Institution: University College London

Unit of Assessment: 12 – Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Treating waste with carbon dioxide: growth of spinout Carbon8 Systems

1. Summary of the impact

Carbon8 Systems (C8S) was founded on joint research between UCL and the University of Greenwich. The company has since developed a technology known as Accelerated Carbonation, which helps to reduce carbon dioxide (CO_2) emissions by using carbon dioxide gas to treat waste materials and form artificial aggregate. In January 2013, C8S completed the first commercial plant for treating municipal solid waste incinerator (MSWI) fly ashes, designed to produce 1,000 tonnes per day of aggregate. Masonry products company Lignacite has also benefited commercially. It has used C8S's aggregate to develop an award-winning building block that captures more carbon dioxide than is emitted during its manufacture. Carbon8 Systems and its offshoot company Carbon8 Aggregates currently employ 11 people.

2. Underpinning research

Accelerated Carbonation Technology (ACT) was originally developed by Dr Colin Hills of the University of Greenwich as a land remediation process to encapsulate toxic metals as carbonates within cement matrices. It was designed to use "bottled" CO_2, provided in cylinders in mobile units at land remediation sites. Professor Simons (UCL 1993-present, Professor of Chemical Engineering since 2002), who has expertise in solids handling and particle technology and who founded the Centre for CO_2 Technology in 1998, was approached by Dr Hills in 2002 and asked to help develop the process design for large-scale operation using flue-gas CO_2. Hills and Simons quickly realised the potential to sequester large quantities of CO_2 emitted from waste-producing industrial processes via the treatment of the waste using the said emissions. Together with Dr Paula Carey of the Centre for Contaminated Land Remediation at the University of Greenwich, they identified waste streams within the UK that potentially had the right chemical characteristics for treatment by this process. One major source of such waste was the increasing use of incineration to convert municipal solid waste (MSW) into energy, which process leaves behind a hazardous waste residue in the form of fly ash, or Air Pollution Control Residue (APCr). The resulting collaboration led to a major research grant under the Biffaward scheme for the use of ACT in treating municipal solid waste incinerator (MSWI) APCr [7]. Together with funding from an industrial consortium of waste management and construction aggregate companies, the work at UCL focused on determining the reaction mechanisms involved and the factors governing the reaction kinetics, never before determined and crucial for the design of any processing plant. Factors such as CO_2 concentration, water-to-solids ratio, reaction temperature (at atmospheric pressure), particle size distribution and reaction rate were optimised to provide the greatest extent of conversion of cementitious material to the carbonate form [1, 2]. The use of fluidisation as the reactor process was also investigated, although the fine ash particles rendered the system too cohesive [3, 4]. The University of Greenwich focused on the properties of the resulting treated material, in relation to its stability for the purposes of either disposal as a now non-hazardous material in landfill sites, or reuse as a construction aggregate [5].

MSWI APCrs were selected as focus for this research since they represent a growing disposal problem in the UK and Europe, where the amount of MSW diverted from landfill and sent to incinerators continues to grow exponentially. The research at UCL and University of Greenwich established ACT as an effective treatment method for APCrs, rendering the ashes non-hazardous and stable over long time periods. However, up until 2002, it was believed that high concentrations (i.e. 100%) of CO_2 were required to drive the carbonation reactions to a rapid conclusion; that is, to conclusion in under 15 minutes, rather than the days and months required for naturally occurring carbonation reactions slowed by the low concentration of CO_2 in the atmosphere. Simons' work at UCL revealed that this was not, in fact, the case, and that the optimum conditions for rapid – but almost complete – reaction depended not only on the concentration of the gas, but on the particle size of the waste being treated, as well as the water-to-solid ratio. As such, the optimum gas concentration was shown to be ~30%, more aligned to the concentrations found in typical coal-fired power station flues [6]. This crucial discovery provided the basis for the design of a continuous process using flue gas streams (further developed using prize money (see below) and

funding from the TSB [8]) and subsequent establishment of Carbon8 Systems. Founded in 2006 by Simons, Hills and Carey, Carbon8 Systems was set up to commercialise ACT as a waste treatment and CO_2 capture process. Simons is currently a non-executive director of the company.

3. References to the research

(i) Journal Publications

Quality of research best demonstrated by references [1], [2] and [6].

1. Fernández Bertos, M., Simons, S., Hills C.D. and Carey, P.J., (2004). A Review of Accelerated Carbonation Technology in the Treatment of Cement-based Materials and Sequestration of CO_2. *Journal of Hazardous Materials*, B112, 193-205. http://doi.org/fpbxd7
2. Fernández Bertos, M., Li, X., Simons, S.J.R., Hills, C.D. and Carey, P.J., (2004). Investigation of Accelerated Carbonation for the Stabilisation of MSW incinerator ashes and the Sequestration of CO_2, *Green Chem.*, 6, 428 – 436. http://doi.org/brkqx7
3. Scuzzarella, A., Simons, S.J.R., Hills, C. D. and Carey, P.J. (2005). Investigation on Assisted Fluidization of a Cohesive Powder, *Trans. IChemE, Part A, Chemical Engineering Research and Design*, vol. 83, issue A11, pp. 1319-1324. http://doi.org/bmfrfz
4. Scuzzarella, A., Fernandez Bertos, M., Simons, S.J.R., Hills, C. D. and Carey, P.J. (2006). Expansion of Cohesive Gas Fluidized Binary Solid Systems, *Powder Tech.*, 163, 18-22. DOI: http://doi.org/fh4jg7
5. Li X., Fernández Bertos M., Hills, C. D., Carey, P. J. and Simons, S. (2007). Accelerated carbonation of municipal solid waste incineration fly ashes, *Waste Management*, 27, 9, 1200-1206. http://doi.org/ddbc6n
6. Sun, J., Fernández Bertos, M. and Simons, S.J.R. (2008). Kinetic Study of Accelerated Carbonation of MSW Incinerator Air Pollution Control Residues for Sequestration of Flue Gas CO_2. Energy Environ. Sci., 1, 370 – 377. http://doi.org/bptb4n

(ii) Research Grants

7. Biffaward, "Artificial Aggregates from Waste and Recycled CO_2", 2002-2005, £370,000. In collaboration with University of Greenwich, Onyx, Millenium Chemicals and Tarmac.
8. Technology Strategy Board, "CarbATTACT: Carbon abatement through accelerated carbonation", 2009-2011, £150,000. Feasibility study under the Energy Generation and Supply: Carbon Abatement Technologies programme, in collaboration with Carbon8 Systems Ltd and BRE.

4. Details of the impact

Carbon8 Systems' (C8S) technology, Accelerated Carbonation, uses carbon dioxide gas to treat waste materials and form artificial aggregate. Within two years of its foundation in 2006, C8S had won several prestigious awards, culminating in its announcement as the **national winner of the 2008 Shell Springboard competition** [a]. Prize money from the latter was used to design and build a pilot-scale plant at a former landfill facility owned by Kent County Council. The closed site was suffering from degradation and associated subsidence and had limited loss in integrity of its clay-capping layer. The pilot plant combusted the landfill gas (mostly methane), normally collected and sent to a flare, to produce a CO_2-enriched gas stream that was then used to carbonate a variety of wastes, including biomass ash and ash from paper recycling, to manufacture engineering fill to assist in the restoration of the landfill site. Up to 20% carbon dioxide by weight can be captured in these wastes. Trials of the plant over a 6-month period successfully demonstrated that an integrated waste collection and treatment facility could be operated, supplied by the site's own waste gas. [b] The success of this project was such that C8S was invited, together with other low-carbon innovation companies, to No.10 Downing Street four days before the start of critical global climate change negotiations in Copenhagen in 2009. At the time, Prime Minister Gordon Brown said: "Our transition to a low carbon economy will be a key driver of our future economic prosperity. Carbon8 Systems…are at the forefront of this transformation. Their innovation and expertise demonstrates why the UK is one of best places in the world for low carbon business." [c] Carbonation is now recognised as a potential option for CO_2 sequestration by the Intergovernmental Panel on Climate Change (IPCC), the world's foremost body advising on climate change science.

In 2009/10 the results of the TSB project were used to optimise the landfill gas pilot plant, which was then showcased in collaboration with Kent County Council and the Environment Agency in September 2010 to a group of invited industrialists, including waste management problem holders and waste management solution providers, such as Aylesford Paper, Shell and SITA [d]. This has led to exploratory studies by C8S on other waste forms, such as oil-drill cuttings, and on-going negotiations with waste-to-energy and waste management companies, all of which are at a commercially sensitive stage and cannot be detailed here. However, it is clear that, due to government and EU regulations on the management and disposal of wastes, there is a great deal of interest in C8S's technology as a means of mitigating costs and adding value to waste streams.

The success of the landfill gas project allowed C8S to leverage an initial equity investment of £120,000 from high-net-worth individuals, and **a second company, Carbon8 Aggregates (C8A), was formed in early 2010** to focus on the commercial opportunities arising from the production of aggregates from such wastes. This company went on to build a larger-scale plant at Grundon Waste Management's site in Brandon, Suffolk and successfully produced – to the manufacturer's specifications – 500 tonnes of aggregate from MSWI APCrs for use as raw material by Lignacite, a major UK block manufacturer. This led, in turn, to **investment in C8A in 2012 by Grundon Waste Management, with the sole purpose of commercialising ACT for the treatment of MSWI APCrs** [e] This second-round investment, which consisted of cash, in-kind support and a bank guarantee, allowed the construction of the first full-scale commercial plant, which was built at the Lignacite block plant in Suffolk in January 2012. The plant, which employs shift teams of three plus the site manager, was designed to process 18,000 tonnes per year, providing Lignacite with 36,000 tonnes of aggregate: processing capacity has since gradually risen to nearly 400 tonnes per month. C8A is currently writing a specification for plants two and three, which are likely to be built within the next six to nine months. The success of the trials and the quality of the product convinced **Lignacite to invest into 50% of Carbon8 Aggregates** [f].

The Environment Agency Modernising Waste Panel confirmed in 2012 that the output from the process meets its End of Waste criteria, which specify when a certain waste ceases to be waste and obtains a status of a product (or a secondary raw material). All companies dealing with waste management are governed under these criteria. For Carbon8 Aggregates, it means that the treated APCRs can be used as an aggregate product, for example in block making. Facilities using this technology are now being developed across the UK, generating a secondary, recycled aggregate – which is carbon negative – to replace land- and sea-won materials. Using the carbonated, recycled material allows **manufacturers to avoid the tax of £2.00 per tonne levied by the UK government on these natural aggregates** whilst making a meaningful contribution to the country's **effective and environmentally sound disposal of CO_2 waste**: blocks produced from the fly ash of waste incinerators encapsulate 14kg of carbon dioxide per tonne.

In May 2013, **Lignacite launched its "Carbon Buster" block, made up of more than 50% recycled material, including the C8A pellets** [g]. In the UK Carbon Buster customers, mainly construction companies, gain credits under the environment assessment schemes of BRE Environmental Assessment Method (BREEAM) and the Code for Sustainable Homes for using Carbon Buster blocks, which enables them to construct homes with attractive sustainability ratings. In July 2013 the **product won the Best Recycled Product award** at the 2013 National Recycling Awards held at the London Hilton in Park Lane [h]. C8S has begun discussions with a number of companies in Australia to market ACT in Australasia, where a patent applies. **The total number of employees of both C8S and C8A currently stands at 11** [i]

In addition to the environmental compliance benefits outlined above, their launch of the **world's first ever carbon-negative building block** brought Lignacite - as well as C8S and C8A - positive media coverage from around the world [j]. The C8S and C8A teams' **contributions to media discourse** about this development not only helped to enhance their own and their commercial partners' standing, but also **enhanced awareness of and engagement with important environmental issues relating to the research among an international public audience**.

The research on APCr has, moreover, had further non-academic **impacts on UK policy**, leading to the **incorporation in 2011 of a recycling option into Defra's guidance on the management of APCr**, in relation to the requirement for UK companies to reduce their waste streams as much as possible to meet the EU's Waste Framework Directive [k]. This change has moved APCr up the waste hierarchy, which sets out the various stages to waste minimisation, from recovery of value from wastes to the prevention of the formation of waste in the first place. Recycling is halfway up the hierarchy. Also in 2012, the Environment Agency removed the Waste Acceptance Criteria derogation allowing APCr to go to landfill from around 2015, since they believe that there are now viable alternatives due to the research and development carried out by Simons and C8S. **C8S can provide Energy from Waste (EfW) plants with a true zero waste to landfill option**, which helps with planning applications. The EfW industry in the UK is currently worth around 6 billion GBP, which is expected to rise to 30 billion GBP in the next 10 years. Hence, C8A has provided a number of letters of support for companies making new planning applications for EfWs.

5. Sources to corroborate the impact

[a] Carbon 8 Systems award of 2008 Shell Springboard prize: http://www.shellspringboard.org/alumni/2008

[b] For information on the success of the CarbATTACT project, contact the Hi Consulting consultant for the Technology Strategy Board. Contact details provided separately.

[c] Carbon8 invited to showcase low-carbon innovation at number 10, 2009, http://www.c8s.co.uk/news.php?nid=25

[d] For information on the North Farm pilot-plant trials, contact Kent County Council's Planning and Environment Manager. Contact details provided separately.

[e] For information on the world's first Air Pollution Control residues (APCr) recycling and carbon-capture, contact Grundon's Technical Director. Contact details provided separately.

[f] For information on the manufacture of "Carbon Buster" blocks, contact the Managing Director at Lignacite Ltd. Contact details provided separately.

[g] For the composition of the Lignacite block, see http://www.lignacite.co.uk/products/carbon-buster/carbon-buster-detail.

[h] Carbon Buster's Best Recycled Product award: http://www.nationalrecyclingawards.com/nationalrecyclingawards.

[i] For information on company structure, relationship with Carbon8 Aggregates, and C8S's zero waste to landfill option, contact the Managing Director at Carbon8 Systems Ltd. Contact details provided separately.

[j] For an example of international media coverage of the Carbon Buster block: http://www.aggregateresearch.com/articles/28317/Lignacite-launch-worlds-first-carbon-negative-block.aspx

[k] For Defra's inclusion of recycling of APCr in its guidelines, see p.25 "Guidance on applying the waste hierarchy to hazardous waste", https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69457/pb13687-hazardous-waste-hierarchy-111202.pdf