

<b>Institution:</b> University of Edinburgh		
<b>Unit of Assessment:</b> 7		
<b>Title of case study:</b> Carbon Capture and Storage including Negative Emissions to deliver UK Net Zero Emissions		
<b>Period when the underpinning research was undertaken:</b> 2004 - 2020		
<b>Details of staff conducting the underpinning research from the submitting unit:</b>		
<b>Name(s):</b>	<b>Role(s) (e.g. job title):</b>	<b>Period(s) employed by submitting HEI:</b>
R. Stuart Haszeldine	Professor of Carbon Capture and Storage	1999 - present
Vivian Scott	Senior Researcher in Greenhouse Gas Removals	2011 - present
Simon Tett	Professor of Earth System Dynamics	2007 - present
Gareth Johnson	Research Associate	2013 - 2018
Juan Alcalde	Research Associate	2013 - 2015
Peter Brownsort	Research Associate	2010 - 2020
R. Jamie Stewart	Research Associate	2009 - 2018
Niklas Heinemann	Research Associate	2015 - present
Stephanie Flude	Research Associate	2014 - 2018
<b>Period when the claimed impact occurred:</b> January 2014 to December 2020.		
<b>Is this case study continued from a case study submitted in 2014?</b> No		
<b>1. Summary of the impact</b> (indicative maximum 100 words) <p>University of Edinburgh (UoE) research on Carbon Capture and Storage (CCS) and negative emissions (CO<sub>2</sub> removal from the atmosphere) underpinned the development of crucial technologies needed to deliver economy-wide decarbonisation for UK and global industry and established the feasibility of a Net Zero target for CO<sub>2</sub> emissions. The research, led by Haszeldine, underpinned continued UK engagement in CCS and ultimately the Chancellor's commitment in the March 2020 UK budget of GBP800,000,000 (increased in November 2020 to GBP1,000,000,000), to establish four CCS industry clusters to develop and apply the technology as part of the UK Government's decarbonisation agenda. Work with the Acorn project, the UK's leading CCS cluster, and their CO<sub>2</sub>SAPLING Transport Infrastructure Project, led to three cycles of sustained investment (total to end-2020 of GBP15,000,000) by Governments in the UK, Scotland, EU and commercial partners. The group's expertise in negative emissions, via staff secondment (Scott) to the UK Committee on Climate Change, made key inputs to the advice resulting in UK's world-leading Net Zero by 2050 climate change legislation, enacted in 2019.</p>		
<b>2. Underpinning research</b> (indicative maximum 500 words) <p>The University of Edinburgh hosts an internationally renowned group on Carbon Capture and Storage (CCS), geological storage of CO<sub>2</sub> and Hydrogen, and Negative Emissions, led by Haszeldine. This group works in the UK and across the world (Europe, Canada, USA, Australia, South Africa and China) in support of the development of these crucial technologies to deliver emissions reductions from industry and fuels and enable delivery of Net Zero emissions targets.</p> <p>Research by the UoE CCS group has established the huge and strategic capacity of the North Sea subsurface to store CO<sub>2</sub> securely. This enables North Sea oil and gas expertise and engineered infrastructures to transfer into a major global CCS industry. Research assessing Europe-wide CO<sub>2</sub> storage planning and supporting infrastructures has proven the importance of</p>		

the UK North Sea for effective Europe-wide deployment of CCS [3.1] leading to EU support and investment in project development in the UK and other North Sea countries. Analysis of the potential for a Scottish CCS cluster identifies St Fergus (Aberdeenshire) as a key national and European CCS infrastructure hub making advantageous use of existing oil and gas infrastructures to accelerate delivery and reduce costs (including avoiding substantial decommissioning costs) [3.2] [3.3] leading to UK and Scotland investment in project design and development.

The group has expanded its research into the field of negative emissions, also known as greenhouse gas removals, the direct removal of CO<sub>2</sub> from the atmosphere to enable reaching Net Zero emissions as required to stabilise climate change. In [3.4] they undertook an important early assessment of the global capability to store CO<sub>2</sub> from negative emissions and developed the distinction between temporary and permanent CO<sub>2</sub> stores. [3.5] assessed the progress on negative emissions development and its deficit in the context of realising the goals of the United Nations 2015 Paris Agreement treaty on climate change. [3.6] undertook an early peer-reviewed analysis of the potential for UK based CO<sub>2</sub> removal by negative emissions technologies and identified feasible approaches to achieving UK Net Zero emissions.

### 3. References to the research (indicative maximum of six references)

[3.1] Stewart, R.J., Scott, V., Haszeldine, R.S., Ainger, D. & Argent, S. (2014) The feasibility of a European-wide integrated CO<sub>2</sub> transport network. **Greenhouse Gases: Science and Technology** 4, 481-494, doi:10.1002/ghg.1410 [10 citations]

[3.2] Brownsort, P.A., Scott, V. & Haszeldine, R.S. (2016). Reducing costs of carbon capture and storage by shared reuse of existing pipeline—Case study of a CO<sub>2</sub> capture cluster for industry and power in Scotland. **International Journal of Greenhouse Gas Control** 52, 130-138, doi:10.1016/j.ijggc.2016.06.004 [13 citations]

[3.3] Alcalde, J., Heinemann, N., Mabon, L., Worden, R.H., de Coninck, H., Haszeldine R.S., James A., Mackay E.J. & Brownsort P. B., (2019) Acorn: Developing full-chain industrial carbon capture and storage in a resource-and infrastructure-rich hydrocarbon province. **Journal of Cleaner Production** 233, pp.963-971, doi:10.1016/j.jclepro.2019.06.087 [17 citations]

[3.4] Scott, V., Haszeldine, R.S., Tett, S.F.B. & Oschlies, A. (2015) Fossil fuels in a trillion tonne world. **Nature Climate Change** 5, 419-423, doi:10.1038/nclimate2578 [44 citations]

[3.5] Haszeldine, R.S., Flude, S., Johnson, G. & Scott, V. (2018) Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments. **Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences** 376 p.20160447, doi:10.1098/rsta.2016.0447 [68 citations]

[3.6] P Smith, P., Haszeldine, R.S. & Smith, S.M. (2016) Preliminary assessment of the potential for, and limitations to, terrestrial negative emission technologies in the UK. **Environmental Science: Processes & Impacts** 18, pp.1400-1405, doi:10.1039/c6em00386a [22 citations]

The underpinning research listed was published in highly ranked academic journals (Scopus citations as of December 2020 shown above), and supported by peer-reviewed grants. Examples include:

PI, Haszeldine, R.S. (2010-2016). SCCS, a Carbon Capture and Storage Knowledge Hub for Scotland. [227160939]. *Scottish Funding Council (SFC)*. GBP2,000,000.

PI, Haszeldine, R.S. (2012-2014). EU Framework Programme 7: European Trans-disciplinary Assessment of Climate Engineering (EuTRACE). [306395]. *EU Government Bodies*. [GBP54,981].

Co-I, Haszeldine, R.S. (2017-2019). Accelerating Low Carbon Industrial Growth through CCUS. [691712]. *Department for Business, Energy and Industrial Strategy*. [GBP287,968].

In recognition of his research leadership in this area, Haszeldine has acted as (a) Director of the Scottish Carbon Capture and Storage ([www.sccs.org.uk](http://www.sccs.org.uk)) research centre - a unique collaboration of CCS expertise in research and development amongst six UK Universities and (b) CO<sub>2</sub> Storage Research Champion Co-I of the EPSRC UK CCS Research Centre ([ukccsrc.ac.uk](http://ukccsrc.ac.uk)) 2017–ongoing to 2022.

#### 4. Details of the impact (indicative maximum 750 words)

##### Route to Impact

*Impact on Policy.* Haszeldine played a pivotal role in advising UK, Scottish and EU governments on CCS and energy and climate policy. He is one of two academics invited onto the Carbon Capture Utilisation and Storage (CCUS) council, advising the UK Department for Business Energy and Industrial Strategy (BEIS) Energy Minister (2016-present) [5.1]. He was the sole academic member of the UK Parliamentary Advisory Group on CCS and co-author of its report to the Secretary of State for BEIS (2016) [5.2a]. Scott and Haszeldine both worked extensively with policymakers in the EU Commission and the intergovernmental North Sea Basin Task Force, and Scott was seconded in 2018/19 to the UK Committee on Climate Change to provide expert advice on Net Zero to the UK and devolved Governments. Scott also acted as an expert reviewer to the UN Intergovernmental Panel on Climate Change Report on 1.5°C (2018).

*Technical solutions.* The UoE CCS group has provided research support to the St Fergus Acorn project (<https://theacornproject.uk>), the UK's leading CCS cluster, including via their CO<sub>2</sub> SAPLING Transport Infrastructure Project described below. Acorn's aim is to repurpose oil and gas industry expertise and infrastructure in the North-east of Scotland to the decarbonisation agenda. Haszeldine helped create NECCUS Ltd - uniquely combining industry actors in collaboration for CCS in Scotland to achieve practical construction and operation by 2024.

##### Impact on practitioners

*UK Government industrial strategy.* The 2016 report to BEIS drew on learning from [3.1] and [3.2] to inform key recommendations on strategic investment by UK Government into CCS infrastructure. Specifically, this involves separating investment in CO<sub>2</sub> capture and CO<sub>2</sub> transportation and storage, and setting up clusters of actors sharing infrastructure with the common goal of decarbonising industry, producing low-carbon hydrogen and enabling negative emissions as a key part of the lowest cost route to achieving the UK's decarbonisation targets. "These features are the basis of all current UK CCS developments -multiple £Bn, and many others worldwide" [5.2b].

The recommendations of the 2016 report to BEIS were "adopted in practise by successive civil servants and UK Energy Ministers" [5.2b], culminating in the major commitment to invest in a "new CCS Infrastructure Fund of at least £800 million" to develop CCS clusters and to support the construction of a CCS gas power plant in the March 2020 UK budget [5.3a]. Announcing this investment, the Chancellor Rishi Sunak said "Carbon capture and storage is precisely the kind of exciting technology where Britain can lead the world over the next decade. I can announce today that we will invest at least £800 million to establish two or more new carbon capture and storage clusters by 2030...The new clusters will create up to 6,000 high-skill, high-wage, low-carbon jobs in areas like Teesside, Humberside, Merseyside or St Fergus in Scotland." [5.3b]. In November 2020 UK CCS funding was increased to GBP 1,000,000,000 in the Ten Point Plan for a Green Industrial Revolution [5.3c].

*European Union CCS policy and investment.* Scott and Haszeldine made "crucial and valuable contributions in shaping EU CCS policy and securing EU funding for CCS planning and development around the North Sea region" [5.4a] by applying their research on North Sea CO<sub>2</sub> storage and CCS projects and infrastructure development [3.1]. This resulted in projects in the UK (see *UK Industry* below), Netherlands, Belgium and Norway being selected as EU Projects of Common Interest eligible for EU Connecting Europe Facility infrastructure funding (2017-2019). This has resulted in funds awarded in 2020 of EUR102,000,000 towards CO<sub>2</sub> infrastructure construction (PORTHOS project, Netherlands), plus EUR5,785,000; EUR 3,187,500 and EUR15,371,781 for engineering design of CO<sub>2</sub> infrastructures and shipping facilities linking Belgium, Netherlands, UK and Norway [5.4b] and [5.4c].

**Scottish Government CCS policy.** The Chief Executive of UK Committee on Climate Change and former Director of Energy and Climate for the Scottish Government writes “*Haszeldine and his team of researchers at Edinburgh University have played a major role in supporting the strategic case for CCS development and deployment in Scotland. Their work on establishing the huge potential of the North Sea’s CO<sub>2</sub> storage resource and the opportunities for the repurposing of oil and gas pipeline infrastructures (and industry skills) to enable lower cost deployment [of which references [3.1]-[3.3] are examples] has informed Scottish policymakers in embracing CCS as a crucial component of Scotland’s climate and energy strategy.*” [5.5].

**UK Industry.** The underpinning research and engagement by Haszeldine and the UoE team supported the development of the St Fergus Acorn CCS project, in particular its CO<sub>2</sub>Sapling Transport Infrastructure Project (<https://pale-blu.com/co2-sapling>). Acorn CCS is the UK’s most advanced CCS technology cluster, underpinning delivery of UK and European industry decarbonisation and low carbon hydrogen fuel [5.6a]. Acorn CCS is led by Pale Blue Dot Energy, with funding and support from industry partners Chrysaor, Shell and Total, the UK and Scottish Governments, and the European Union. It is strategically located in the North East of Scotland to repurpose legacy oil and gas pipeline and wells to CO<sub>2</sub> storage, rather than undertake costly decommissioning, as recommended by [3.3]. This ‘upcycling’ or infrastructure reuse enables rapid and cost-effective project delivery saving up to GBP750,000,000 compared with commissioning new pipelines and boreholes. In 2018, Acorn’s CO<sub>2</sub>Sapling project was awarded funding by the EU as a Project of Common Interest (EUR374,000) [5.6b] with co-funding from the UK (GBP175,000) and Scotland (GBP175,000) [5.6c]. In 2019 Acorn was awarded a further EUR 2,800,000 from the EU [5.6b], GBP4,8000,000 from UK BEIS CCUS Innovation Programme [5.6d], and in 2020 GBP2,700,000 from UK BEIS Hydrogen supply competition [5.6e]. Together these initiatives represent a sustained investment of GBP15,000,000 by Governments in the UK, Scotland, and EU alongside commercial partners.

**Integrated action by Government, Industry, and Research practitioners.** In November 2019, building out from the Acorn project, Haszeldine and SCCS helped establish the North East Carbon Capture Utilisation and Storage ([www.neccus.co.uk](http://www.neccus.co.uk)) alliance of 33 industries (including Shell, Total, Ineos, SSE, Doosan Babcock), government agencies and research institutions as the delivery vehicle for CCS on UK industry, funded by GBP300,000 from the Scottish Government [5.6a]. In April 2019 NECCUS was awarded GBP100,000 to prepare bids to the UK Government’s Industrial Strategy Challenge Fund [5.6f].

**UK Central and Devolved Government climate change legislation.** Scott led the assessment of negative emissions potential for the UK Committee on Climate Change (CCC) 2019 which provided formal advice on Net Zero emissions to the UK, Scotland and Wales Governments [5.7a]. Informed by UoE work on negative emissions (including [3.4, 3.5, 3.6]) Scott’s “*work made a key contribution to the CCC’s Net Zero advice*” [5.5] which was subsequently adopted by UK and Scottish governments passing legislation in 2019 updating their Climate Change Act targets to Net Zero by 2050 [5.7b] and Net Zero by 2045 respectively [5.7c]. The UK Budget 2020 states “*the transition to a net-zero economy by 2050 will require radical changes in every sector*” and presents a range of measures to advance Net Zero action including to “*at least double the size of the energy innovation programme*” and “*an additional £10 million in 2020-21 to support the design and delivery of net zero policies and programmes*” [5.3a]. Furthermore, “*Vivian [Scott’s] work helped identify the importance of Direct Air Capture (DAC) technologies - machines that scrub CO<sub>2</sub> from the air - as a permanent and potentially rapidly scalable GGR [Greenhouse Gas Removal – alternative term for negative emissions] approach. This led to the inclusion of a strategic cost discovery scale of DAC deployment in our [CCC] UK Net Zero emissions pathway.*” [5.5]. This has been taken up by UK government with the announcement in June 2020 of “*up to £100 million*” of funding for Direct Air Capture R&D [5.7d], and in Dec 2020 by a further GBP180,000,000 of funding for Hydrogen, CCS and Negative Emissions Technologies announced by Scottish Government [5.7e].

**UN and international climate action.** The group’s research outputs, including [3.5] were cited in the UN Intergovernmental Panel on Climate Change Report (IPCC) on 1.5°C (2018) [5.8a]. The findings of the 2018 IPCC 1.5°C Report which provide scientific assessment of the actions required to achieve the UN Paris Agreement, underpins the subsequent strengthening of climate



change targets worldwide with many major economies (together around 70% of the world's economy) following the UK in setting Net Zero emissions targets in 2019 [5.8b].

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

[5.1] BEIS CCUS Council <https://www.gov.uk/government/groups/ccus-council>

[5.2] a) Lowest Cost Decarbonisation for the UK: The Critical Role of CCS (2016) [https://www.sccs.org.uk/images/expertise/reports/oxford/oxburgh\\_report\\_the\\_critical\\_role\\_of\\_CCS.pdf](https://www.sccs.org.uk/images/expertise/reports/oxford/oxburgh_report_the_critical_role_of_CCS.pdf); b) Chief Executive, Carbon Capture and Storage Association CCSA, London (Testimonial Letter, 22/12/2020)

[5.3] a) UK Budget 2020 <https://www.gov.uk/government/publications/budget-2020-documents> (p.81); b) Hansard Chancellor Sunak UK budget 2020 <https://hansard.parliament.uk/commons/2020-03-11/debates/72444685-77EB-4AB3-83C4-7AF234096ACD/FinancialStatement>; c) UK Ten Point Plan for a Green Industrial Revolution (November 2020) <https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title#point-8-investing-in-carbon-capture-usage-and-storage>

[5.4] a) *Department for Business, Energy and Industrial Strategy* (Testimonial letter 27/10/2020); b) CEF Energy Call for Proposals 2020 selected for receiving financial assistance (p.2) [https://ec.europa.eu/energy/sites/default/files/list\\_of\\_all\\_projects\\_receiving\\_eu\\_support\\_under\\_the\\_2020\\_cef\\_call.pdf](https://ec.europa.eu/energy/sites/default/files/list_of_all_projects_receiving_eu_support_under_the_2020_cef_call.pdf) c) Deputy Director, *Bellona Europe*, Brussels (Testimonial letter, 12/2020)

[5.5] Chief Executive of *UK Committee on Climate Change* and former Director of Energy and Climate *Scottish Government* (Testimonial letter, 19/10/2020)

[5.6] a) Managing Director of *Pale Blu Dot Acorn and CO2 Sapling projects* (Testimonial letter 16/12/2020); b) EU Connecting Europe Facility awards to UK Acorn CO2 Sapling project. [https://ec.europa.eu/inea/sites/inea/files/cefpub/cef\\_energy\\_factsheet\\_uk.pdf](https://ec.europa.eu/inea/sites/inea/files/cefpub/cef_energy_factsheet_uk.pdf); c) BBC news UK, Scotland and EU funding for Acorn project <https://www.bbc.co.uk/news/uk-scotland-scotland-business-46358715>; d) UK BEIS CCUS Innovation Programme funding <https://www.gov.uk/government/publications/call-for-ccus-innovation/ccus-innovation-programme-selected-projects#acorn-ccs--feed-programme>; e) UK BEIS Low Carbon Hydrogen Supply Competition <https://www.gov.uk/government/publications/hydrogen-supply-competition/hydrogen-supply-programme-successful-projects-phase-2>; f) UK Industrial Strategy Challenge Fund award to North East Carbon Capture Utilisation and Storage (NECCUS) [https://www.neccus.co.uk/wp-content/uploads/2020/04/UKRI\\_PN\\_150420.pdf](https://www.neccus.co.uk/wp-content/uploads/2020/04/UKRI_PN_150420.pdf)

[5.7] a) UK Committee on Climate Change, Net Zero – The UK's contribution to stopping global warming <https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/> (2019). b) UK Climate Change Act net-zero amendment <https://www.legislation.gov.uk/ukxi/2019/1056/contents/made> and <https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law>; c) Scotland Climate Change Act net-zero amendment <http://www.legislation.gov.uk/asp/2019/15/enacted> and <https://www.gov.scot/policies/climate-change/>; d) GBP100,000,000 for Direct Air Capture development (UK Government June 2020) <https://www.gov.uk/government/news/pm-a-new-deal-for-britain>; e) GBP180,000,000 Emerging Energy Technologies Fund supporting Hydrogen, CCS, and Negative Emissions (Scottish Government December 2020) <https://www.gov.scot/news/steering-scotlands-pathway-to-net-zero/>

[5.8] a) Intergovernmental Panel on Climate Change: Global Warming of 1.5C (2018) [https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15\\_Full\\_Report\\_High\\_Res.pdf](https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf). b) UN Climate Ambition Summit December 2020 <https://www.un.org/sites/un2.un.org/files/climate-ambition-summit-release.pdf>