Institution: Aberystwyth University

Unit of Assessment: 9 Physics

Title of case study: Impact of research on coloured glass on the social enterprise Ten Green Bottles.

1. Summary of the impact

This case study describes the impact of physics research, carried out in the Department of Mathematics and Physics (DMAP), on the small business and social enterprise Ten Green Bottles through the development of specific commercial applications, transfers of technology, and the development of new products. Fundamental research on the atomistic origin of the structural and optical properties of recycled and synthetic coloured glass has provided an opportunity for Ten Green Bottles to gain an economic advantage. The collaboration between DMAP and Ten Green Bottles benefits the enterprise's workforce, whose educational ambitions have been extended through the interaction with DMAP research, and also benefits the local community, whose understanding of physics research has been enhanced through their interaction with Ten Green Bottles.

2. Underpinning research

As part of the materials research programme into glass and glass-forming liquids at Aberystwyth, started by Greaves [3.1] in 1996, a programme of study has been developed focussing on coloured glass. The broader research programme into glass, glass-forming liquids and amorphous materials at Aberystwyth University involves the use of neutron and high energy X-ray diffraction. The structures of liquids and glasses change under extremes of temperature and pressure and new techniques (high flux, high energy X-rays and aerodynamic levitation [3.2, 3.3]) have been developed to allow a connection to be made between transient metastable structures and structure-dependent properties such as viscosity. This connection also allows the local environment around colour centres to be established.

Although coloured glasses have been available for centuries, a detailed understanding of the physics of colour is a more recent development. The colour reflects the local environment around transition metal ions (crystal-field effects) or nanophase gold or silver particles. Coloured glasses are beneficial in many applications because they are cheap, they contain no organic material, the colour centres are dispersed throughout the glass host and the glass hosts themselves are sufficiently robust to be able to withstand climatic and radiative extremes [3.4]. Coloured glasses are therefore of interest in a variety of applications, including their potential to be used as calibration targets for the ExoMars 2016 and 2018 missions; this is the subject of an on-going interdisciplinary research programme between DMAP and the Department of Computer Science at Aberystwyth University [3.5].

The optical properties of these glasses that provide strong colour can be measured and modelled using spectroscopic techniques and X-ray absorption measurements and this is one focus of a Knowledge Economy Skills Scholarship (KESS) established between DMAP and the social enterprise Ten Green Bottles (TGB) in 2011, in which TGB sponsor a current PhD student.

3. References to the research

[3.1] Greaves, G.N. et al. Composition and polyamorphism in supercooled yttria-alumina melts, Journal of Non-crystalline solids 35, 435-441, 2011.
DOI: 10.1016/j.jnoncrysol.2010.06.072

[3.2] Weber, J.K.R., Benmore, C.J., Jennings, G., Wilding, M.C., Parise, J.B. Instrumentation for fast in-situ X-ray structure measurements on non-equilibrium liquids. Nuclear Instruments and Methods in Physics Research, *A* 624, 728-730, 2010.

DOI: 10.1016/j.nima.2010.09.125

[3.3] Greaves, G.N. et al., Detection of First-Order Liquid/Liquid Phase Transitions in Yttrium Oxide-Aluminum Oxide Melts. Science 322, 566-570, 2008.
DOI: 10.1126/science.1160766. REF2 submitted.

[3.4] Wilding, M.C. et al., Changes in the local environment surrounding magnesium ions in fragile MgO-SiO_2 liquids, Europhysics Letters 89, 26005, 2010.
DOI: 10.1209/0295-5075/89/26005.

[3.5] ExoMars 2018 PanCam Instrument and Calibration Target and Mars Science Target Identification (2003-2013), PPARC/STFC/ UK Space Agency funded. Total £3.3M.

4. Details of the impact

Research on coloured glass forms the basis of impact on the social enterprise Ten Green Bottles (TGB) [5.7], a company based in New Radnor (Powys), that uses recycled glass to make a variety of products including jewellery, tableware and stained glass artefacts, thus providing innovative and interesting uses for recycled glass. As part of its mission to secure a more sustainable future by reducing the amount of waste glass, TGB also aims to provide employment opportunities for individuals that would normally be excluded from the workplace, for example those with learning difficulties and mental health issues.

The collaboration between DMAP and TGB includes a jointly-funded KESS PhD project that contributes to the use of coloured glass in TGB's products, such as the development of a solar water heater made from recycled glass. The connection between the fundamental research on colour centres and the optical properties of the recycled glass (and simple analogues) allows the effectiveness of the heat transfer of solar radiation to be optimised. Here a fundamental and practical understanding of the optical and thermal properties of the recycled glass is required; this is coupled with advanced thermal and fluid-flow modelling, a level of expertise and insight that has not been previously available to this small company. Thus the KESS partnership acts as an enabler for impact as it enhances the level of communication between DMAP researchers and TGB.

Ten Green Bottles is able to benefit directly from access to DMAP research into glasses and liquids, which has enabled new processes and products to be developed. As the CEO of Ten Green Bottles acknowledges in a letter to one of the key DMAP researchers, it is because of the SME's '*interaction with* [DMAP that they have] *been able to benefit from direct access to physics research'* which has *'provided an opportunity* […] to *enhance* [TGB's] *current business and also the potential to develop new products, specifically the development, design and manufacturing of solar water heaters, made from recycled glass*' [5.1] Thus the DMAP research makes a major contribution to the '*tangible, economic advantage*' [5.1] acknowledged by Ten Green Bottles.

As a social enterprise, Ten Green Bottles has a direct and positive impact on the community in south Powys and its regeneration. In its capacity as one of the UK's Community Interest Companies (CIC), TGB offers workshops that allow participants to make their own piece of recycled glass, thus gaining an understanding of the process and benefiting from the SME's knowledge [5.2]. Ten Green Bottles CIC is also a recognised training centre that offers community members the opportunity to gain qualifications and to develop work skills, which creates benefits for socially challenged individuals as well as the long-term unemployed. TGB's website states that '*previous trainees have been very successful with a high percentage acquiring long term employment after their time here*.' [5.3]. It is therefore vital for Ten Green Bottles to continually gain further insight '*into the atomic scale structure of their aesthetically pleasing materials*' [5.1]. The CEO of Ten Green Bottles also states that '*The research and development into coloured glasses not only provides* [the] *social enterprise with a strong commercial foundation but in a wider sense will provide* [the SME] *with the knowledge and insight into the use of recycled materials such that* [Ten Green Bottles] *can contribute and inform the sustainability and environmental debate*' [5.1].

Including socially challenged individuals as well as student volunteers, the diversity of Ten Green Bottles' workforce underscores the SME's CIC mission which is promoted through a number of events including presentations and visits to other countries. This is exemplified in the SME's recent visit to the Czech Republic, which proved beneficial to one of the student volunteers. As part of its mission Ten Green Bottles is '*pleased to offer a forum for students to understand business with social values and enterprise that is sustainable*.' [5.1]. It is through its ties with academic researchers, strengthened by the KESS studentship that contributes to the knowledge transfer between DMAP and Ten Green Bottles, that the SME can be '*recognised as having research innovation and design at the heart of* [their] *business*' [5.1]. Considering Ten Green Bottles' efforts to support those who work for the SME, a major success of the knowledge transfer between DMAP and Ten Green Bottles is that it '*introduced* [Ten Green Bottles'] *workforce and volunteers to academia and extended their ambitions to higher education*.' [5.1]

5. Sources to corroborate the impact

[5.1] Letter from the CEO of Ten Green Bottles.

[5.2] http://www.greenglassmountain.com/services/tours-and-workshops.html

[5.3] http://www.greenglassmountain.com/services/training.html