Institution: University of Cambridge		
Unit of Assessment: 8		
Title of case study: Supramolecular encapsulation technology		
Period when the underpinning research was undertaken: 2010–2013		
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:**
Professor Chris Abell	Professor of Biological Chemistry	1984-2020
Professor Oren Scherman	Professor of Supramolecular and Polymer Chemistry	2006-present
Period when the claimed impact occurred: 01/08/2013–31/07/2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Research in the Department of Chemistry, at the University of Cambridge, into supramolecular assembly of microcapsules using cucurbiturils led to the spin-out company Aqdot. Aqdot has developed a range of products based on the cucurbituril encapsulation technology. Oderase is a unique odour-erasing household product sold by Ocado, and Acticote is an agrochemical product used throughout Europe to increase crop yield. Aqdot currently [text redacted for publication] employs 26 staff. The technology has been scaled up to multi-tonne capability for incorporation into plastics, sanitary, air purification, cosmetics and food products.

2. Underpinning research

The early proof-of-concept experiments on microcapsule self-assembly that led to the spin-out company Aqdot took place in the Department of Chemistry at the University of Cambridge in laboratories led by Professor Oren Scherman and Professor Chris Abell. The Scherman group has a long-standing interest in supramolecular polymer chemistry. The Abell group is interested in the development of new applications of microfluidics in chemistry, biology and materials science.

Microcapsules. In 2010, there was a growing interest in synthetic microcapsules, because bespoke design of the size, shell structure and core contents would allow tailoring to specific applications, such as drug delivery, cell encapsulation or food additives. However, the existing methods, such as the layer-by-layer technique or colloidal emulsion-templating, suffered from poor stability, encapsulation and loading efficiencies, as well as heterogeneity in microcapsule composition and dispersion. Hence the industry faced a challenge in achieving efficient, scalable production of microcapsules with uncompromised functionality.

The supramolecular approach. Professor Scherman had been studying the formation of termolecular complexes between a macrocyclic host (cucurbituril or CB[8]) and two guests, methyl viologen and naphthalene. Together with the Abell laboratory, they showed that it was possible to use CB[8] at an oil-water interface to form cross-linked networks between gold nanoparticles functionalised with methyl viologen and polymers functionalised with naphthalene. This system provided the basis for a one-step approach to generate porous microcapsules with customisable functionality by implementing the host–guest chemistry in microfluidic droplets.[R1] The supramolecular approach offered opportunities for variation in properties through selection of different host–guest combinations, and chemical reduction of the methyl viologen guest could provide the on-demand release of cargo. Moreover, the capsules were stable, heat resistant and highly monodisperse (60 μm diameter). In 2012, the scope of the approach was expanded further by fabricating supramolecular polymer microcapsules without the need for gold nanoparticles, instead relying on self-assembly driven by electrostatic interactions.[R2] Subsequently, the hierarchical assembly of amphiphilic copolymers on the molecular, submicron and micron scale was realised, allowing the formation of hollow, uniformly-sized supramolecular microcapsules. These microcapsules could be loaded with two different incompatible cargoes,

i.e. a hydrophilic and a hydrophobic compound, and the contents could be released in controlled manner.[R3]

Exploitation. Realising the potential of their discoveries, Professors Abell and Scherman patented the key technology.[R4–R6] In 2012, they founded Aqdot Limited to exploit the new supramolecular approach to microcapsule fabrication. The Chief Scientific Officer is Dr Roger Coulston, the post-doctoral research associate who worked in the Scherman group on the project, and the Marketing Director is Dr Jing Zhang, the PhD student who worked in Abell lab on the project.

3. References to the research

R1. Zhang, J.; Coulston, R. J.; Jones, S. T.; Geng, J.; Scherman, O. A.; Abell, C. One-Step Fabrication of Supramolecular Microcapsules from Microfluidic Droplets. *Science* **2012**, *335*, 690-694.

R2. Parker, R. M.; Zhang, J.; Zheng, Y.; Coulston, R. J.; Smith, C. A.; Salmon, A. R.; Yu, Z.; Scherman, O. A.; Abell, C. Electrostatically Directed Self-Assembly of Ultrathin Supramolecular Polymer Microcapsules. *Adv. Funct. Mater.* **2015**, *25*, 4091-4100.

R3. Yu, Z. Y.; Zheng, Y.; Parker, R. M.; Lan, Y.; Wu, Y.; Coulston, R. J.; Zhang, J.; Scherman, O. A.; Abell, C. Microfluidic Droplet-Facilitated Hierarchical Assembly for Dual Cargo Loading and Synergistic Delivery. *ACS Appl. Mater. Interfaces* **2016**, *8*, 8811–8820.

R4. Scherman, O. A.; Coulston, R.; Abell, C.; Zhang, J. Supramolecular Capsules. US9439868 (B2), 2016.

R5. Zhang, J.; Coulston, R.; Parker, R.; Abell, C.; Scherman, O.; Yu, Z. Nested Supramolecular Capsules. US2015/0368407 (A1), 2015.

R6. Rauwald, U.; Scherman, O. A. Supramolecular Handcuffs in Polymeric Architecture. US2010/0247477 (A1), 2010.

Research published in peer-reviewed journals.

4. Details of the impact

Aqdot Limited. The company was spun out as a platform technology company to develop commercial opportunities using the supramolecular microcapsules developed in the Abell and Scherman laboratories for applications in the food, cosmetics, textile, pharmaceuticals and agrochemical industries.[E1] In 2018, the global microencapsulation market size was valued at USD7,880,000,000 with an annual growth rate of 13.7%,[E2] so Aqdot's novel approach to microencapsulation led to three successful rounds of venture capital funding, raising GBP2,550,000 in 2014, GBP5,000,000 in 2016, and GBP6,000,000 in 2019.[E3] Due to the potential environmental benefit of the technology, Aqdot has also received substantial support from Climate-KIC, the EU's main climate innovation initiative.[E3] The company is currently located at Iconix Park in Cambridge, [text redacted for publication], and employs 26 staff.[E4] Aqdot has grown into a unique supramolecular chemistry company with a focus on developing, licensing and selling novel proprietary products based on cucurbituril encapsulation technology across multiple industrial sectors. Professors Scherman and Abell are both members of the Scientific Advisory Board, which is chaired by Abell.[E1]

AqBit encapsulation technology. Aqdot is working in partnership with a number of companies to develop bespoke applications of their cucurbituril encapsulation technology, which they have branded AqBit. The key component of AqBit is currently manufactured on the multi-tonne scale by Aqdot. AqBit completed REACH registration without hazard labelling or environmental classification and has achieved a platinum level Material Health Certificate, which is the highest possible certification level under the Cradle to Cradle Certified product standards framework.[E5] The assessment is based on chemical hazard identification and qualitative exposure considerations during manufacture, use, and end-of-use. Cradle to Cradle certification guarantees that a material does not contain carcinogens, mutagens, reproductive toxicants,

volatile organic compounds, or other harmful substances, and is therefore safe to use in a wide range of applications.

AqFresh is a product developed in collaboration with a leading aerospace air filtration company. AqBit technology provides a new solution for cabin air quality by capturing odour molecules and other volatile organic compounds that cannot be removed using current filter technologies.[E6]

AqHealth is another product currently being developed with one of the world's leading pharmaceutical companies using AqBit for delivery of therapeutics for cancer.[E7]

Oderase. Aqdot has also launched its own branded products. Oderase is a fragrance-free air freshener, which contains the AqBit technology and is available to consumers from Ocado.[E8] Oderase works through encapsulation of volatile organic compounds within cucurbiturils, and the difference between traditional air fresheners is that Oderase does not contain any fragrances or come in a pressurised aerosol, which has led to approval by Allergy UK and Good Housekeeping Institute.[E6] Oderase has also achieved platinum level Cradle to Cradle Certification.[E9]

Tommee Tippee® nappy odour neutralising spray. In 2020, Aqdot announced a major partnership with Mayborn Group, owner of the global baby brand Tommee Tippee. They have used AqBit to develop an odour neutralising product, which is being sold as a hand held spray as well as for use alongside the Tommee Tippee Twist & Click nappy disposal system, the current market leader in nappy bins.[E10]

AqStar M1. The use of cucurbituril-mediated assembly of natural amphiphilic copolymers was commercialised by Aqdot as AqStar M1 in 2018. AqStar M1 is a cosmetic emulsifier that uses AqBit soft cross-linking technology to boost the performance of natural starch with flexibility to create a wide variety of natural skin-care formulations with distinctive aesthetics. AqStar M1 is currently distributed in the EU by Grolman and in the US by ChemSpec. Although AqStar M1 was only launched in 2018, it has already reached the consumer market.[E11]

Acticote. The product developed for the agrochemical market is Acticote, which is an adjuvant pod sealant for oilseed rape. Rape is the major EU oilseed crop (17.5 megatonnes per annum worth USD15,000,000,000), and the oil is widely used in the food industry, and to produce biodiesel. Acticote gives 18% yield increase in oilseed rape by reducing the incidence of pod shatter, and is currently being distributed throughout the EU by Intracrop.[E7,E12]

5. Sources to corroborate the impact

[E1] Aqdot – Company website 14.08.2019. "Our Business – Our People – Our Investors"
[E2] Grand View Research - Microencapsulation Market 03.2019. "Microencapsulation Market Size, Share & Trends Analysis Report By Technology (Emulsion, Spray), By Application (Pharmaceutical, Home & Personal Care), By Coating Material, And Segment Forecasts, 2019 - 2025"
[E3] Cambridge Enterprise - Imperial Innovations, Cambridge Enterprise and Climate-KIC Investment 17.12.2014. "Aqdot closes £2.55m funding round". Financial Times – Series A Funding Round 08.02.2016. "Innovations leads £5m Series A round in Aqdot". IP group - Series B Funding Round 10.04.2019. "Aqdot Ltd - Aqdot Completes Series B to Accelerate Product Launches" (pp. 1, 3 and 8)
[E4] Letter from CSO of Aqdot 20.02.20
[E5] Cradle to Cradle – AqBit Certification 12.2018. "Material Health Certificate"
[E6] Aqdot – AqFresh Air and Oderase 15.08.2019. "Air Quality Solutions"
[E7] Aqdot – AqHealth and Acticote 15.08.2019. "Life Science Solutions"
[E8] Oderase – Product Website 21.08.2019. "Oderase"
[E9] Cradle to Cradle – Oderase Certification 10.2018. "Material Health Certificate"
[E10] Business Weekly – Mayborn Group Partnership 24.01.2020. "Nappy return as Aqdot scents success with Tommee Tippee deal"
[E11] AqStar M1 product and distributor information.

[E12] Advanced Crop Pod Sealing – Aqdot.