Institution: University of Greenwich

Unit of Assessment: (UoA 8) – Chemistry

Title of case study: Treating waste with carbon dioxide

1. Summary of the impact

Accelerated Carbonation Technology (ACT) is an innovative solution to several key environmental issues - CO_2 emissions to the atmosphere, sustainable use of resources and the reliance on use of virgin stone for construction. ACT rapidly stabilises industrial waste recycling it into valuable aggregate, thereby reducing the amount going to landfill. ACT simultaneously captures the greenhouse gas CO_2, via the rapid production of carbonate, which solidifies the waste into a hardened product. ACT has been commercialised through two spin-out companies leading to the first commercial production of carbon negative concrete blocks, taking hazardous waste from the bottom to the top of the waste hierarchy.

2. Underpinning research

Government regulations have encouraged both the diversion of waste from landfill and the development of alternative aggregate sources. These include the EU Landfill Directive 2004, requiring hazardous wastes to be treated before disposal to landfill, Waste Acceptance Criteria; the UK Landfill Tax escalator, and Aggregate Levy on the extraction of primary aggregates. The European Union Emissions Trading Scheme 2005 has focused attention on ways of managing emissions, including geological carbon capture and storage. New technologies that can redirect hazardous air pollution control residues (APCRs) into inert products with commercial value, using the carbon emitted in their production – the closing of the 'loop' -therefore have an important place in the market.

Dr Colin Hills, Director of the Centre for Contaminated Land Remediation at the University of Greenwich, showed that certain contaminants inhibit the hardening of cements used to stabilise and solidify contaminated soil and waste but that this retardation can be overcome by exposure to CO_2 gas. The 'accelerated carbonation' reaction produces solid carbonates rapidly in contrast to the slow development of 'normal' hydrated phases. Having shown that the carbon dioxide concentration and water-to-solid ratio (w/s) were important he patented Accelerated Carbonation Technology (ACT). Hills saw the opportunity to sequester significant quantities of CO_2 into solid waste streams, thereby minimising industrial emissions. The major advance he made was the discovery that the 100% CO_2 atmosphere thought necessary to drive carbonation reactions to a rapid conclusion – under 15 minutes, rather than the weeks or months required for natural carbonation – was erroneous [unpublished work, due to IP considerations]. He established that lower gas concentrations as found in flue gases, are often optimal for a rapid, substantially complete reaction, and that optimal conditions also depend on the particle size distribution of the waste and w/s ratio.

Following these and other advances in waste processing, the spin-out company **Carbon8 Systems (C8S)** was established in 2006 to commercialise both ACT as a waste treatment step and the CO_2 capture process. **Carbon8 Aggregates (C8A)** was founded in 2010 specifically to commercialise the engineering applications of the technology to UK-derived APCR.

The first major grant, which was to research the use of ACT to treat Municipal Solid Waste (MSW) APCRs, was received in 2002. Supported with additional industrial funding, Hills examined the properties of carbonated APCRs: their physical and chemical stability, including leaching properties; and suitability either for disposal, at non-hazardous landfill sites, or for re-use as an aggregate in construction. The research investigated a number of UK APCRs with varying physical and chemical characteristics, and defined the key characteristics affecting the efficacy of carbonation and product properties. It was quickly established that ACT is an effective treatment method, which renders the APCRs non-hazardous and stable over long time periods. Following substantial grant income from TSB, KTP and others, the most recent award to Hills (€860,000) is to evaluate French and UK waste streams for incorporation in new sustainable building materials.

3. References to the research (REF1 submitted staff in **bold,** **REF2 Outputs) *Joint UCL/UoG doctoral student.

3.1 Fernández Bertos, M.*, Simons, S. J. R., **Hills, C. D.**, & 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://dx.doi.org/10.1016/j.jhazmat.2004.04.019

3.2 Fernández Bertos, M.*, Li, X., Simons, S. J. R., **Hills, C. D**., & Carey, P. J. (2004). Investigation of accelerated carbonation for the stabilisation of MSW incinerator ashes and the sequestration of CO_2. *Green Chemistry*, *6*, 428–436. http://dx.doi.org/10.1039/B401872A

3.3 Scuzzarella, A., Simons, S.J.R., **Hills, C. D.,** & Carey, P.J. (2005). Investigation on Assisted Fluidization of a Cohesive Powder, *Trans. IChemE, Part A, Chemical Engineering Research and Design, 83(A11)*, 1319-1324. http://dx.doi.org/10.1205/cherd.05098

3.4 Scuzzarella, A., Fernandez Bertos, M*., Simons, S. J. R., **Hills, C. D.,** & Carey, P. J. (2006). Expansion of Cohesive Gas Fluidized Binary Solid Systems, *Powder Tech.*, *163*, 18-22. http://dx.doi.org/10.1016/j.powtec.2006.01.002

3.5 Li X., Fernández Bertos M***, Hills, C. D.,** Carey, P. J.**,** & Simons, S. J. R. (2007). Accelerated carbonation of municipal solid waste incineration fly ashes, *Waste Management*, *27*, 1200-6. http://dx.doi.org/10.1016/j.wasman.2006.06.011

3.6 Gunning, P., **Hills, C. D., & Carey, P. J. (2009) Production of Lightweight Aggregates from Waste and Carbon Dioxide. *Waste Management*, *29(10),* 2722-2728. http://dx.doi.org/10.1016/j.wasman.2009.05.021

Example Research Grants

1. C. D. Hills. *Artificial Aggregates from Waste and Recycled CO_2.* Grant Ref. B197. Biffaward. 2002-2005. £370,000. In collaboration with UCL, Onyx, Millennium Chemicals and Tarmac.
2. P.Carey. *CarbATTACT: Carbon abatement through accelerated carbonation*. Grant Ref. 130028 [PPBR007H] Technology Strategy Board, Energy Generation and Supply: Carbon Abatement Technologies Programme. 2009-2011. £150,000. Collaboration with Carbon8 Systems Ltd and BRE.
3. C. D. Hills. *To develop a novel accelerated carbonation process for the treatment of ashes from paper recycling and municipal waste incineration.* Grant Ref. KTP0006243. Technology Strategy Board, Knowledge Transfer Partnership. 2007-2010. £104,508.
4. A. Maries. *Feasibility study*. Grant Ref. BT223L. Technology Strategy Board, Energy Generation and Supply: Carbon Abatement Technologies Programme. 2009-2010. £32,000. In collaboration with Carbon8 Systems Ltd and MIRO (Greenwich, sub-contractor to C8S).
5. C. D. Hills. *Sustainable Aggregate Production with Imbibed Carbon Dioxide (SAPICO2).* Grant Ref. 4188. INTERREG IVA (Channel). 2013-2015. €860,000.

4. Details of the impact

Accelerated Carbonation Technology (ACT) is a single, elegant and powerful solution to a lot of serious environmental threats - CO_2 emissions, reliance on sending waste to landfill, extraction of virgin stone for construction, and managing the impact of emissions on the environment.

Colin Hills and the University of Greenwich proved that ACT is a cost effective technology, which can help organisations meet their responsibilities, through its commercialisation with spin-out company **Carbon8 Systems (C8S)**. Now they have taken hazardous residues from the bottom of the waste hierarchy to the top by commercialising ACT's application to UK-derived APCR to produce building materials, via spin-out company **Carbon8 Aggregates (C8A)**. By 2012 **C8A** had commissioned the world's first commercial plant using ACT to produce aggregate from APCR in Brandon, Suffolk, at a cost of £1M [5.1]. Today the plant is producing 32,000 tonnes of carbonated aggregate (C8Agg) per year, which block manufacturer Lignacite turns into the world's first carbon negative concrete blocks with values as low as -40 kg CO_2/ tonne of product. The way is now open to apply ACT to many other waste streams, including contaminated soil.

ACT delivers five main benefits by:

- reducing the risks associated with hazardous waste and contaminated soil

- capturing and stores significant volumes of greenhouse gas CO_2
- recycling waste into a valuable aggregate
- reducing waste going to landfill
- producing aggregates in minutes rather than months, making the process commercially viable.

The CO_2 used in ACT comes from industrial processes, thereby recycling gas, which would otherwise pollute the atmosphere. However to date it has been supplied in tankers from a sugar beet manufacturing plant. C8A is now working with key UK waste management companies to 'close the loop' by using the actual CO_2 produced by the incineration of municipal solid waste (MSW) that also produces the APCRs: thus the gaseous and solid wastes are valorised simultaneously. This is a perfectly sustainable method for managing the 185,000 tonnes of MSW APCRs produced in the UK every year; if adopted it would offset the CO_2 produced by 10,000 cars.

Two more ACT plants will be built in 2014 and another is in planning, increasing production capacity to >100,000 tonnes by the end of 2014. UK incinerator operators have included ACT treatment of APCRs in tenders for new-build MSW incinerators, allowing them to demonstrate improved sustainability credentials (zero landfill) and lower costs. **C8S** has also identified potential for simultaneous valorisation of other key waste streams.

C8S developed the technology to optimise the continuous treatment of ashes through strategic partnerships with Viridor Waste Management, Kent County Council and the Environment Agency, together with funding from Knowledge Transfer Partnership (KTP) and the Technology Strategy Board. As a result a new company **C8A** was formed to treat Air Pollution Control Residues (APCr) and a commercial-scale plant was built in 2010 at Brandon in Suffolk. More than 200T of aggregate was made and tested by two major UK block manufacturers. It was this proof of concept that led to the UK's largest independent waste management company, Grundon, investing in C8A. Grundon were looking for an alternative to the landfill disposal of APCRs.

The significance of ACT was quickly recognised. **C8S** won several prestigious awards in quick succession including the 2008 national *Shell Springboard* competition, established to identify the UK's next 'big idea' in low carbon enterprise and innovation. The *Shell* prize money helped paid for a pilot-scale facility to treat waste at a Kent County Council landfill site in 2010 using the CO_2 generated by the site itself. The C8S team, were invited to No.10 Downing Street four days before critical global climate change negotiations in Copenhagen in 2009. 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." [5.3]. C8S has also been one of UK Trade & Investment's (UKTI) case studies for UK low carbon innovation.

Overseas potential for ACT appears significant and, with UKTI support, discussions are on-going to market ACT in Australasia. Other overseas markets including Europe and Canada are also being explored. C8S is partnering Canadian low carbon company, CarbonCure Technologies, in a submission to the $35M Alberta Grand (Carbon) Challenge 2013, and has successfully completed the first-round of the application process. C8A's aggregate was recognised Best Recycled Product at the 2013 UK National Recycling Awards.

5. Sources to corroborate the impact

Prizes and awards for Carbon8 Systems Ltd.:

Dates	Detail of prize or award	Awarding/electing body
2006	Kent Innovative Climate Change Technology Award	Kent County Council
2006	Kent Environment Business of the Year, 2006	Kent County Council
2006	IChemE Green Technology Award (Chemistry Innovation)	IChemE
2007	Winner, Kent Innovation Challenge	Kent County Council
2008	National winner (and winner of South-East final), Shell Springboard	Shell plc
2008	Times Higher Education Award for Outstanding Contribution to Innovation and Technology	Times HE

2013	Best Recycled Product (*for* C8Agg)	National Recycling Awards
2013	CIWM, Murphy Innovative Practice SME Award Winner	Chartered Institution of Wastes Management

Press releases

1. www.agg-net.com/news/lignacite-launch-world-s-first-carbon-negative-block?source=search&highlight=lignacite
2. www.agg-net.com/news/carbon8-achieve-a-world-first
3. http://www.theargus.co.uk/news/4793103.print/
4. http://www.agg-net.com/news/lignacite-launch-world-s-first-carbon-negative-block
5. http://www.mrw.co.uk/best-recycled-product-carbon8-aggregates/8650293.article

Reports:

- A reference to ACT and the work at UCL was made in the Intergovernmental Panel on Climate Change (IPCC) Special Report on "Carbon Dioxide Capture & Storage", 2005. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml
- Technology Strategy Board "Collaboration nation; Carbon abatement feasibility studies", 2008. http://www.innovateuk.org/publications/competition-and-project-documents.ashx
- Technology Strategy Board "Energy Portfolio, 2009/10. http://www.innovateuk.org/publications/competition-and-project-documents.ashx

Selected national press articles:

http://www.telegraph.co.uk/finance/2789256/Bringing-waste-not-want-not-to-life.html;
http://www.thesundaytimes.co.uk/sto/business/energy_and_environment/article347620.ece

Organisations who could corroborate claims:

Carbon8 Systems Ltd.

Shell Springboard, http://www.shellspringboard.org/home/

Kent County Council.

IChemE.

Grundon Waste Management Ltd.