal), and environmental products (such as carbon offsets, acid rain allowances, and renewable energy credits).

USA

University of Wyoming

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Natural Gas Engineering	4200				

Studies development of natural gas reservoirs for normal production and as storage fields. Includes back pressure tests, hydrates, pipeline problems, cycling and use of the material balance equation. Also processing of natural gas, including compression, expansion, refrigeration, separation, sour gas treating, sulfur recovery, LNG production and carbon dioxide separation. Prerequisites: PETE 2050. (Normally offered fall semester).

USA

Virginia Polytechnic Institute and State University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
Society, Sustainability Biomaterials, and Energy	3454				

Sustainability, raw materials and energy needs of society. Use of sustainable biomaterials to meet society's needs and reduce impact on the environment. Methods to evaluate and certify the sustainability of materials and consumer goods. Carbon sequestration and the use biomass for energy.

USA

West Virginia University

Course Name	Course Code	Units	Offered:	Year(s)	Instructor(s)
3-D Seismic Visualization	GEOL 556				Dengliang Gao

This course focuses on the application of 3-D seismic data visualization and interpretation technologies to the characterization of subsurface structure, facies, and reservoirs, with particular reference to hydrocarbon exploration and CO2 sequestration.

Seismic Attribute	GEOL 558				Dengliang Gao

The effective seismic attribute technologies and attribute interpretation workflows, their application to the characterization of subsurface structures, facies, and reservoir properties, with particular reference to hydrocarbon exploration and C)2 sequestration