

Business Models for Carbon Capture, Utilization and Storage Technologies in the Steel Sector: A Qualitative Multi-Method Study

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Semi-structured interview questions

1. In your opinion, what are the main barriers to introducing CCUS (Carbon capture, utilization and storage) into the steel sector specifically, and the industrial sector more generally?
2. In your opinion, what are the main drivers to introducing CCUS into the steel sector specifically, and the industrial sector more generally?
3. What are the most important elements in building a successful business case for CCUS in the steel industry?
4. What are the most applicable revenue stream options which may support the economics of CCUS in the steel industry?
5. Which entities should be liable to funding CCUS projects in the steel industry?
6. What are the main risks facing CCUS projects in industry?

Table S1. CCUS (Carbon capture, utilization and storage) business model case studies.

Country	Project	Sector	Ownership structure	Investment	Revenue and value	Public involvement	Risk management
United Kingdom	Teesside (proposal) [1]	CCS – industrial	Capture owned by emitter, T&S by government	CAPEX and OPEX: government support, Emitter equity repaid	Avoidance of CO ₂ price, government incentives and guaranteed returns	Grant funding, OPEX funding, risk sharing	Government carries capital risk
	Cadent HyNet [2]	CCS – hydrogen & industry	Uncertain – likely Cadent partial ownership of chain	Potential public funding for T&S	RAB sales of hydrogen	Ofgem RAB regulation, Ownership of key risks	Performance risk shared Multiple emitter and CO ₂ stores. Government will need to take on key risks
	CCS Commer. Program [3]	CCS – power	Private	DECC grant, equity, Debt (65%)	Electricity sales (CfD)	Grant funding, Risk sharing, CfD	Government carries majority of risks (storage, some capital, CfD price)
United States	Petra Nova [4]	CCS – power EOR	JV owns & operates capture.	JV equity (\$600m), DOE grant (\$190m), Debt (\$325m)	EOR & oil sales, potential 45Q Tax Credits	Small support, Japan ExIm Bank export credit guarantee for Japanese lenders	JV holds all technical and commercial risks. Lender exposure minimized through export credit guarantee
	Illinois Basin [5]	CCS - industrial	PPP DOE and partners	Government grant, partner equity	Potential 45Q Tax Credits, RD&D benefits	Majority funder	Technical and commercial risks largely taken on by Government
	Lake Charles CCS [6]	CCS – industrial EOR	Private	Equity investors (\$1.8bn), government loan guaranteed (\$2bn)	EOR: CO ₂ sales, chemical sales	DOE loan guarantees, equity investor tax credits	Existing T&S infrastructure, good investment rating. Public private risk sharing
Norway	Norwegian CCS [7]	CCS – industrial	PPP likely	Government support and private equity	Avoidance of CO ₂ price (Norway) & possible new CO ₂ tax	Promoter & lead developer	Likely largely public risk ownership
	Sleipner [8]	CCS – industrial/O&G	Private JV	JV funded	Avoidance of Norwegian CO ₂ tax, natural gas sales	CO ₂ taxes	Single party for whole chain

China	Sinopec Qilu Petrochem [9]	CCS – industrial	Public (Sinopec state owned)	Likely public – 100% equity Sinopec	EOR oil sales	State-owned enterprise	State owned – government bears all risk
Canada	Quest [10]	CCS – Hydrogen	Private	Government grants & private equity	CO ₂ price avoidance offset credits	Grants and Alberta Offset Credits	Government backed, reduced investment risk. Technical risk held by JV
UAE - Abu Dhabi	Al Reyadah/ Emirates Steel [11]	CCS – industrial	Public – Abu Dhabi National Oil Company	JV equity	CO ₂ use for EOR, oil sales, emissions reduction	ADNOC & Masdar are state owned	State owned – Government bears all commercial and technical risk
Netherlands	Rotterdam CCS (Porthos)*	CCS – industrial	PPP likely for capture, semi-public T&S	Public incentives & private investment	Avoidance of CO ₂ price, Government incentives (Cost Plus or CfD-like)	Support financially and risk sharing	Public private risk sharing, limited details – pre-FID
France Dunkirk	District Heating [12]	District heating waste heat	Plant owned by industry, heat network by city council	Public – initial CAPEX, then 50% industry second capture facility	Waste heat sales, avoidance of CO ₂ price, tax benefits, public perception	Financing & risk of initial heat network	Contracts for heat supply & demand, public investment and capital risk

Abbreviations: CAPEX (capital expenditure); OPEX (operational expenditure); T&S (transport and storage); RAB (Regulated Asset Base); CfD (Contracts for Difference); DECC (formerly UK Department of Energy and Climate Change, now Department for Business, Energy and Industrial Strategy); DOE (US Department of Energy); EOR (Enhanced Oil Recovery); PPP (Public-Private Partnership); JV (Joint Venture); Abu Dhabi National Oil Company (ADNOC); pre-FID (pre-Final Investment Decision).

*Data collected during personal communication with the project leader of the Rotterdam CCS project.

Table S2. Questionnaire coding frame.

Code Structure, with categories numbered by roman numbers, sub-categories as letters and codes as numbers.
Categories, Sub-categories and Codes
I. Barriers to CCUS implementation in the steel sector
A) <i>Economic barriers</i>
B) <i>Technical barriers</i>
II. Drivers of CCUS implementation in the steel sector
A) <i>Financial drivers</i>
B) <i>Regulatory/economic drivers</i>
III. Key elements to building a CCUS business model
A) <i>Revenue models</i>
1. Reward mechanisms, or ‘carrots’, such as tax credits, CfDs, carbon credits, etc.
2. Punishment mechanisms, or ‘sticks’, such as carbon taxation.
B) <i>Funding streams</i>
C) <i>Risk management</i>
D) <i>Ownership structure</i>

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