Hydrogen Masterclass: Production, Geological Storage and Operational Engineering (G552)

Tutor(s)

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Overview

Future energy scenarios foresee a prominent and growing role for hydrogen. Demand is likely to rapidly exceed the capacity of typical above-ground energy storage technologies, necessitating the need for the geological storage of hydrogen in engineered hard rock caverns, solution mined salt caverns, depleted gas fields and saline aquifers. This course will firstly provide participants with an overview of the current hydrogen landscape, including its likely role in the energy transition, production and economic challenges. The course will then focus on the need for geological storage, introducing the geological storage options available for the secure storage and withdrawal of hydrogen from these different geological stores. The main body of the course will then explore the key considerations involved in geological hydrogen storage including hydrogen flow processes and thermodynamics, geomechanical responses to rapid injection and withdrawal cycles, geochemical and microbial interactions during storage, and the operational considerations and monitoring of hydrogen storage sites that may impact storage integrity, withdrawal rates and hydrogen purity.

Duration and Logistics

Classroom version: A 3-day course comprising a mix of lectures, case studies and exercises. The manual will be provided in digital format and participants will be required to bring a laptop or tablet computer to follow the lectures and exercises.

Virtual version: Five 4-hour interactive online sessions presented over 5 days. Digital course notes and exercise materials will be distributed to participants before the course. Some exercises may be completed by participants off-line.

Level and Audience

Intermediate. The course is largely aimed at geoscientists, but engineers will also find the course instructive. Intended for sub-surface scientists, with an emphasis on geoscience topics. Participants will probably have a working knowledge of petroleum geoscience. However, the main subject matter of this course, the geoscience of hydrogen production and storage, is covered from basic principles.

Objectives

You will learn to:

1. Appreciate the role of geoscience in the hydrogen economy and the contribution hydrogen can make to the energy transition in support of Net Zero emission targets.
2. Describe the different processes involved with hydrogen production and the associated lifecycle carbon intensity of this production.
3. Recall details of the developing hydrogen supply chains, including infrastructure considerations,

distribution networks and pathways for market growth.
4. Describe the different geological storage options available and their capacity and spatial constraints.
5. Understand hydrogen as a fluid in the subsurface, including its thermodynamic and transport properties.
6. Characterize the geomechanical considerations for storage integrity and associated risks, including caprock sealing considerations.
7. Appreciate the impact of geochemical and microbial interactions in subsurface hydrogen stores and the relevant monitoring and management tools.
8. Describe the operational engineering considerations and monitoring of hydrogen storage sites.

Course Content

Session 1: Background, the hydrogen landscape, production and economics

Lectures

- Role of hydrogen in the energy transition (is it more than the last 20% of clean power?)
    - energy storage to balance renewables
    - decarbonizing hard to abate sectors
- Energy system integration
    - power to X
    - existing energy system overview
    - renewable energy and curtailment
    - grid scale energy storage requirements/challenges
- Policy and regulatory landscape
    - policy drivers
    - legal and regulatory frameworks
    - licencing and permitting
    - safety standards and gas regulations
    - just transition
- Existing / planned hydrogen projects globally
- Hydrogen production – the full rainbow
    - natural hydrogen accumulations (white hydrogen)
    - methane (SMR), autothermal (ATR) reformation, partial oxidation (POX) or pyrolysis of hydrocarbons (grey hydrogen) and coal (brown/black hydrogen)
    - above with capture and secure geological storage of the CO2 (blue hydrogen)
    - electrolysis using renewable electricity (green hydrogen)
    - metabolic microbial processes using light energy to produce hydrogen from water
    - fermentation of biomass to produce hydrogen
    - pyrolysis or gasification of biomass
    - Photoelectrochemical Water Splitting
    - Solar Thermal Water Splitting (yellow hydrogen)
    - electrolysis powered by nuclear energy (pink hydrogen)
    - in-situ hydrocarbon combustion
    - methane pyrolysis to produce hydrogen and solid carbon (turquoise hydrogen)
- Lifecycle carbon intensity of hydrogen production

- Storing and moving hydrogen
    - properties of hydrogen as an energy carrier
    - pressures of hydrogen within the entire chain
    - storing compressed / liquid hydrogen (line pack – tanks – geological)
    - hydrogen carriers and adsorbents, including ammonia, liquid organic hydrogen, metal hydrides
    - pipelines
        - suitability to hydrogen (e.g. embrittlement)
        - hydrogen blending / de-blending
        - repurposed vs new systems
- Costs and efficiency penalties
    - hydrogen production methods
    - cost, efficiency and infrastructure considerations in compression and liquification application
- Developing hydrogen supply chains for a just energy transition (uses)
    - approaches to hydrogen market growth
    - scaling up
    - development of the hydrogen distribution and storge infrastructure
    - industrial clusters and hubs
    - hydrogen value chain
    - innovation and technology opportunities
    - hydrogen / carbon trading
- Impact of increased hydrogen concentrations form fugitive emissions in the atmosphere
- Assessment of critical mineral needs in batteries versus fuel cells

Activities

- Using the MacKay Carbon Calculator, create pathways to find out how we might reduce the UK's greenhouse gas emissions to Net Zero by 2050 and beyond and highlight the opportunities for hydrogen
- Estimate emission savings associated with a range of different hydrogen switching options.

Session 2 Options for the geological storage of hydrogen

Lectures

- Existing experience in underground gas storage operations
    - natural gas
    - hydrogen
- Engineered rock caverns
    - technology description
    - design requirements (including geological requirements)
    - hydrodynamic sealing design principles
    - cavern construction and groundwater control
    - hydrogen injection and withdrawal operational procedures / considerations

    - hard rock cavern rock types / distribution / inventory
    - costs and safety considerations
- Abandoned conventional mines / subsurface silos
    - technology description
    - design requirements (including geological requirements)
    - sealing / subsurface silos and groundwater control
    - hydrogen injection and withdrawal operational procedures / considerations
    - abandoned conventional mine distribution / inventory
    - costs and safety considerations
- Salt caverns
    - technology description
    - design requirements (including geological requirements)
    - cavern construction
    - hydrogen injection and withdrawal operational procedures / considerations
    - salt cavern rock types / distribution / inventory
    - costs and safety considerations
- Porous rock storage – aquifers
    - technology description
    - design requirements (including geological requirements)
    - hydrogen injection and withdrawal operational procedures / considerations
    - aquifer storage distribution / inventory
    - costs and safety considerations
- Porous rock storage – depleted gas fields
    - technology description
    - design requirements (including geological requirements)
    - hydrogen injection and withdrawal operational procedures / considerations
    - aquifer storage distribution / inventory
    - costs and safety considerations

Activities

- Calculate volumetric capacities / energy densities of hydrogen under the different storage options
- Using EU and global geological map viewers, geographical locations for the various hydrogen storage opportunities will be explored and evaluated within the context of existing energy infrastructures, renewable energy and industrial centres.

Session 3: Hydrogen flow and geomechanics

Lectures

- Thermodynamic and transport properties of hydrogen / Hydrogen P-T phase diagram
- Thermodynamic and transport properties of hydrogen mixtures (water, CO2, N2, CH4 and natural gas)
- Hydrogen transport properties (all storage types)

    - porosity (primary / secondary)
    - permeability and its influence on hydrogen injection and flow
        - absolute and effective permeability
        - permeability isotropy and anisotropy
        - homogeneity and heterogeneity
    - relative permeability
    - capillary entry pressure
        - pore size
        - interfacial tension
        - contact angle
        - wettability
    - advection
    - molecular diffusion
    - dispersion
    - diffusion
    - viscous fingering
- Geomechanical considerations for storage integrity during cyclic injection
    - temperature changes during injection / withdrawal
    - pressure changes during injection / withdrawal
    - reservoir deformation
- Caprock sealing potential
    - capillary pressure column height conversion
    - diffusive losses
    - stress / strain and hysteresis
        - injection / withdrawal pressures
        - stress state in the subsurface
        - failure mechanics
        - formation damage
        - faults and leakage risk
        - fractures and microfractures
    - drainage / imbibition
        - residual trapping

Activities

- Hydrogen column height calculations
- Hydrogen caprock diffusion calculations
- Hydrogen contact angle calculations; Injection rate calculations for varying permeability.

Session 4: Impact of geochemical and microbial interactions

Lectures

- Hydrogen solubility and impact of pressure, temp, Ph and salinity
- Geochemistry
    - range of minerals that may react with hydrogen and their associated lithology, e.g. Pyrite / pyrrhotite, anhydrite, hematite, clays, calcite, etc.
    - mechanisms and kinetics of redox reactions
    - kinetics of precipitation and dissolution
    - mineral reaction rates
    - reactions with well cements and casing
    - impact of geochemical activities
        - gas composition changes
        - dissolution of minerals and change in reservoir properties
        - souring and H2S
        - steel corrosion
    - geochemical impacts from experiences of hydrogen underground storage
- Risks associated with microbial activities
    - microbes in the subsurface (what and where)
    - environmental parameters for microbial life
    - microbial hydrogen consumption processes
    - impact of microbial activities
        - gas composition changes
        - souring and H2S
        - microbial induced plugging or clogging
        - steel corrosion
        - dissolution of minerals and change in reservoir properties
        - impact of H leakage on soil and groundwater microbial communities
- microbial activity impacts from experiences of hydrogen underground storage sites
- microbial effects in salt caverns
- recommendations on design, monitoring and management tools to manage microbial risks

Activities

- Classification of storage sites in terms of risks of mineral dissolution
- Classification of storage sites in terms of risks of microbial consumption of hydrogen.

Session 5: Operational considerations and monitoring of hydrogen storage sites

Lectures

- Optimization of injection-withdrawal strategies
- Cushion gas
    - role of cushion gas
    - implications of using different types of cushion gas on the effectiveness of storage operations
- Analyses and assessments of potential interactions with existing (sub)surface usage and resources
- Integrity of surface facilities and wells
    - evaluation of storage facility lifecycle
    - well cement integrity
    - suitability of materials for wells and surface facilities
    - storage facility operational parameters
    - safety and monitoring concepts
- Risk of leakage through abandoned wells
    - abandonment completion assessments
    - leakage assessment
- Risk of micro seismicity during cyclic injection and production operations
- Monitoring strategies
    - geophysics: seismic / microseismic, electrical resistivity, etc.
    - monitoring wells
    - conventional monitoring: annulus pressure, radioactive tracer survey, casing inspection log, pressure test on the casing, neutron log, sonic detection, cement bond log, temperature log, spinner survey, pump and plug test, and camera inspection, etc.
- Public perception

Activities

- Risk assessment of hydrogen leakage
- Assessment of re-purposing depleted gas field for hydrogen storage.