Institution: University of Chester		
Unit of Assessment: 12 Engineering		
Title of case study: Cryogenic carbon capture from difficult industrial CO_2 emitters		
Period when the underpinning research was undertaken: August 2016 – ongoing		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Carolina Font Palma	Dr, Senior Lecturer	2015 – 2021
Joseph Howe	Professor Exec. Dir. of Energy	2014 – ongoing
Georgios Lychnos	Dr, Researcher	2019 – 2020
David Cann	Research Assistant	2019 – 2020
Period when the claimed impact occurred: August 2016 – ongoing		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Research on cryogenic separation for the removal of CO_2 from a gas mixture has involved experimental research and modelling work. This research has led to the establishment of the start-up company PMW Technology Ltd. by Paul Wilson, former Head of Innovation at consultants WSP. The research underpinned the development of the patented A3C (advanced cryogenic carbon capture) process. This process mitigates CO_2 emissions from industrial sources that are harder to decarbonise through conventional technologies. The impact of this process is reduction of carbon emissions, helping to meet national and international commitments to tackling climate change, in line with the Government's Clean Growth Strategy. This work has created a full-time job and the innovation has attracted industrial collaborators, such as Thyson Technology and Houlder Ltd, demonstrating the commercial potential of this cryogenic technology. Thyson Technology is a process engineering company specialising in complex analyser systems for oil and gas, with a global reach. Houlder Ltd is a marine design and clean technology company focussed on maritime decarbonisation.

2. Underpinning research (indicative maximum 500 words)

The research involves a novel cryogenic carbon capture process patented by the start-up company PMW Technology Ltd. The established technology for carbon capture is chemical absorption using amine-based solvents, but the large volumes of solvent used require significant thermal energy for regeneration. Cryogenic carbon capture through freezing out the CO_2 in industrial emissions is a physical separation that avoids dealing with hazardous chemicals, achieves high CO_2 removal levels and delivers a high purity CO_2, which could be further used in the food industry and/or to produce chemicals. Since cryogenic separation often involves multiple beds and heavy frost deposition, at temperatures below -100ºC, the advanced cryogenic carbon capture (A3C) technology, which we are working on, overcomes some limitations of previous cryogenic systems by using a moving bed of metallic beads as a heat transfer medium and frost capture surface.

The University of Chester has contributed to this research through the expertise in process simulation of Dr Carolina Font Palma and Dr Georgios Lychnos, and with the construction and demonstration of the cryogenic process by the PhD student David Cann. One final year MEng project student and 5 BEng project students have also contributed to the project, exemplifying the University of Chester approach to engaging students with research at all levels.

Our earlier work involved a feasibility study and we secured £157k funding to evaluate the process performance and commercial potential under various industrial scenarios, we and found that at small scales the cost of capture of the A3C process was up to 70% lower than the benchmark amine-based process [1]. In our earlier work, carried out between October 2017 and December 2018, the University of Chester and PMW Technology developed a model using Aspen Plus®

software (material and energy balance process simulation tool) to model and simulate the cryogenic process; the University of Sheffield produced a model and performed the economics of the benchmark amine-based carbon capture process; and industrial partners WSP Consultants, DVN GL and Costain provided support for the design and costing of the A3C process [2].

Subsequent work with PMW Technology has identified that the A3C process can be adapted to produce biomethane (a green non-fossil source of energy) from agricultural waste converted through anaerobic digestion to upgraded biogas, which can then be injected into the gas grid [4].

Further, our PhD student (David Cann), sponsored by the Eco-Innovation European Regional Development Fund (ERDF) from October 2017 until September 2020, has built an experimental rig which demonstrates the fundamentals of the cryogenic separation process [3].

Both projects have led to national and international conference presentations. The promising results are being used to support further grant applications, and the Transport-Technology Research and Innovation Grants (T-TRIG) project has secured funding from the Department for Transport from January to July 2020, with the aim to continue proving the concept and ultimately to build a pilot plant.

The strength of this innovative research was recognised through a Fossil Fuels Award at the Rushlight Show 2018-19 for the outstanding A3C carbon capture process [5].

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

1. P. Willson, G. Lychnos, A. Clements, S. Michailos, C. Font-Palma, M. E. Diego, M. Pourkashanian, J. Howe. Evaluation of the Performance and Economic Viability of a Novel Low Temperature Carbon Capture Process. *International Journal of Greenhouse Gas Control*. 2019, 83: 1-9, DOI: 10.1016/j.ijggc.2019.04.001 (Impact Factor: 3.231)
2. Poster presented at UKCCSRC Network Conference, Cardiff University, 16-17 April 2019. P. Willson, G. Lychnos, C. Font-Palma, J. Howe, M. E. Diego, A. Clements, S. Michailos, M. Pourkashanian, Techno-Economic Study of A3C Capture Process https://ukccsrc.ac.uk/sites/default/files/documents/event/Paul%20Willson%20Cardiff%202019.pdf
3. D. Cann, P. Willson, C. Font Palma. Experimental Exploration of CO_2 Capture Using a Cryogenic Moving Packed Bed. *14th Greenhouse Gas Control Technologies Conference Melbourne 21-26 October 2018 (GHGT-14)*. Available at SSRN: https://ssrn.com/abstract=3366196
4. C. Font-Palma, G. Lychnos, P. Willson. Production of biomethane from agricultural waste using a cryogenic carbon capture process. *Energy Proceedings, 11th International Conference on Applied Energy, 12-15 August 2019, Västerås, Sweden* Proceedings of (energy-proceedings.org)
5. Fossil Fuels Award at the Rushlight Show 2018-19 for the outstanding A3C carbon capture process https://www.rushlightevents.com/rushlight-awards/background/press-release/

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

Impacts on commerce and the economy

A Thornton Science Park-based start-up company, PMW Technology (founded in August 2016), was created as a result of preparing a project proposal and securing Innovate UK funding to perform a feasibility study of the concept for cryogenic carbon capture and identification of its commercial applications [1]. The collaboration has involved knowledge transfer from the University to the start-up company [2, 3] on process simulation, resulting in creation of one job for a process analyst.

This research collaboration has led to the design of a novel process to remove carbon dioxide from industrial sources [4]. The technology offers economic advantages over existing well-established technologies, offering a cost-effective way forward for industries where carbon

capture is difficult by conventional methodologies. The A3C process has potential applications in diverse areas such as marine decarbonisation and in food, drink, and metals sectors, where high purity CO_2 captured from exhaust gases can be directly recycled to replace imported gas.

The innovative A3C process is already attracting interest from larger industrial partners: Thyson Technology is willing to invest in this development and commercialisation for biogas upgrading. Subject to raising investment to build a pilot plant, Thyson Technology [5] have committed to an investment of £250k. In a second collaboration, Houlder Ltd is interested in a marine transport application to aid decarbonisation of shipping [6] and has become an industrial partner through the feasibility study 'Decarbonising the Transport System - Evaluation of the Marine Application of Advanced Carbon Capture Technology.' This is funded through the Transport-Technology Research and Innovation Grants (T-TRIG) programme of the Department for Transport. The A3C process offers a relatively simple solution to marine decarbonisation that may be 50% cheaper than switching to alternative fuels.

This project has generated societal impact through inspiring undergraduate students to do research placements. Five undergraduate students have undertaken research placements and one MEng student has collaborated with the research group on this research project, extending their experience and enthusiasm for careers in industry-relevant research [7].

Impacts on the environment

The A3C process is an essential mechanism to deliver the urgent need for reduction of significant greenhouse gas emission from different sectors. The lower cost and more widely applicable technology gives rise to opportunities to implement carbon capture in industries where conventional methods have proved difficult.

The A3C process requires less than 150 kWh/tCO_2 for separation and is simple to apply as no heat or hazardous chemicals are required, thereby adding a secondary benefit to the environment.

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

1. UKRI website for grant holders https://gtr.ukri.org/projects?ref=132957
2. PMW Technology website https://www.pmwtechnology.co.uk/about.html
3. Press coverage when the feasibility study funded by Innovate UK was launched, partners included PMW Technology, Universities of Chester and Sheffield, WSP, DVN GL and Costain. The project ran from October 2017 to December 2018. https://www.powerengineeringint.com/articles/2017/09/uk-consortium-launches-feasibility-study-for-new-ccs-method.html
4. Press coverage for PhD partnership through the European Development Regional Fund (EDRF) with the University's Eco-Innovation Cheshire and Warrington programme: https://www.gasworld.com/carbon-capture-experts-create-synergy-at-thornton-science-park/2013687.article
5. Thyson Technology www.thyson.com
6. Houlder Ltd www.houlderltd.com
7. Press coverage about how this project has inspired undergraduate students to do research placements. Five undergraduate students have undertaken research placements and one MEng student has done her research project. https://www.chemicalindustryjournal.co.uk/thornton-energy-project-captures-students-scientific-imagination