Institution: University of Glasgow (UofG)		
Unit of Assessment: UoA 9 Physics		
Title of case study: Using plasma technology to extend food shelf-life and for safe, powerful decontamination		
Period when the underpinning research was undertaken: 2004–present		
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 Declan Diver Dr Hugh Potts	Professor of Plasma Physics Research Associate; Research Fellow; CTO, Anacail Ltd	2004–present 2008–2011; 2011–2015; 2015–2019
Period when the claimed impact occurred: 2009–present		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Ozone is a practical, safe biocide that has presented technological challenges in its effective and safe production. UofG research developed a novel production solution for generating ozone inside pre-sealed packages, which was spun-out in 2011 into dedicated business Anacail, focusing on food decontamination, and in 2020 into its successor company Glanadair, focusing on medical device and environmental decontamination. Since 2014, Anacail has improved the shelf-life of >1 million packages of soft fruit by ~50%, reducing the amount of food typically wasted by >30%. Glanadair has used the same technology to decontaminate medical devices and pathogen-harbouring drains/surfaces more effectively than existing gold-standard techniques. Collectively, societal impacts include improved food quality, reduced wastage, and effective suppression of cross-infection, reducing dependence on toxic sterilisation chemicals.

2. Underpinning research

The significance of ozone

Ozone is a natural biocide, which can kill bacteria, fungi and viruses, and it is used in a variety of industrial processes. However, the hazard it presents to operators has severely restricted the practical harnessing of ozone's commercial potential — until now. Research at UofG has successfully developed a novel, practical and low-energy means of ozone generation inside pre-sealed packages via an external monolithic electrode, without compromising seal integrity. This was used to produce ozone for commercial biocidal applications across several sectors by the UofG spin-out company Anacail.

Experimentation to create ozone

Prototype electrode showing patented spiral conduction elements and vacuum drainage

Diver and Potts explored the creation of partially ionized atmospheres consistent with the Solar surface [3.1−3.4]. To facilitate this study, a laboratory device capable of replicating photospheric ionization levels (in air) was constructed, which could be modulated at acoustic frequencies to explore the sensitivity of reaction rates to voltage and pressure modulations. The underpinning science uses a dielectric barrier discharge which seeds the air with free electrons that can bind to oxygen − perfect for the air within sealed packs [3.5]. The negative oxygen ion that is produced can then combine with oxygen molecules, forming ozone in a low-energy pathway [3.6]. A key inventive step was the recognition, confirmed by expertise in electric field modelling from astrophysical plasma research, that a unique monolithic electrode design (pictured, showing plasma glow) that combined short-range electric field fringing in conjunction with vacuum suction allowed ionizing fields to penetrate thin packaging layers in contact with the electrodes, allowing only the air inside sealed packages to be seeded with ozone (and with no external ozone generation): this formed a key part of the patented system [5.5].

With encouragement from potential investors IP Group, Potts and Diver secured definitive evidence of efficacy and practical potential via an STFC Follow-on Fund grant (ST/H00274X/1).

This enabled testing of food shelf-life extension at the Campden BRI food testing laboratories, and the favourable result triggered the company spin-out (2011) and the first of several venture capital injections: our major investors, IP Group, Scottish Investment Bank & Sussex Place Ventures, injected GBP6 million in total equity in 3 stages, allowing Anacail to expand to employ 12 engineers and scientists across two manufacturing sites (HQ and a test lab).

Anacail subsequently secured multiple Innovate UK grants (alone and in partnership with industry and academia) over the next 6 years, demonstrating not just food shelf-life extension and waste reduction, but also biofilm destruction and device sterilization in healthcare contexts, summarised as follows (with independent verification information supplied where appropriate [5.7]):

1. Spoilage reduction in packaged fruit (verified by producer/retailer labs, including Campden BRI).
2. Medical device decontamination. Results (Andersen Caledonia) showed reduction of bacterial load on endoscopes by 9 orders of magnitude.
3. Drain decontamination (including factory floor drains and hospital drains at the Queen Elizabeth Hospital Isolation Unit), killing >99.9% of pathogens. Laboratory research (University of Glasgow Dental School) has shown that Anacail's device can inactivate the bioburden contained in the biofilms coating inaccessible surfaces.
4. Decontamination of samples infected with a range of pathogens including viruses, bacteria and fungi (verified by two independent accredited medical microbiological testing labs – BluTest Laboratories and Andersen Caledonia).

3. References to the research

3.1 Potts, H.E., Khan, J. and Diver, D. (2007) Small scale energy release driven by supergranular flows on the quiet Sun. *Solar Physics*, 245(1), pp. 55–68. (doi:10.1007/s11207-007-9021-7)

3.2 Diver, D.A., Potts, H.E. and Teodoro, L.F.A. (2006) Gas-plasma compressional wave coupling by momentum transfer. *New Journal of Physics*, 8(11), pp. 265–279. (doi:10.1088/1367-2630/8/11/265) *

3.3 Diver, D.A., Fletcher, L. and Potts, H.E. (2005) FIP enhancement by Alfven ionization. *Solar Physics*, 227(2), pp. 207−215.(doi:10.1007/s11207-005-2447-x)

3.4 Potts, H.E., Barrett, R.K. and Diver, D.A. (2004) Balltracking: a highly efficient method for tracking flow fields. *Astronomy and Astrophysics*, 424(1), pp. 253−262. (doi:10.1051/0004-6361:20035891) *

3.5 Potts, H.E., Diver, D.A., Everest, P.C. and O'Connor, R.D. (2011) Plasma Decontamination of Sealed Packages. In: 30th International Conference on Phenomena in Ionized Gases (ICPIG 2011), Belfast, UK, 28 Aug−02 Sep 2011. http://eprints.gla.ac.uk/234079/

Best indicators of research quality indicated with *

Grant Funding: Innovate UK awarded 9 grants to Anacail 2012−2018, total value GBP952,000

4. Details of the impact

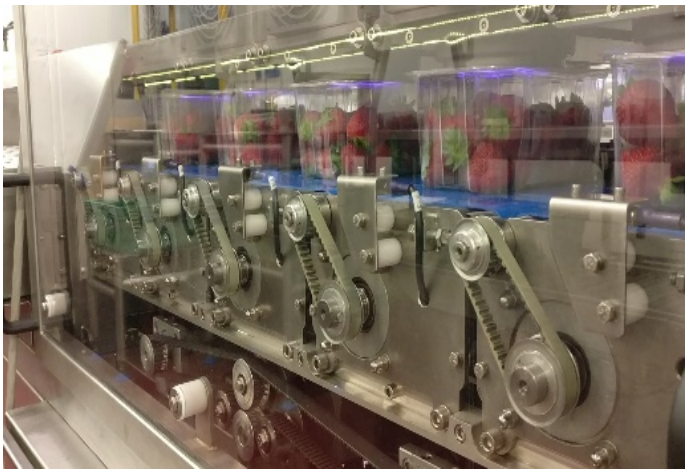
UofG plasma research impact via Anacail spans economic, technological policy and societal aspects. Applications include the food process industries and applications in surgical decontamination and environmental hygiene.

The economic impacts of this technology include:

(1) creating high-value employment in Anacail (12 jobs) and associated subcontractors
(2) reducing food spoilage and waste, extending shelf-life, maintaining food quality
(3) generating new activity across the UK manufacturing sector producing scalable, production-line ready technology

Food Processing

Food spoilage from bacteria and mould is a major problem for fresh food, with high-value soft fruit being particularly vulnerable. Production-scale depot trials of Anacail's technology with supplier Berry Gardens involved plasma treatment of [text removed for publication] packs of fresh fruit, which were distributed through the leading UK supermarket, [text removed for publication]. Retail wastage was significantly reduced [text removed for publication] and food shelf life extended by typically an additional two days [text removed for publication] beyond the normal end-of-life sell-by date [5.1a]. Earlier trials [text removed for publication] showed an associated [text removed for publication] reduction in customer complaints [5.2]. Food quality is important to consumers, and by addressing shelf-life extension and reducing spoilage, Anacail's technology was identified as a means of reducing waste and greenhouse gas emissions [3.1].



Anacail 10-head 120 packs/minute machine in factory showing plasma glow in packaged fruit

Large-scale UK commercial success was evident from Anacail's exclusivity contract with Berry Gardens, who had 40% of the UK fresh fruit market (supplying retailers such as Tesco, Sainsbury, Asda, Waitrose, M&S). [text removed for publication]. Anacail established that the technology is scalable, production-line-capable at TRL9, and versatile. The first production-line machine was installed in Kent in November 2018.

These production-line machines were manufactured by Western Mechanical Handling UK Ltd (WMH), a family-owned company offering automation solutions to food and pharmaceutical companies around the world. Contracts for Anacail's production machines enabled WMH to expand its technical and engineering staff by five (from a base of 39) in the period 2017−2019, including development of an innovative pack-positioning system to address Anacail's requirements, but with wide-ranging cross-sector application [text removed for publication]. Anacail's manufacturing activity also benefited the supply chain in the UK e.g. specialist power supplies and electronics, bespoke steel casings and wiring looms; and highly-specialised electrode manufacture from Kyocera, Japan.

Technological Impacts

Anacail's plasma decontamination technology pioneered, in 2017, the safe use of ozone in retail packaged food manufacturing [5.4] consistent with the Food Standards Agency (FSA) in the UK. International patents have been granted in the UK, US, Russia, Japan, China, and Brazil, and 23 European countries [5.5, 5.6]. This technological breakthrough by Anacail has transformed the use of ozone across multiple sectors, including but not limited to food processing, decontamination of surgical equipment and environmental hygiene. The key innovative steps for the core patent are (i) spiral electrode formation behind a flat glass coating allowing very uniform plasma across

a large surface area (ii) incorporation of air drainage grooves and holes to ensure vacuum-tight suction of packaging to the electrode (iii) unique monolithic electrode design.

In 2018, Anacail sponsored (in conjunction with the James Hutton Institute) a 4-year CASE studentship at the Oxford Interdisciplinary Bioscience DTP (Prof Preston − Oxford; Dr Holden − James Hutton, Dr Crozier − Anacail) to determine the impact of ozone treatment on the microbiota of fresh produce. Anacail supplied ozone-generating equipment to support the student in addition to cash funding (GBP15,500) [5.7].

[text removed for publication]

Applications in surgical decontamination and environmental hygiene

UofG research enabled Anacail to develop two plasma decontamination devices, one for drain decontamination and the second for medical equipment. Drain hygiene is critical in environments such as hospitals, food factories and laboratories to reduce risk posed by pathogenic organisms. Anacail's novel drain decontamination system (TRL7) has proven, in both laboratory and site-based trials, to eliminate pathogens harmful to human health such as bacteria, mycobacteria, viruses, yeast, and fungus [5.8a-c].

Sensitive medical devices such as flexible endoscopes are reusable and require careful decontamination between patients to minimise cross-contamination. Anacail have designed a device for the high-level disinfection of devices such as endoscopes. The Anacail device was proven in trials to achieve a >5log reduction on the most common contaminating pathogens − *Pseudomonas aeruginosa, Staphylococcus aureus, Bacillus subtilis and Candida albican* [5.8d]. Glanadair continues the pioneering work of Anacail in plasma generation of ozone from oxygen for surface decontamination. Glanadair's immediate focus is on the commercialisation of both the medical and environmental applications above. In response to the demand for disinfectant from coronavirus concerns, Glanadair has produced a novel prototype device (currently TRL4). This device generates reusable disinfecting wipes, using only water and ozone, and passed the test to achieve the BS 16615 (2015) standard for chemical disinfectants. This new, innovative device has been found to out-perform medical-standard alcohol wipes under accredited trials conducted by *Andersen Caledonia* [5.8e]. UofG's plasma technology is proven to kill *Staph. A,* and abolish the need to dispose of wipes as clinical waste. The use of ozone offers a route to reducing toxic chemicals and other respiratory irritants from the cleaning chain.

Policy Change Impacts

In 2013, Anacail became a founder-member of the European Ozone Trade Association (EuOTA) to develop commercialisation of UofG plasma technology [5.9]. As a full member of EuOTA and member of its core Ozone Task Force, Potts (as CTO of Anacail) played a full part in the crafting of the Ozone-Dossiers. These key policy documents resulted in the inclusion of "ozone generated from oxygen" by EuOTA members in the list of substances and suppliers published under Article 95(1) of the Biocidal Products Regulation (BPR) by the European Chemicals Agency (ECHA) on 4th Aug 2017 [5.10]. Inclusion in Article 95(1) permits Anacail, and its successor Glanadair, as EuOTA members accreditation, training and certification of manufacturing of ozone producing devices across the European market [5.8, 5.9]. EuOTA has now grown to represent >128 ozone manufacturers across Europe, US and China.

5. Sources to corroborate the impact

5.1 [text removed for publication]
5.2 [text removed for publication]
5.3 Testimonial letter of support from WMH.
5.4 a) STFC Impact report 2013, p18
b) STCF Impact report 2016, p24
5.5 Core Patent: BR112012010526 (A2) (priority date 2009-11-03) Plasma Generation Apparatus and Use Of The Plasma Generation Apparatus. EP 2497343, WO 2011/055113

5.6 Independent verification of efficacy

a) BluTest Report EN14561:2006 Chemical disinfectants and antiseptics. Quantitative carrier test for the evaluation of bactericidal activity for instruments used in the medical area.

b) BluTest Report EN14563:2008 Chemical disinfectants and antiseptics — Quantitative carrier test for the evaluation of mycobactericidal or tuberculocidal activity of chemical disinfectants used for instruments in the medical area.

c) BluTest Report EN 14562 2006 Chemical disinfectants and antiseptics. Quantitative carrier test for the evaluation of fungicidal or yeasticidal activity for instruments used in the medical area.

d) Andersen Caledonia Report RIN14041: Decontamination of ENT non lumen scope commonly used within endoscopy units

e) Andersen Caledonia Report RIN20036: Validation of the Biocidal Efficacy of Ozonated Wipes

5.7 Job Advertisement for CASE Studentship between Anacail and University of Oxford

5.8 Patent WO2015092419 (A1) for the treatment of floor drains in the UK. Additional patents received for 'Decontamination apparatus providing ozone and its use for decontaminating a floor drain' in 2016-2017 are: US20170030068, WO2015092419A1, CN105874132A, US20170030068, WO2015092419A1, CN105874132A

5.9 a) Anacail EuOTA certificate

b) EuOTA website - https://www.euota.org listing membership of Ozone Task Force

c) Testimonial letter from EuOTA Chair

5.10 Article 95(1) of Biocidal Products Regulation (BPR) by the European Chemicals Agency (ECHA) on 4th Aug 2017. p284