Role of blue hydrogen In the UK: Key learnings from recent activities

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Revised

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Element Energy, a consultancy focused on the low carbon energy sector

Element Energy covers all major low carbon energy sectors:

- CCUS & industrial decarbonisation
- Energy Networks
- Smart Energy Systems
- Hydrogen
- Low Carbon Transport
- Built Environment

Selected clients:

Public sector
- Department for Business, Energy & Industrial Strategy
- Committee on Climate Change
- European Commission
- Transport for London
- Birmingham City Council
- Scottish Cities Alliance
- Sustainable Energy Authority of Ireland
- Greater London Authority

Public-Private Partnerships
- United Nations Development Programme (UNDP)
- World Bank Group
- IEA
- Climate Foundation
- LowCVP
- FCH JU

Private Sector
- Shell
- OiG
- Equinor
- UK Power Networks
- Air Products
- Bosch
- British Gas
- Daimler
- Rolls-Royce
- ESB
- National Grid
- Zipcar
Recent blue hydrogen projects led by Element Energy

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
<th>Clients</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hy-Impact Series: Hydrogen in the UK,</td>
<td>▪ Hy-Impact is a series of four studies delivered by Element Energy exploring the introduction of hydrogen and CCS to the UK economy, including economic benefits of deployment, production of net-zero hydrogen, hydrogen for power generation and H₂ in Yorkshire &amp; Humber [LINK]</td>
<td></td>
<td>2019</td>
</tr>
<tr>
<td>from technical to economic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net-zero target:</td>
<td>▪ The UK government has asked the CCC for formal advice on the date by which the UK should achieve a net zero GHG/carbon target. Element Energy was commissioned to lead the analysis on net-zero industries considering all fuels (incl. internal fuels), sectors and key technologies [LINK]</td>
<td></td>
<td>2019</td>
</tr>
<tr>
<td>Deep decarbonisation of UK industries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hy4Heat:</td>
<td>▪ Element Energy leads this study, which aims to provide evidence to understand the issues relating to potential future conversion of industry to hydrogen, and to de-risk this opportunity; and to inform strategic options for wider conversion from natural gas to hydrogen. [To be published]</td>
<td></td>
<td>2018-19</td>
</tr>
<tr>
<td>industrial H₂ appliances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial fuel switching competition:</td>
<td>▪ Element Energy led the first phase of the Competition, which for all three phases has been allocated up to £20m. The aim is to understand economic potential for industrial fuel switching and CCUS and key barriers. [LINK]</td>
<td>Department for Business, Energy &amp; Industrial Strategy</td>
<td>2018</td>
</tr>
<tr>
<td>Market assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial carbon capture</td>
<td>▪ BEIS commissioned Element Energy to identify a set of promising business models and incentive mechanisms for the deployment of industrial carbon capture projects. [LINK]</td>
<td>Department for Business, Energy &amp; Industrial Strategy</td>
<td>2018</td>
</tr>
<tr>
<td>business models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ supply chain modelling tool</td>
<td>▪ Project involved gathering an extensive engineering dataset on the cost and performance of technologies across the whole hydrogen supply chain, including the application of CCS. [LINK]</td>
<td>Department for Business, Energy &amp; Industrial Strategy</td>
<td>2017</td>
</tr>
<tr>
<td>Analysis of future heat infrastructure</td>
<td>▪ Project into the costs associated with different pathways to decarbonising heat. The cost analysis considers all levels of the system, including the building level costs, and the distribution and transmission network level. [LINK]</td>
<td>National Infrastructure Commission</td>
<td>2017</td>
</tr>
</tbody>
</table>
Recent CCS projects led by Element Energy

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
<th>Clients</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Carbon Humber project</td>
<td>Drax Group, Equinor and National Grid formed a partnership to build a zero-carbon industrial cluster and decarbonise the North of England. Element Energy has been supporting the Consortium. <a href="#">LINK</a> <a href="#">LINK</a></td>
<td><img src="image" alt="National Grid" /> <img src="image" alt="Drax" /> <img src="image" alt="Equinor" /></td>
<td>2019</td>
</tr>
<tr>
<td>Net-zero target: Fossil fuel production and fugitive emissions</td>
<td>The UK government has asked the CCC for formal advice on the date by which the UK should achieve a net zero GHG/carbon target. Element Energy was commissioned to lead the analysis on decarbonising fossil fuel production emissions and fugitive emissions including methane. <a href="#">LINK</a></td>
<td><img src="image" alt="Committee on Climate Change" /> <img src="image" alt="Department for Business, Energy &amp; Industrial Strategy" /></td>
<td>2019</td>
</tr>
<tr>
<td>Shipping CO₂: UK cost estimation study</td>
<td>Study aims to estimate costs of shipping CO2 from different terminals and at a range of scales to geological CO₂ storage sites in the UK, and elsewhere; and to identify the circumstances (scales/capacity/locations/time) in which shipping costs may represent value for money. <a href="#">LINK</a></td>
<td><img src="image" alt="Department for Business, Energy &amp; Industrial Strategy" /></td>
<td>2018-19</td>
</tr>
<tr>
<td>Policy Mechanisms to support the large-scale deployment of CCS</td>
<td>Study assessed the barriers to CCUS deployment, and developed policy suggestions to incentivise large scale CCUS take up. The study also explored the key applications of CCUS market mechanisms in different regions such as North America, Europe, Middle East, China and India. <a href="#">LINK</a></td>
<td><img src="image" alt="OGG Oil &amp; Gas Climate Initiative" /> <img src="image" alt="IEAGHG" /></td>
<td>2018</td>
</tr>
<tr>
<td>Industrial CCS clusters; Power CCUS; CO₂ shipping; Digital technologies</td>
<td>Element Energy and its partners have been commissioned by IEAGHG to assess CCUS globally. 5 separate studies have assessed global deployment of industrial CCS clusters, role of power CCUS globally, CO₂ shipping infrastructure, impact of emerging technologies; and construction of CCUS.</td>
<td><img src="image" alt="IEAGHG" /> <img src="image" alt="Department for Business, Energy &amp; Industrial Strategy" /> <img src="image" alt="IEAGHG" /> <img src="image" alt="OGG Oil &amp; Gas Climate Initiative" /></td>
<td>2017-19</td>
</tr>
<tr>
<td>CCUS deployment at dispersed industrial sites</td>
<td>Project identified and assessed a range of high-level deployment options for Industrial Carbon Capture (ICC) technology on sites isolated from CO2 transport infrastructure, including shipping, onshore pipelines, road transport, rail, hydrogen fuel switching and CO₂ utilization.</td>
<td><img src="image" alt="Department for Business, Energy &amp; Industrial Strategy" /></td>
<td>2019</td>
</tr>
<tr>
<td>European funds and financing options for industrial CCUS clusters</td>
<td>Element Energy-led study assessed European funds and financing instruments along with multiple public and private sources of capital. The project demonstrated how part-chain ICC and T&amp;S infrastructure projects can be financed. <a href="#">LINK</a></td>
<td><img src="image" alt="European Climate Foundation" /></td>
<td>2017</td>
</tr>
</tbody>
</table>
“Developing carbon capture and storage technology and low-carbon hydrogen is a necessity, not an option”

Committee on Climate Change Net-zero Report Press Release May 2019

Hy-Impact is a series of four studies exploring the introduction of hydrogen and carbon capture and storage to the UK economy

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
Capturing emissions from natural gas powerplants

Enabling negative emissions through bioenergy + CCS

CCS enables clean hydrogen, industry, and power production

Use in fuel cell vehicles to achieve low-carbon transport

Replacing natural gas in gas turbines

Hydrogen provides multi-sector decarbonisation

Process and combustion emissions capture from heavy industries

Providing clean heat for several industrial sectors

Decarbonising domestic and commercial heat

Net-zero Blue Hydrogen

Green Hydrogen

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
Study 1 - Hydrogen for Economic Growth:
Unlocking jobs and value whilst reducing emissions in the UK

£18 billion in value and over 200,000 jobs could be generated by deployment of hydrogen and CCS in the UK economy.

This series of studies starts by examining how a future UK economy could benefit from the development of hydrogen and CCS technologies. Three ambition scenarios for hydrogen and CCS deployment were developed to understand the level of investment required and the potential economic, strategic, environmental and employment benefits.

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
Study 2 - Net-zero Hydrogen:
Hydrogen production with CCS and bioenergy

There is sufficient bioenergy to enable net-negative hydrogen production in even the most ambitious scenario

Net-zero or net-negative hydrogen can be produced by blending biogas into the natural gas feedstock. The second study examines the bioenergy resource required to meet future hydrogen demand, as well as the financial and emissions implications of different decarbonisation scenarios.

Biogas blending has a significant impact on hydrogen production costs and emissions

Emissions savings1 (MtCO₂/year)
- 89
- 93
- 98

Hydrogen fuel costs
- £40/MWh
- £44/MWh
- £48/MWh

Abatement cost1
- £109/tCO₂
- £123/tCO₂
- £137/tCO₂

Estimated bioenergy supply could satisfy even the most ambitious net-negative hydrogen deployment scenarios

UK hydrogen demand ambition 2050 (TWh/year)2
- 272
- 505
- 1,040

Maximum bioenergy demand for hydrogen3 2050 (TWh/year)
- 50
- 77
- 105

2 First two scenarios are different from Study 1; see full report for details
3 Total bioenergy availability in the Central Case (226 TWh/year) exceeds demand required to achieve net-negative hydrogen production

Natural gas prices based on BEIS central forecast (€21/MWh 2050 onwards)

Assuming 9.3% biogas mix for hydrogen production

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
Study 3 - Hydrogen for Power Generation: Opportunities for hydrogen and CCS in the UK power mix

Hydrogen and CCS power technologies can cost-effectively replace a significant number of planned power generation assets

Hydrogen and CCS can be used for low-carbon power generation to diversify the power portfolio, reduce electricity imports and provide resilience to high levels of renewable energy generation. Our work assessed the financial and emissions implications of these generation methods when compared with current and future natural gas and nuclear options.

UK power in 2035 under three low-carbon generation scenarios...

... would require a diversification of technologies with opportunities for hydrogen and CCS...

hydrogen and CCS technologies could reduce grid intensity by 24% and achieve significant cost savings

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
The Humber region could represent an opportunity for early hydrogen deployment, with potential demand of 13 TWh/yr hydrogen in industry and up to 165 TWh/yr in power plants.

The wider Humber region is the UK’s largest industrial cluster by both greenhouse gas emissions and energy usage. Our work identified large industrial and power sites in the region and assessed their potential for use of hydrogen in 2030.

...and could provide a base for early hydrogen economy development.
Energy intensive industries can enable the “hydrogen for heat” transition in Europe

Reference: Element Energy for Equinor, Hy-Impact Series, 2019
Hydrogen for industry: no showstopper barriers were identified for hydrogen conversion; however, a wide range of industrial hydrogen equipment should be developed.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Enablers</th>
<th>Impacted equipment</th>
<th>Impact Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiative Heat Transfer</td>
<td>Lower emissivity results in decreased radiant heat flux</td>
<td>Furnaces, Kilns</td>
<td></td>
</tr>
<tr>
<td>Convecitive heat transfer</td>
<td>Lower air requirement reduces the gas volume available to transfer heat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{x} emissions</td>
<td>May be increased through higher flame temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FGR Recirculation (FGR)</td>
<td>Increases gas volume, and is also beneficial elsewhere (e.g. NO\textsubscript{x} emissions), equipment recalibration for indirect fired equipment</td>
<td>All equipment</td>
<td></td>
</tr>
<tr>
<td>Flue Gas Composition</td>
<td>Increased moisture content with H\textsubscript{2} might impact product quality</td>
<td>Direct fired equipment</td>
<td></td>
</tr>
<tr>
<td>Gas Engine Conversion for CHP</td>
<td>Period of R&amp;D, small scale and large-scale trials. May require full replacement with potential new design, rather than retrofit.</td>
<td>Gas Engines</td>
<td></td>
</tr>
<tr>
<td>Piping and fittings (leakage risks and embrittlement)</td>
<td>Materials and standards currently exist for hydrogen piping. Site distribution systems would need to be checked for hydrogen compatibility and replaced if incompatible.</td>
<td>All sites</td>
<td></td>
</tr>
<tr>
<td>Hydrogen burner development, including materials</td>
<td>Burner materials currently exist, though further R&amp;D by burner manufacturers is required.</td>
<td>All equipment</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Typical Equipment</th>
<th>Equipment Conversion Cost – Variation with Size (£'000's)*</th>
<th>Conversion Cost for Typical Equipment (£'000's)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food and Drink</td>
<td>Steam Boiler</td>
<td>170</td>
<td>1,040</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Steam Boiler</td>
<td>100</td>
<td>780</td>
</tr>
<tr>
<td>Vehicle Manufacturing</td>
<td>Hot Water Boiler</td>
<td>170</td>
<td>1,040</td>
</tr>
<tr>
<td>Basic Metals</td>
<td>Furnace</td>
<td>110</td>
<td>980</td>
</tr>
<tr>
<td>Paper</td>
<td>Direct Dryer</td>
<td>140</td>
<td>200</td>
</tr>
<tr>
<td>Glass</td>
<td>Glass Furnace</td>
<td>150</td>
<td>1,140</td>
</tr>
<tr>
<td>Ceramics</td>
<td>Kiln</td>
<td>150</td>
<td>390</td>
</tr>
<tr>
<td>Lime</td>
<td>Lime Kiln</td>
<td>150</td>
<td>640</td>
</tr>
<tr>
<td>Other NM Minerals</td>
<td>Rotary Dryer</td>
<td>140</td>
<td>520</td>
</tr>
<tr>
<td>Electric and Mechanical Engineering</td>
<td>Hot Water Boiler</td>
<td>170</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>Oven</td>
<td>150</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>Steam Boiler</td>
<td>170</td>
<td>450</td>
</tr>
</tbody>
</table>

*All costs are in thousands of GBP

Reference: Element Energy for BEIS/Hy4Heat (Confidential until published)
Several promising business models were identified for industrial carbon capture including hydrogen production – drawing on comparable existing policies

<table>
<thead>
<tr>
<th>Contract for difference:</th>
<th>Cost plus:</th>
<th>Regulated asset base:</th>
<th>Tradeable tax credits:</th>
<th>CCS certificates:</th>
<th>Low carbon market:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CfD on CO₂ price relative to market CO₂ price (e.g. EU ETS) to provide guarantee of revenue</td>
<td>All properly incurred ICC operational costs are reimbursed through taxpayer funding</td>
<td>Public regulation allows costs to be recovered through product prices e.g. of Hydrogen</td>
<td>CCS tax credits awarded $/tCO₂ to reduce firms tax liability (e.g. 45Q) or trade with other firms.</td>
<td>Certificates representing tCO₂ abated through CCS, which can be traded and emitters have an obligation.</td>
<td>End-use regulation e.g. on buildings to create a low carbon market &amp; achieve product premium</td>
</tr>
</tbody>
</table>

**Acceptability to industry evaluation**

- **Cost Plus**: Simplicity, Revenue strength, Capital availability, OPex uncertainty, CO₂ price, Competitiveness
- **RAB**: Simplicity, Revenue strength, Capital availability, OPex uncertainty, CO₂ price, Competitiveness
- **Tax credits**: Simplicity, Revenue strength, Capital availability, OPex uncertainty, CO₂ price, Competitiveness
- **CCS certificates**: Simplicity, Revenue strength, Capital availability, OPex uncertainty, CO₂ price, Competitiveness
- **Low carbon market**: Simplicity, Revenue strength, Capital availability, OPex uncertainty, CO₂ price, Competitiveness

**Acceptability to government evaluation**

- **Cost Efficiency**: Implementation, CCS Phases, Track record, Administration
- **Cost Plus**: Implementation, CCS Phases, Track record, Administration
- **RAB**: Implementation, CCS Phases, Track record, Administration
- **Tax credits**: Implementation, CCS Phases, Track record, Administration
- **CCS certificates**: Implementation, CCS Phases, Track record, Administration
- **Low carbon market**: Implementation, CCS Phases, Track record, Administration

Reference: Element Energy for BEIS, Industrial carbon capture business models, 2018
Shipping can unlock several opportunities for blue hydrogen; however, feasible CO₂ transport and storage business models should be introduced across Europe

Enabling the deployment of multiple clusters in parallel

Enabling short duration CCUS projects of small scale

Enabling cross-border CO₂ transport in Europe and globally

Enabling CCUS clusters without nearby storage options

Reference: Element Energy for BEIS, Shipping CO₂ – Cost estimation study, 2018
Element Energy is a leading low carbon energy consultancy working in a range of sectors including industrial decarbonisation, carbon capture utilisation and storage (CCUS), hydrogen, low carbon transport, low carbon heat, renewable power generation, energy networks, and energy storage. Element Energy works with a broad range of private and public sector clients to address challenges across the low carbon energy sector.

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