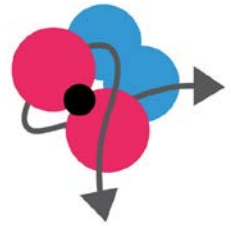

Hydrogen and CCS to reduce emissions from domestic heating and industrial clusters, H21 North of England and Grangemouth case studies, UK

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British Geological Survey, Imperial College London, INEOS and Sustainable Decisions Ltd

ELEGANCY Project, Webinar Series, 19 June 2020

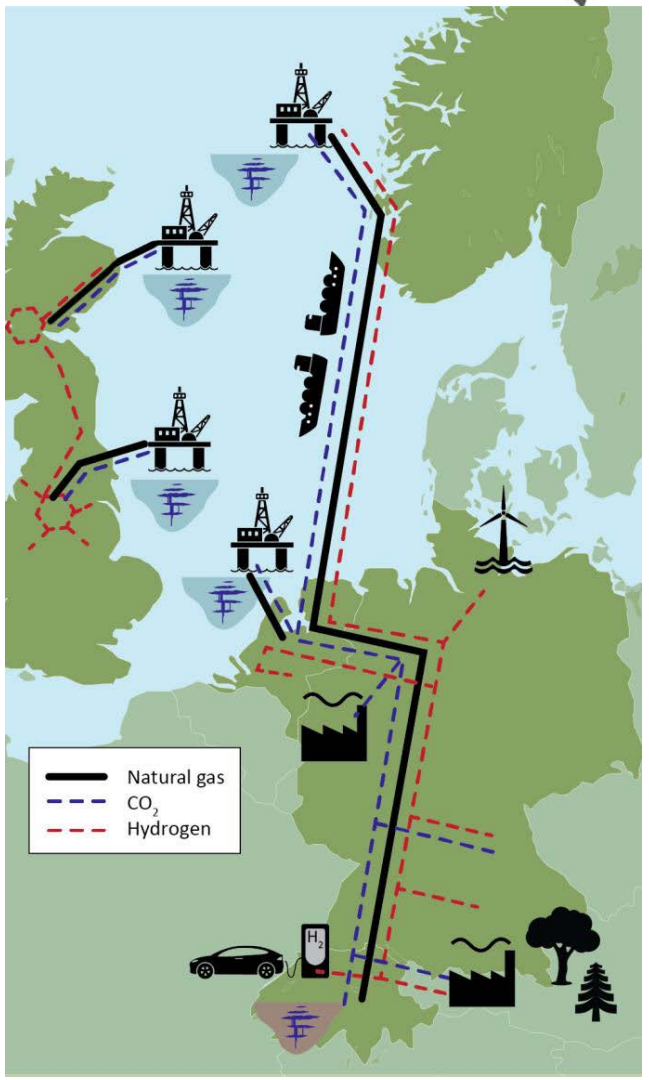
Case study overview

- Context for the ELEGANCY UK case studies for H21 and Grangemouth
- Profiles of CO_2 supply and storage requirements for the case studies
- UK hydrogen storage capacity in salt caverns
- UK network development for net-zero emissions heating with hydrogen:
  - Net-zero emissions from heat; value of hydrogen storage; deployment pathway; net-zero in industrial clusters; cost of CO_2 avoidance
- Conceptual business case for H21 case study:
  - Definition of the business case; business case development; delivery concept; example system business model
- Summary of UK case studies

Context - H21 North of England, Teesside & Grangemouth case studies, UK

ELEGANCY UK case study

- Research findings and tools developed in ELEGANCY applied to:
  - Grangemouth industrial cluster.
  - H21 North of England conversion of heating to 100% hydrogen
- Profiles of CO_2 supply present day to 2100
- Storage options for CO_2 from Teesside & Grangemouth industry clusters
- Capacity for inter-day and inter-seasonal subsurface storage of hydrogen
- UK constraints have informed application of the ELEGANCY chain tool for network development:
  - Assessed Grangemouth as a case study for a refinery and petrochemical site for emission reduction by implementation of CCS & H_2-CCS
  - Conversion of natural gas supply for heating of seven large cities to 100% hydrogen as planned by H21 North of England
- Business model and business case tool to present an example business system model for the UK



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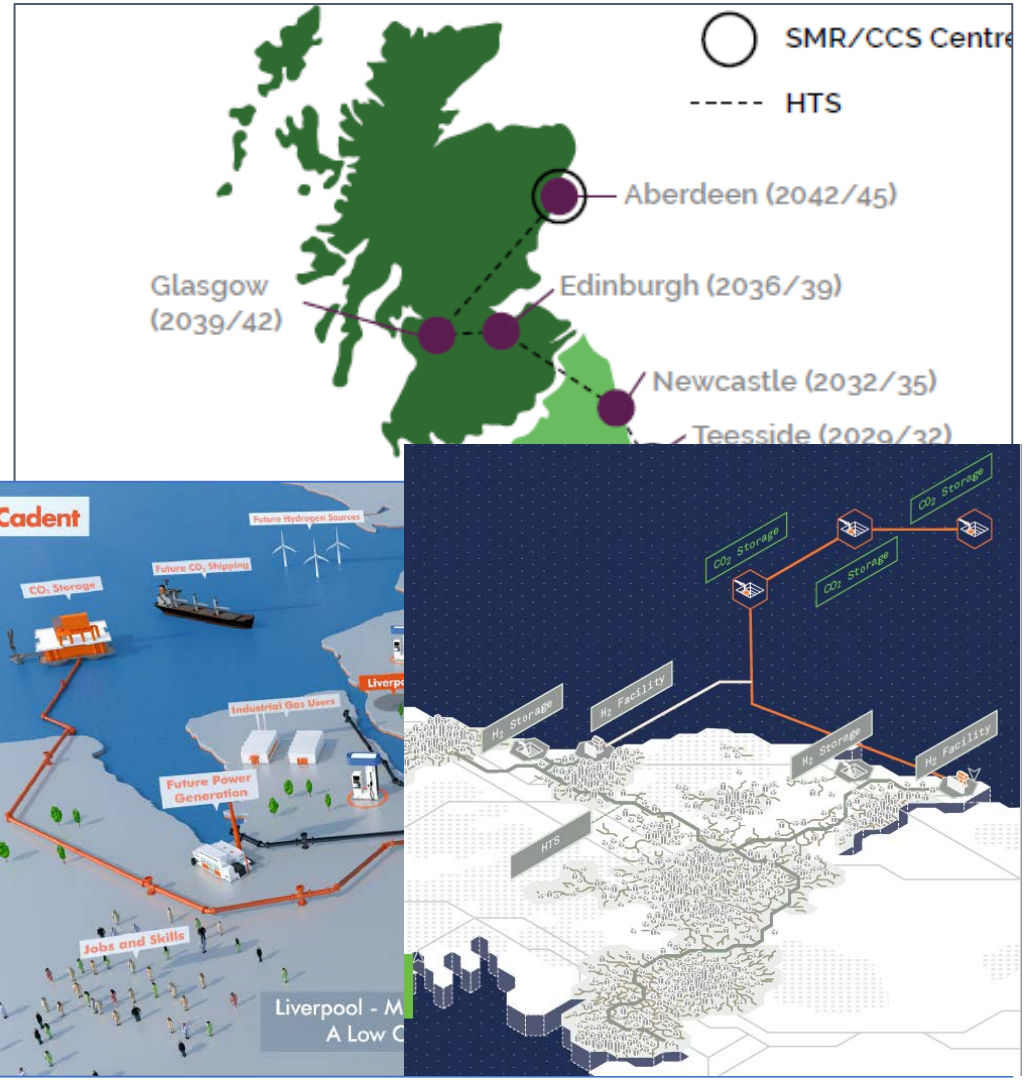
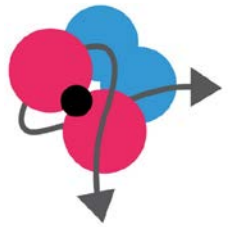
Profiles of CO_2 supply - approach Teesside & Grangemouth

Review existing project concepts for industrial CCS and H_2-CCS in the UK

- CCS potential in industrial sectors for Clean Growth Strategy
  - Teesside pre-FEED studies
  - Summit Power's East Coast Network
  - Proposals including Acorn project's estimates for CCS and H_2 -CCS in Scotland
- Decarbonisation of heat with H_2 and CCS:
  - H21 Leeds City Gate - Northern Gas Network
  - H21 Roadmap, (illustrated)
  - Liverpool-Manchester cluster - Cadent's HyNet Project (illustrated)
  - H21 North of England Project (illustrated)
  - Petrochemical and refinery appraisal at Grangemouth – INEOS, ELEGANCY case study



UK profiles of CO_2 supply for H_2 and CCS - approach

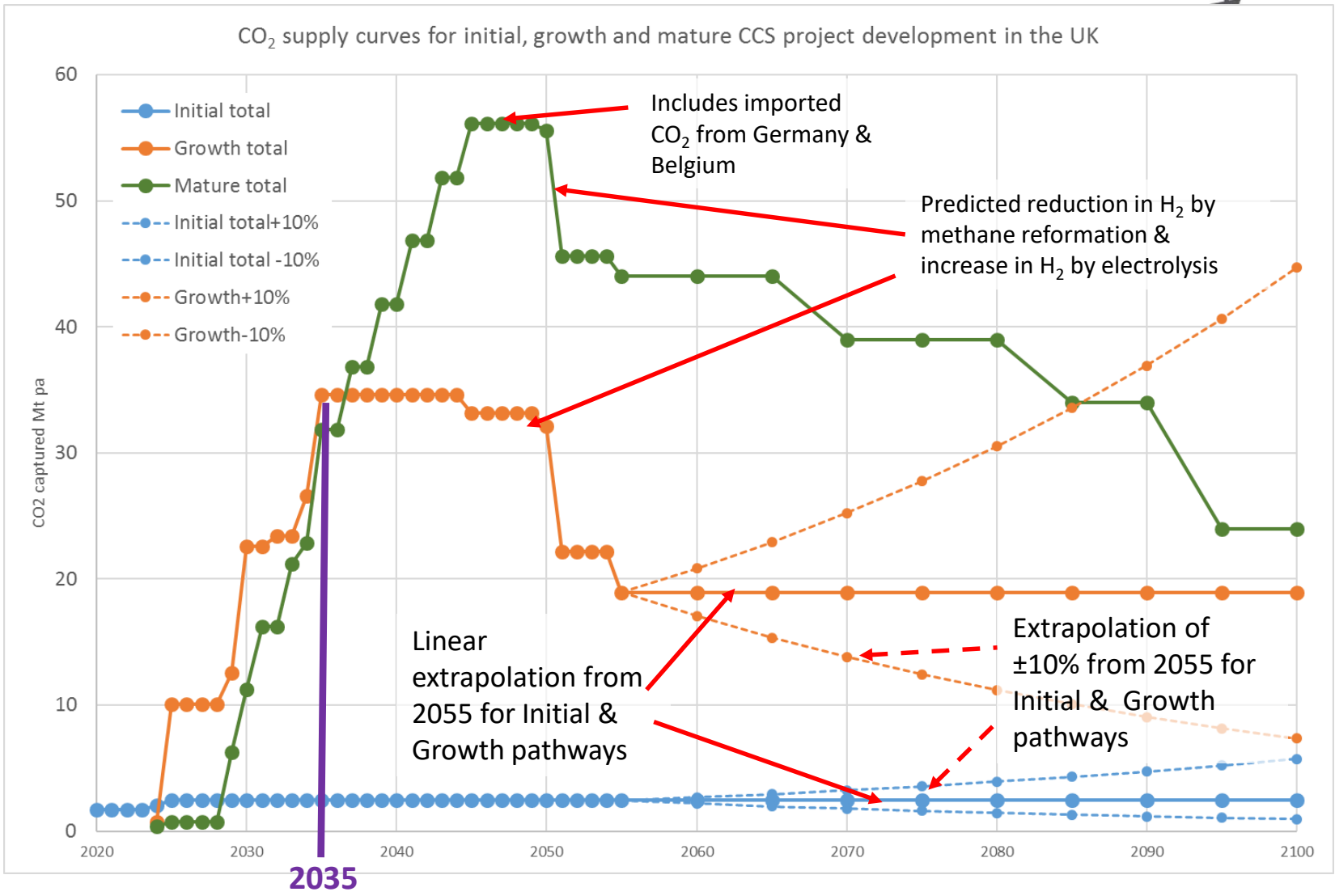


- Combined concepts for CCS application in the two regions and different industrial sectors
- Produced one scenario H_2-CCS and CCS for industry and power
- Low, intermediate and high CCS projects deployment variants:
  - Two east coast industrial clusters with North Sea CO_2 storage

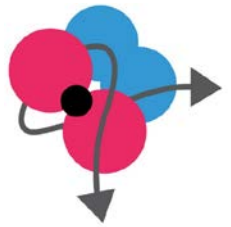
CCS projects deployment	UK Scenario variants	Summary
Low	Initial (existing) projects	Mainly existing industries at Teesside and Grangemouth
Intermediate	Growth of projects	More industry sources, Caledonian Clean Energy Project at Grangemouth, H21 Leeds City Gate with large-scale hydrogen at Teesside
High	Mature projects	H21 North of England
		Import of CO_2 from Germany & Belgium via the Netherlands

UK CO_2 supply profile to 2100 – variants for Initial, Growth and Mature CCS projects development

- Plot of planned annual supply to 2055 for existing **initial**, **growth** and **mature** CCS projects
- UK storage target rate of **30 Mt at 2035** exceeded
- Extrapolated to 2100 at constant rate or ±10%
- Required storage capacity by 2055
  - **Initial** projects 84 Mt
  - **Growth** projects 576 Mt
  - **Mature** projects 852 Mt
- Identified and simulated storage options for each supply variant



UK subsurface hydrogen storage capacity



- National-scale theoretical onshore hydrogen storage capacity estimate
  - Three regions suitable for salt cavern construction in Cheshire, East Yorkshire and Wessex
  - Current operating, planned and cancelled hydrogen storage facilities
- Considered new underground salt cavern construction for hypothetical use-cases:
  - 60 to 80 GWh capacity for inter-day storage
  - 140 to 160 GWh capacity for inter-seasonal storage
- Estimate represents the theoretical storage capacity, from the total sum of the storage resource available
- Theoretical maximum values, the practical capacity will be less:
  - Detailed screening might preclude some of the modelled cavern locations
  - Comprehensive subsurface characterisation studies are required to validate suitability of any particular area
- Estimated theoretical hydrogen storage capacities significantly exceed:
  - Current operational hydrogen storage capacity
  - Projected storage requirements of H21 Leeds City Gate & H21 North of England
- H_2 storage capacity would not be a constraint on network modelling if cavern construction is determined solely by demand

Net-zero CO_2 emissions from heat

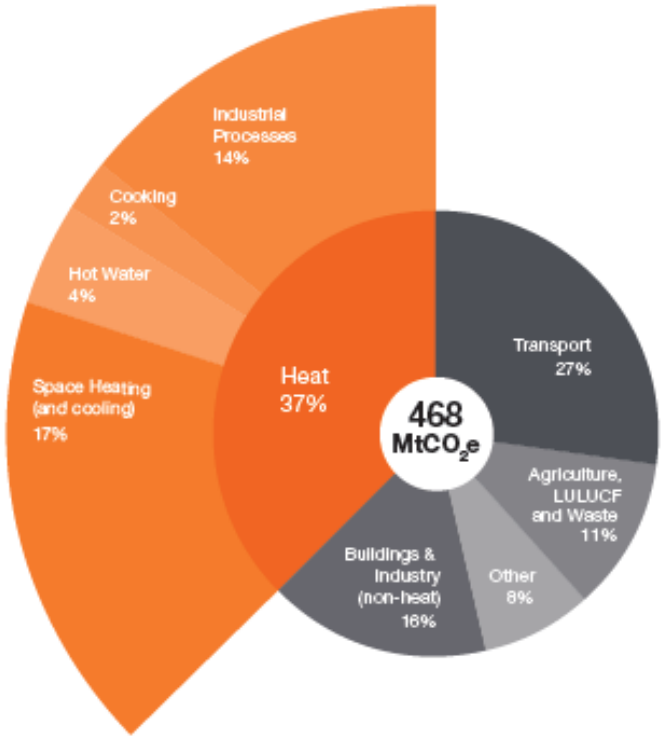
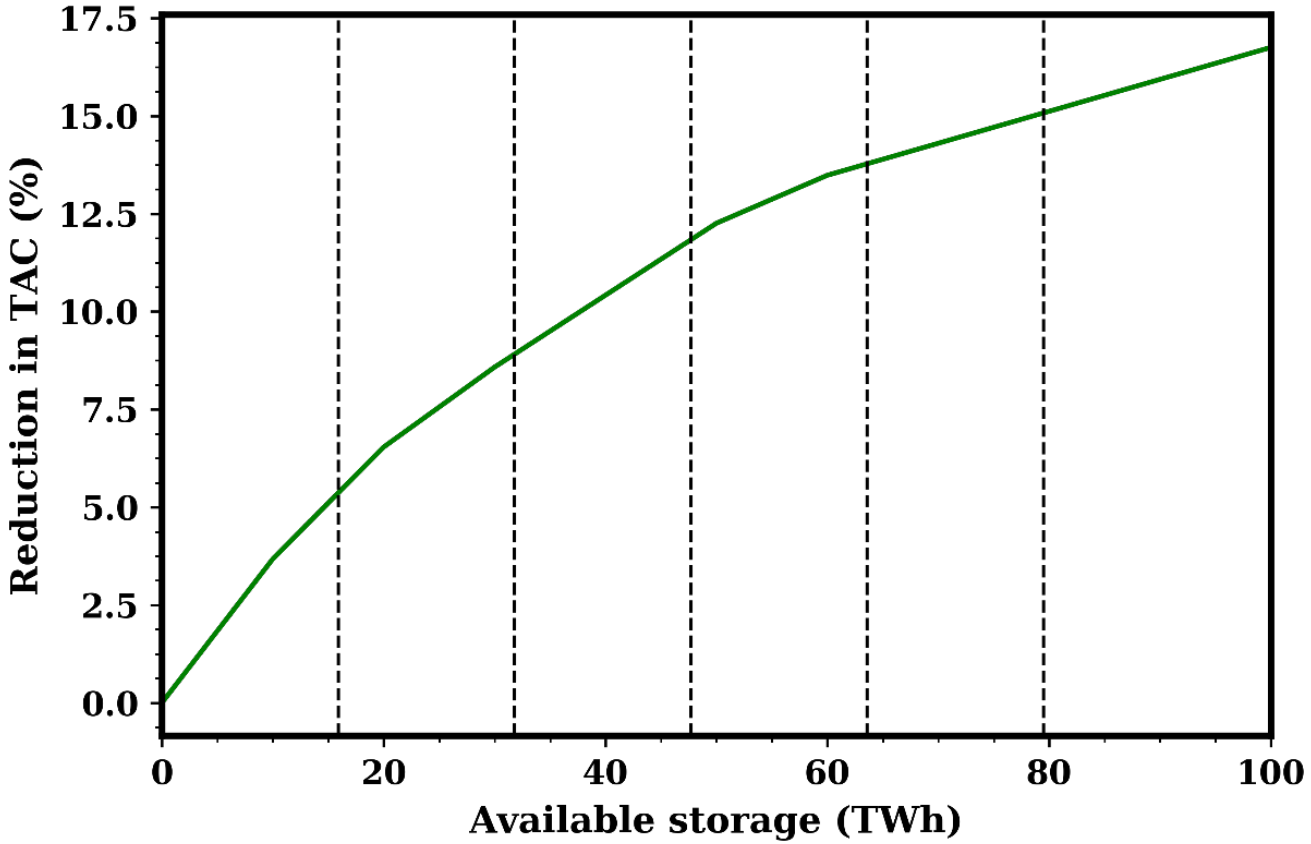


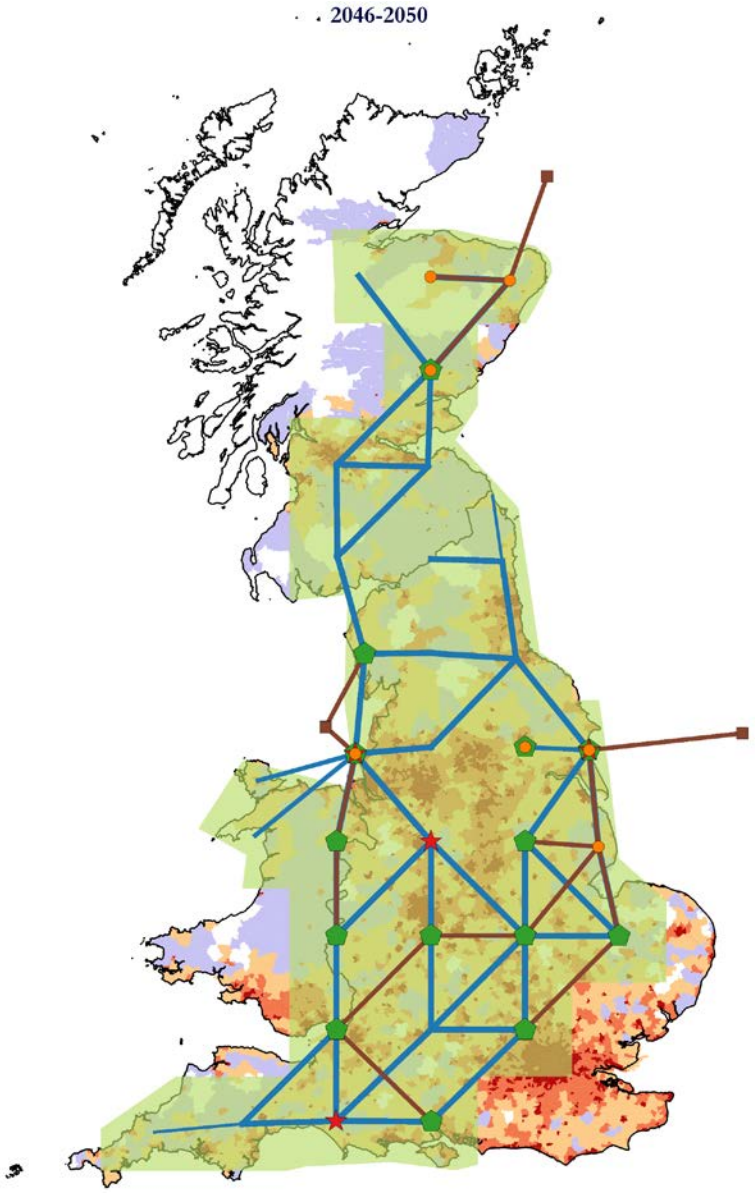
Figure 2.1 UK emissions in 2016 across different sectors[4]

Data for image: BEIS, “Sub-national consumption statistics for 2015”, 2018

Value of H_2 storage



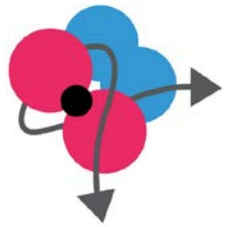
Deployment pathway: How do we get there?



Net-zero in industrial clusters

- Site emits approximately 3.5 - 4 Mt CO_2 yr-1.
- Majority of overall CO_2 emissions as a result of direct combustion of fuel
  - – primarily refinery fuel gas and imported natural gas.
- Several emission point locations of interest with CO_2 ~ 10 mol%.

UK H21 Conceptual Business Case Definition



The business case concept definition for the UK H21 case study is directed at the objective to achieve:

A commitment to phased investment in H_2-CCS infrastructure to cost effectively decarbonise residential heating in the north of England and to support UK energy system decarbonisation to meet a net zero emissions target by 2050.

A. PROJECT PRESENTATION

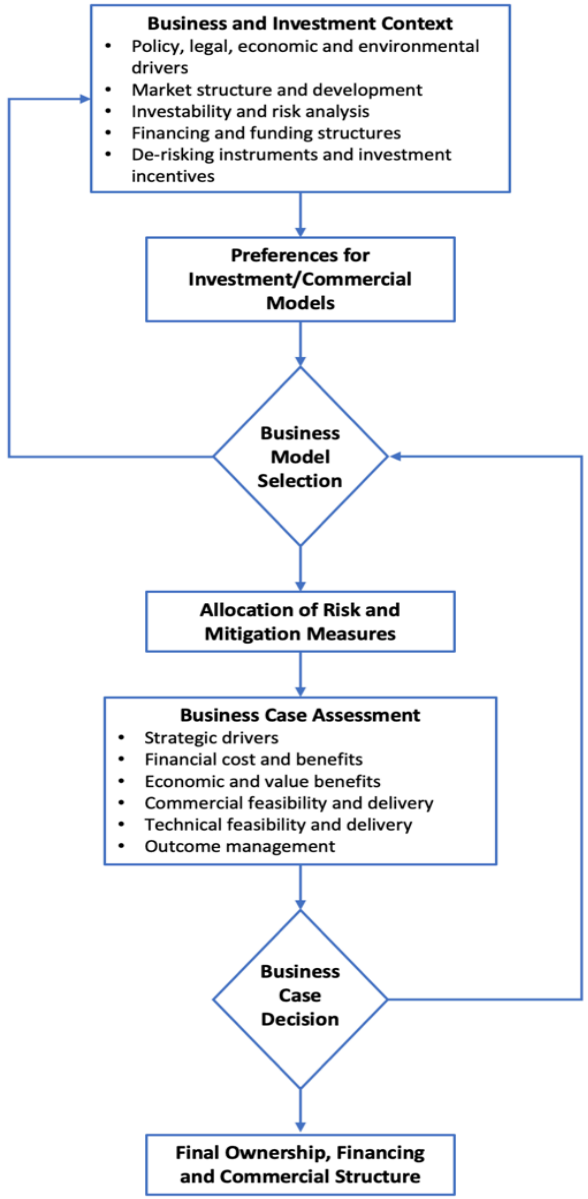
H2-CCS Sectors	Full H_2-CCS chain, H_2 for gas network conversion and other sectors
Project Status	Concept
Project Type	First of a Kind Large Scale Infrastructure Deployment
Project Scale (financial)	CAPEX: £22.78 billion OPEX: £955 million per annum post 2035
Project Scale (emissions)	CO_2 emissions reduction 12.5 Mtpa

Geographical Extent	North of England
Implementation Timeline	2023-2035
Market Maturity	Market creation
Main Public Sector partners/stakeholders	General government - to be defined later
Main Private Sector partners/stakeholders	Gas distribution companies (Northern Gas Networks, Cadent), H2 production companies (BOC, Air Liquide), oil and gas companies (BP, Shell, Total, Equinor, ENI, National Grid, Power generation companies

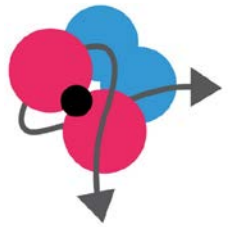
UK H21 System Business Case Development

- Use of WP3 Structured Process and Tools at System Level
  - Business and Investment Context
  - Market Failure Analysis and Policy Needs Analysis
  - Risk Assessment, Mitigation, Sharing and Collaboration
  - Business Model Options
  - Business Case Development with 6 Dimensions

- Outcome: Conceptual System Business Case
  - Assessment of Business Drivers
  - Phased System Delivery Concept
  - Strategic Rationale
  - Conceptual System Business Model (options)
  - High Level System Risk Outcome Management



UK H21 Business Case Delivery Concept



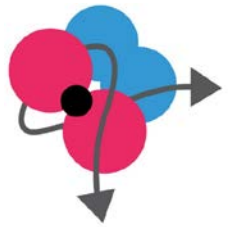
Phased system delivery requiring public and private sector collaboration:

- An initial commitment is required by 2023 to construction and funding
- 2026-2029 First phase H_2-CCS network in the north of England to prepare for a gas network conversion
- 2029-2035 north of England network conversion and development of markets for H_2 and CO_2.

The first phase H_2-CCS system commissioned in 2026 will comprise:

- a modular H_2 ATR production facility at scale [initial capacity 1.35 GW];
- associated H_2 transmission pipeline(s) and geological cavern storage;
- facilities and market appliance upgrades for H_2 blended with methane up to 20%;
- conversion or construction of a power station capable of burning blended hydrogen and natural gas up to 90% hydrogen [initial capacity of 2 or 3 x 440 MW turbines];
- connection to a large industrial cluster [Humber, Teesside, Manchester/Liverpool];
- oversized CO_2 transport and storage infrastructure in the Southern North Sea [initial pipeline capacity of 15-20 Mt per annum] anchored flexibly through combination of power, domestic and industrial users

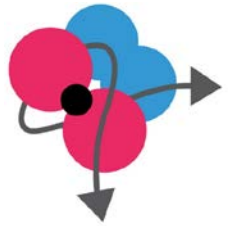
UK H21 System Business Model



E. BUSINESS MODEL PREFERENCE

Business Model	Ownership	Capital Sourcing	Market Development		Physical Delivery	
			Responsibility	Revenue Model	Responsibility	Business Structure
H_2 Production	PRIVATE	PRIVATE	PUBLIC	Targeted Revenue Support	PRIVATE	Free Market Enterprise
H_2 Transmission	PRIVATE	PRIVATE	PUBLIC	Price Regulated Revenue + Construction Support	PRIVATE	Regulated Asset Base (New)
H_2 Distribution	PRIVATE	PRIVATE	PUBLIC	Price Regulated Revenue	PRIVATE	Regulated Asset Base (Existing)
H_2 Storage	PUBLIC	PRIVATE	PUBLIC	Price Regulated Revenue	PRIVATE	Public Concession (Design-Build-Finance-Operate)
CO_2 Capture						
CO_2 Gathering						
CO_2 Transmission	JOINT	JOINT	PUBLIC	Price Regulated Revenue	PRIVATE	Joint Venture
CO_2 Storage	JOINT	JOINT	PUBLIC	Price Regulated Revenue	PRIVATE	Joint Venture
Mobility						
Industry	PRIVATE	PRIVATE	PUBLIC	Targeted Revenue Support	PRIVATE	Free Market Enterprise
Decentralised Heat & Power						
Centralised Heat & Power	PRIVATE	PRIVATE	PUBLIC	Targeted Revenue Support	PRIVATE	Free Market Enterprise

Summary of UK case study



- Presented profiles of CO_2 supply from hydrogen reformation and industrial sources at Teesside for the H21 projects and Grangemouth industrial cluster,
  - Scenarios of initial, growth and mature CCS projects deployment
  - Identified storage options and simulated secure storage for the three scenarios
- Provided a first national-scale theoretical salt cavern hydrogen storage capacity estimate for the UK
- Applied the H_2-CCS full-chain systems simulation and optimization tool to the H21 projects, including hydrogen demand profiles, CO_2 sources and potential infrastructure routes
- Undertaken model studies and analyses of the economic, environmental & energy output to optimize the H_2-CCS system for H21
- Completed an industrial feasibility case study on the potential of CCUS and H_2 at the Grangemouth refinery and petrochemicals site
- Mapped business case parameters, risk allocation, market failures and barriers to investment in the UK case study
- Presented a policy gap analysis and recommendations to address investment and delivery issues raised by regional stakeholders

Acknowledgement

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