GEOL 40310: Fossil Fuels and CCS

MODULE COORDINATOR: Assoc. Prof. Tom Manzocchi

ADDITIONAL LECTURERS: Prof. Ravindranathan Thampi
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CREDITS: 5	**MODULE LEVEL**: 4	**SEMESTER**: I

PRE-REQUISITES/PRIOR LEARNING:

This module assumes little prior geological knowledge.

OVERVIEW OF MODULE:

Most of the World's energy requirements are currently provided from fossil fuels (oil, gas, coal). Ireland currently imports all its oil and coal and much of its gas and in the current absence of significant indigenous fossil fuels reserves or resources the county is particularly vulnerable to interruptions of these energy supplies. This module will examine the geological setting of fossil fuels, both conventional and non-conventional, together with techniques for exploration and production. It will also deal with the chemistry and engineering of crude oil refining and examine current and likely developments in this field in the light of increasing global concern over carbon emissions. Carbon capture and storage/sequestration (CCS) is increasing becoming a potentially important method of moderating emissions while of maintaining carbon-based energy systems. The range of current and potential methods of capture and of sequestration will be examined.

LEARNING OUTCOMES:

On completion of this module students should be able to:

1. Identify the major rock types that host fossil fuels, and describe the broad geological setting of the major fossil fuels;
2. Explain the geological and engineering processes associated with exploration for and extraction of conventional and unconventional oil and gas;
3. Discuss the relative importance of the major fossil fuel types;
4. Explain the chemical and engineering processes involved in petroleum refining;
5. Understand the current and potential methods of carbon capture;
6. Appreciate the current methods and the potential, uncertainties and trends in carbon storage/sequestration.

ASSESSMENT:

Multiple Choice Questionnaire: 60%
(2-hour end of semester MCQ examination)

Continuous Assessment: 40%
(Continuous Assessment of practical work, written topic report, and oral presentation during semester)

LECTURES:

Lecture 1: Introduction to Fossil Fuels (*Assoc. Prof. T. Manzocchi*)
Historical and Projected Global Energy Consumption by type. Conventional and unconventional oil and gas. Tight oil and shale gas. LNG (Liquefied Natural Gas). Irish Energy Consumption: Imported energy and indigenous production, Historical and projected gas production. Global Energy Production and Consumption: Oil, Gas, Coal; Nuclear; Hydroelectric and Other renewables; Biofuels. Fossil Fuel Reserves to Production (R/P) Ratios.

Lecture 2: Structure of the earth and plate tectonics (*Assoc. Prof. T. Manzocchi*)
Seismic waves and the earth's structure: P-waves, S- waves; Crust, Mantle; Lithosphere, Asthenosphere. The formulation of Plate Tectonics. Divergent Plate Boundaries: Failed rifts; Passive Margins. Convergent Plate Boundaries: Subduction zones; Mountain chains. Transform Plate boundaries. The three basic types of rock: igneous, sedimentary, metamorphic.

Lecture 3: Sedimentary basins and Petroleum Systems (*Assoc. Prof. T. Manzocchi*)
Sedimentary Basins. Sedimentary rocks: Siliciclastics, Biochemical, Chemical; Depositional environments. Petroleum Systems: Source rocks and hydrocarbon maturation; Reservoir rocks; Seal rocks; Traps; Timing (Migration and accumulation).

Lecture 4. Petroleum Exploration 1: Seismic and drilling (*Assoc. Prof. T. Manzocchi*)
Exploration, Appraisal, Development, Production Phases. Phased in Irish Exploration. Phases in the Ula Field. UKCS Creaming curves. Reflection Seismic data: Acquisition, processing, interpretation. Drilling operations. Sediment compaction. Pore Pressure. Fracture Pressure. Mud weight and casing. Operational disasters: Lusi, Maconodo.

Lecture 5. Petroleum Exploration 2: Exploration Examples. (*Assoc. Prof. T. Manzocchi*)
The North Sea: The Permo-Triassic Rotliegend Play; The Jurassic Brent Play; Tertiary deep-water Plays; Alpine Inversion. Norwegian Exploration. The Barents Sea. Irish Exploration: Small companies - Shared risk through farm-ins. Exploration in the Chukchi Basin: Large Companies - Big risk; Big Rewards.

Lecture 6. Reservoir Appraisal 1: Determination of hydrocarbons in place. (*Assoc. Prof. T. Manzocchi*)
Objectives of reservoir appraisal. Hydrocarbon volume in place: Gross-rock volume; Net:gross Ratio; Porosity; Oil saturation. Factors influencing porosity and permeability: Grain structure; Diagenesis and cementation. Wireline logging: Gamma Log - Determination of Net:Gross; Formation density log - Determination of porosity; Resistivity log - Determination of saturation; RFT log - Determination of Fluid Contacts. Controls on Recovery Factors. Appraisal of the Atlantis Field.

Lecture 7. Reservoir Appraisal 2: Fluids. (*Assoc. Prof. T. Manzocchi*)
Chemical Classification of Petroleum. Natural Gas: The Paraffin series; Hydrocarbon-associated gasses. Crude oil: PNA classification. Normal crude, waxy crude, heavy crude. Physical Classification of Petroleum: Fluid density, Viscosity. PVT behaviour of 5 conventional hydrocarbons. Dry gas, Wet Gas, Gas Condensate, Volatile Oil, Black Oil. Saturated and unsaturated reservoirs.

Lecture 8: Reservoir Appraisal 3: Fluid flow. (*Assoc. Prof. T. Manzocchi*)
Reservoir fluid pressures; Phase pressure and capillary pressure; Repeat Formation Testing (RFT); Finding Fluid/Fluid Contacts. Permeability: Darcy's Law; Radial flow and the well productivity index; Drill Stem Testing (DST). Recovery factors: Pore-scale displacement efficiency; Sweep efficiency; Reservoir Heterogeneity and connectivity.

Lecture 9: Reservoir Development and Production 1 – Primary and secondary drive mechanisms (*Assoc. Prof. T. Manzocchi*)
Primary Drive mechanism for Gas: Pressure depletion. Primary Drive mechanisms for Oil: Pressure depletion; Solution Gas Drive; Gas Cap Drive; Water-drive. Secondary drive mechanism: Immiscible Water and/or Gas injection. Ekofisk reservoir example: Combination drive including an element of compaction drive. Basic PVT properties of Gas and Oil Reservoirs: Gas Reservoirs: Gas Formation volume Factor. Oil Reservoirs: Oil Formation Volume Factor; Solution Gas Oil Ratio; Gas Formation Volume Factor.

Lecture 10: Reservoir Development and Production 2 – Development plans (*Assoc. Prof. T. Manzocchi*)
Designing a development plan. Surface facilities - separation, infrastructure, Platform; Ekofisk Area; Lincolnshire Offshore Gas Gathering System. Vertical, Horizontal and Multilateral wells. Well flow rates. Logging while drilling and Geosteering - Wytch Farm Field Example; Well completions and workovers - Nelson Field Example. Seismic technology: Processing - Machar field example; Acquisition – Atlantis field example; 4D seismic - South Arne Field Example. Abandonment and decommissioning.

Lecture 11. Unconventionals, Coal and Coal derivatives. (*Assoc. Prof. T. Manzocchi*)
Future hydrocarbon use: An increasing reliance on unconventionals. Shale oil and Shale Gas; USA vs. Europe experience. Heavy Oil, Extra heavy oil, Bitumen; Canadian Production. Oil Shale; Green River Formation of Utah. Coal: Coal Gassification; Coal to Liquid; Coal Bed Methane. Gas Hydrates.

Lecture 12: The Chemistry and Processing of hydrcarbons 1. (*Prof. R. Thampi*)
Index of unsaturation, hydrocarbon sources. Coal, Direct coal liquefaction, Fischer-Tropsch chemistry. Petroleum refining and upgrading: products. Oil refining. Synthetic hydrocarbons. Nature of hydrocarbon conversion reactions. Use of hydrcarbons.

Lecture 13: The Chemistry and Processing of hydrcarbons 2. (*Prof. R. Thampi*)
Syngas. Syngas reactions and processes. Stream reforming process: Feedstock purification; syngas requirements; initial conditions.

Lecture 14: The Chemistry and Processing of hydrcarbons 3. (*Prof. R. Thampi*)
Secondary reforming. Other operating tasks. NH3 synthesis, methanol synthesis, higher alcohol synthesis, F-T synthesis.

Lecture 15: The Chemistry and Processing of hydrcarbons 4. (*Prof. R. Thampi*)
Petroleum cracking. Fluidized catalytic cracking (FCC). Thermal cracking. Energetics of cracking reactions. The beta rule.

Lecture 16. The Chemistry and Processing of hydrcarbons 5. (*Prof. R. Thampi*)
Catalytic cracking issues: Cyclisation and coke formation; catalyst choice; operation and reactor variables; reactor sequence, operating conditions.

Lecture 17: The Chemistry and Processing of hydrcarbons 6. (*Prof. R. Thampi*)
Hydro-cracking. Reactions; Advantages and disadvantages; Catalysts; Process. Naphtha reforming: purpose; feed compostion; Reaction mechanisms; catalysts, Process.

Lecture 18: The Chemistry and Processing of hydrcarbons 7. (*Prof. R. Thampi*)
Selective and partial oxidation of hydrocarbons. Partial oxidation: conversions; temperature; energy balance. Ammoxidation: Reaction; Catalysists; side reactions. Ammoxidation in a fixed bed. Other ammoxidations.

Lecture 19: The Chemistry and Processing of hydrcarbons 8. (*Prof. R. Thampi*)
Pyrolysis of Low density PolyEthylene and other plastics for petrochemical feedstocks. Polymerization mechanism. Polymerization reactiors. Types of polymers and plastics. Plastic wastes; recycling. Combustion, Hydrolysis, Hydrogeneration. Fluidised bed pyrolysis.

Lecture 20: Overview of CO_2 emission sources and capture technologies. (*Dr D. Mooney*)
The carbon cycle. Atmospheric CO_2 levels. Risk and mitigation. Climate change policies. Emissions by sector. Energy sources and CO_2 Emissions in Ireland. Carbon capture during power generation. Costs of carbon capture.

Lecture 21: CO_2 Capture 2: Post-Combustion Capture. (*Dr D. Mooney*)
Typical CO2 adsorption technique. Passive absorption, Chemical absorption. Solvent regeneration. Energy requirements.

Lecture 22. CO_2 Capture 3: Pre-Combustion Capture. (*Dr D. Mooney*)
Pre-combustion syngas technology. Gasification processes. Fluidised bed gasification processes. Gasification unit design . Minimum power requirements.

Lecture 23. CO_2 Capture 3: Oxy-fuel processes. (*Dr D. Mooney*)
Oxy-fuel technology. Adiabatic flame temperature calculation. Challenges. Air Separation using Liquefaction. Air Separation using Membranes. Case Studies: Oxy-fuel operation in an auT.obile; Oxy-fuel operation in Moneypoint. Minimum Power Requirements.

Lecture 24. CO_2 Capture 3: Novel Capture Technologies. (*Dr D. Mooney*)
Micro/Mesoporous Solids for Ambient Temperature CO_2 Adsorption. Membrane Separations Process. Chemical Looping Combustion – Unmixed Combustion. Can Ireland Live on its Renewables.

Lecture 25: Carbon sequestration 1: Policies and Principles. (*Assoc. Prof. T. Manzocchi*)
Point sources for carbon capture; Contribution of CCS to CO_2 emissions reductions; CCS systems and costs. Mineral sequestration; urface or sub-Surface Marine Sequestration: Dissolution-Type; Lake-Type; CO_2 hydrates (clathrates). Sub-surface sequestration: Mineral Sequestration; Enhanced Oil Recovery (EOR); Depleted oil/gas fields; Unminable coal seams; Saline aquifers.

Lecture 26: Carbon sequestration 2: Geosequestration. (*Assoc. Prof. T. Manzocchi*)
CO_2 use in EOR projects. Miscible CO_2 flooding: Sweep efficiency and pore-scale recovery. SACROC unit, Denver Unit examples. Immiscible CO_2 Flooding: Great Plains / Weyburn project. EOR: Sequestration or anti-sequestration? CO_2 Storage in saline aquifers: Physical properties of CO_2; Structural and stratigraphic trapping; Injectivity pressure and seal failure; Residual trapping, solubility trapping, mineral trapping. CO_2 Storage in depleted hydrocarbon reservoirs. CO_2 Storage in Unminable Coal seams.

Lecture 27 Carbon Sequestration 3: Projects and monitoring. (*Assoc. Prof. T. Manzocchi*)
Objectives of monitoring. Petroleum reservoir parallel sequestration examples: Sleipner, In Salah, Snøhvit examples. EOR for sequestration: Wayburn Example. Coal-fired electricity with CCS - Boundary Dam example. UK planning: Upstream Driven - Goldeneye project; Downstream driven - White Rose project. Sequestration site inventories: Global inventory; Ireland inventory.

Lecture 28 Wrap-up and Summary. (*Assoc. Prof. T. Manzocchi*)
Fossils Fuels, the carbon cycle, CCS. Petroleum Systems. Hydrocarbon Exploration Appraisal, Production. Energy consumption, Long term ol supply cost curve. Energy options for 2100. Carbon Capture and Storage. Employment options. Module evaluation discussion.

PRACTICAL CLASSES *(2 hours)*

Practical 1. Minerals and Igneous rocks (*Assoc. Prof. T. Manzocchi*)
Recognition and description of common rock-forming minerals and igneous rocks from hand-specimens.

Practical 2. Sedimentary and metamorphic rocks (*Assoc. Prof. T. Manzocchi*)
Recognition and description of sediments, sedimentary rocks (including clastic, coal, and carbonate rocks) and metamorphic rocks, from hand specimens.

Practical 3. Reservoir volume calculations (*Assoc. Prof. T. Manzocchi*)
Analysis of fluid contacts and reservoir volumes. Includes use of wire-line log data, RFT data, and oil-field PVT data.

Practical 4. Review. (*Assoc. Prof. T. Manzocchi*)
Discussion and review of practicals 1 to 3.

Student seminar Sessions 1 and 2. (*Assoc. Prof. T. Manzocchi; Prof. R. Thampi*; *Dr D. Mooney*)
In-depth seminars from a range of topics covering the course content. Each group comprises 3 or 4 student member, and questions are expected from all other students.