Institution: University of Nottingham

Unit of Assessment: Chemistry UoA8

Title of case study: Empowering Chemists in Africa Through Green Chemistry (**CS4**)

1. Summary of the impact

University of Nottingham researchers have been at the forefront in promoting and establishing Green Chemistry in developing nations. Working with and influencing colleagues and policymakers in both the UK and Africa, they have increased awareness of the importance of introducing sustainable technologies that meet local communities' needs. As a result, they have invigorated the chemistry teaching curriculum in Ethiopia, placing Green Chemistry at its core, and helped shape the approaches of professional bodies, including the Royal Society of Chemistry, for the benefit of the developing world. This has led to what the British Council has described as "a sense of empowerment and confidence" among Ethiopian chemists.

2. Underpinning research

One of the principal aims of Green Chemistry is to bring the benefits of modern chemical manufacture to developing countries without imposing the environmental burden that has plagued the industrialised world. Green Chemistry is particularly relevant to the needs of African countries, which have little indigenous oil to rely on yet face increasing demand for chemicals from rapidly expanding populations.

The School of Chemistry at the University of Nottingham (UoN) has a long-established track record of research excellence in Green Chemistry [3.1-3.4]. The work of Professor Martyn Poliakoff CBE, FRS (now Research Professor of Chemistry, University of Nottingham, 1979-present) and Professor Peter Licence (now Professor of Chemistry, University of Nottingham, 2005-present) covers a range of sustainable methodologies that focus on reducing the environmental impact of chemical processes. Their research includes cleaner reaction chemistry in supercritical fluids [3.1], continuous reactions in supercritical carbon dioxide from lab-scale to commercial plant [3.2] and UHV spectroscopic techniques for the characterisation and *in-situ* monitoring of catalytic processes in ionic liquids [3.3-3.4]. Poliakoff and Licence have also disseminated their findings and communicated the importance of Green Chemistry to a wider scientific audience through a number of review articles in high-profile journals and participation in influential conferences/policymaking working groups.

In 2003 Poliakoff was invited to present his research on Green Chemistry at an event in Ethiopia. After his lecture, which focused on the hydrogenation of organic compounds in supercritical fluids [3.1], he was approached by Dr Nigist Asfaw (University of Addis Ababa (AAU)), who expressed her concern that Green Chemistry did not feature in AAU's curriculum. Discussions about further collaboration to help raise awareness of the discipline in Ethiopia resulted in Asfaw spending three months in UoN's laboratories, where, alongside Licence, she completed the first comparative study of Greener methods for the extraction of essential oils from Ethiopian plants [3.5].

This area of research is a major focus for academics in Ethiopia, as it offers unique opportunities to discover new biologically active molecules – for use in pharmaceuticals or agrochemicals – from the wide variety of flora endemic to the region. The plant at the centre of this work, *Artemisia Afra*, has for many generations been traditionally employed as a fragrance, an insect repellent and a treatment for minor ailments such as coughs and heart murmurs. Conventional techniques for the collection of essential oils (e.g. hydrodistillation) are expensive in terms of equipment and energy, and the oils' components are known to decompose during such high-temperature processes. The sustainable, low-energy methods used in this study, which was published in 2005, were shown to extract the essential oils rapidly, reducing energy costs and resulting in differing compositions that could subsequently lead to the discovery of biologically interesting molecules.

Continued collaboration between Licence and Asfaw investigated the use of the seed oil of the Ethiopian indigenous plant *Moringa stenopetala* as biodiesel [3.6]. These two publications highlighted the impact Green Chemistry could have in Ethiopia – in doing so laying the foundations for a wider appreciation of the School's other work in this vital field.

3. References to the research (indicative maximum of six references)

Publications:

1. M. G. Hitzler and M. Poliakoff, Continuous hydrogenation of organic compounds in supercritical fluids, *Chemical Communications*, 1997, 17, 1667-1668, DOI: 10.1039/a704371f

2. P. Licence, J. Ke, M. Sokolova, S. K. Ross and M. Poliakoff, Chemical reactions in supercritical carbon dioxide: from laboratory to commercial plant, *Green Chemistry*, 2003, 5(2), 99-104, DOI: 10.1039/b212220k

3. E. F. Smith, I. J. Villar Garcia, D. Briggs and P. Licence, Ionic liquids in vacuo; solution-phase X-ray photoelectron spectroscopy, *Chemical Communications*, 2005, 5633-5635, DOI: 10.1039/B512311A

4. S. J. Craythorne, K. Anderson, F. Lorenzini, C. McCausland, E. F. Smith, P. Licence, A. C. Marr and P. C. Marr, The Co-Entrapment of a Homogeneous Catalyst and an Ionic Liquid by a Sol-Gel Method: Recyclable Ionogel Hydrogenation Catalysts, *Chemistry – A European Journal*, 2009, 15, 7094-7100, DOI: 10.1002/chem.200801809

5. N. Asfaw, P. Licence, A. A. NovitskiiI and M. Poliakoff, Green Chemistry in Ethiopia: The Cleaner Extraction of Essential Oils From Artemisia Afra: A Comparison Of Clean Technology With Conventional Methodology, *Green Chemistry*, 2005, 7, 352-356. DOI 10.1039/b417961g

6. A. Ejigu, A. Asfaw, N. Asfaw and P. Licence, *Moringa stenopetala* seed oil as a potential feedstock for biodiesel production in Ethiopia, *Green Chemistry*, 2010,12, 316-320 DOI: 10.1039/B916500B

Grants:

a. EPSRC Grant (GR/H95464/01),*Organometallic Chemistry in Supercritical Fluids*, P.I. Poliakoff, 1993-1996, £154,124

b. EPSRC Grant (GR/M73644/010), *The Continuous Production of Fine Chemicals in Supercritical Carbon Dioxide,* P.I. Poliakoff, 2000-2003, £194,772

c. EPSRC Platform Grant (GR/S87409/01),*Cleaner Chemistry & Processing in Supercritical Fluids*, P.I. Poliakoff, 2004-2009, £430,004

d. EPSRC Advanced Fellowship (EP/D073014/1), *Ionic Liquids in-vacuo; marrying Surface Science with Solution Chemistry*, P.I. Licence, 2006-2011, £870,688

4. Details of the impact

The University of Nottingham (UoN) has led the way in addressing the key challenge of establishing Green Chemistry in the developing world. The joint paper with Ethiopian researchers on the cleaner extraction of essential oils from *Artemisia Afra* stimulated considerable interest among the chemistry community in Ethiopia, with subsequent discussions highlighting not only the benefits Green Chemistry could bring to the country but also the need to raise awareness of the topic among the public, government and industry. Poliakoff and Licence have participated in a range of activities that have changed the curriculum in universities, informed government policy and influenced training and services offered by professional bodies and learned societies.

Increasingly, the benefits of these efforts have been felt across Africa.

Four Green Chemistry Workshops have been organised by UoN, AAU and the Chemical Society of Ethiopia during the 2008-2013 period [5.1]. Held in Ethiopia, each has attracted up to 100 high school/university students, chemists, chemical engineers from Ethiopian industry and members of the general public. Researchers from Poliakoff and Licence's team have given talks on their work – including research into ionic liquids, reaction optimisation and hydrogenation using supercritical fluids – and have held discussions with students to share experiences. According to AAU's Dr Nigist Asfaw, these events have been fundamental in raising Green Chemistry's wider profile, even featuring on Ethiopian national television and in the national print media. Asfaw has remarked: "It has been great to see Green Chemistry, which was once an unknown topic in our country, being discussed and employed across my country." [5.2]

Building on the success of the initial research collaboration and the subsequent workshops, a British Council DelPHE-funded partnership between AAU's Science Faculty and UoN's School of Chemistry was secured. Showcased as a DelPHE case study in 2010 [5.3], the arrangement has continued to deliver benefits throughout the impact period. Knowledge transfer between the two universities, coupled with Licence's appointment as an Adjunct Professor at AAU, has resulted in a new course, Introduction to Green Chemistry, for the undergraduate curriculum. In addition, PhD students trained by Poliakoff and Licence have taken up positions at other Ethiopian universities, including Jimma, Haramaya, Hawassa and Bahir Dar, where they are now promoting and initiating Green Chemistry research. Licence has also hosted four visiting researchers in Nottingham as part of their PhD studies in Ethiopia. In 2013 the British Council's Director of Science observed: "A little over a decade ago the field of Green Chemistry was virtually unknown in Ethiopia. Now, as a direct result of the University of Nottingham's pioneering efforts, it is taught across the country. We consider this to be one of our most successful recent DelPHE projects. Your work... has given Ethiopian chemists a sense of empowerment and confidence." [5.4]

In 2012 the Ethiopian Ministry of Education and UoN reached an agreement for jointly funded scholarships for outstanding young Ethiopian academics to undertake one-year research programmes at UoN in areas likely to advance the country's development. Green Chemistry is one of these areas. In an August 2013 letter to Poliakoff – who twice met with Ethiopia's Deputy Prime Minister, His Excellency Derek Mekonnen, in 2011 – the Ethiopian Ambassador to the UK said: "His Excellency was most impressed to hear how the ideas of Green Chemistry are being incorporated into the curriculum at AAU and other universities... [He] and I would like to thank you and your colleagues for your great efforts over nearly 10 years in increasing the understanding of science and science education in my country." [5.5]

The influence of UoN's work has also been felt beyond Ethiopia. As a result of his connections with Nottingham, Royal Society of Chemistry (RSC) President Simon Campbell attended the inaugural Federation of African Societies of Chemistry (FASC) congress in 2006, where he announced RSC would be the first learned and professional organisation to provide developing countries with free access to science journal archives. The current RSC Chief Executive has described UoN's input as "critical" to this move, noting: "Your work has transformed how the concept of Green Chemistry is perceived and pursued in Africa." [5.6] Between 2008 and 2013 more than 49,000 journal articles have been downloaded and 25,000 textbooks and RSC journals distributed to universities in 12 different African countries – including 800 to aid the reconstruction of Liberia University – under the Journals for Africa initiative.

The success of the collaboration between FASC and RSC led to the formation of the Pan-African Chemistry Network (PACN), including the establishment in 2008 of two hubs – one in Addis Ababa. PACN aims to enhance cooperation between governments, universities, industry and communities to help build a sustainable science base across the continent. The RSC's CEO has acknowledged UoN's "significant input" into PACN [5.6], including its contribution to Wealth Not Waste: Green Science and Engineering for Sustainable Growth in Africa [5.7], a report whose cover featured Poliakoff's Thirteen Principles for Green Chemistry for Africa. According to RSC, Wealth Not Waste has reached an estimated 20,000 scientists and 2,500 global policymakers since its launch at

launch at the United Nations UNECA CODIST-2 meeting. Further UoN support for PACN has included Licence's participation on the PACN Advisory Board since 2009. He has also lectured at the PACN Sustainable Water Conference, University of Nairobi (August 2009), been a member of the organising committee for the 1st PACN Green Chemistry Congress (November 2010) held in Addis Ababa and sat on the organising group of PACN, Nigeria – Health Water and Waste, Lagos (July 2012). These interactions have seen Green Chemistry research feature at the heart of PACN activities further raising awareness of the topic across Africa.

5. Sources to corroborate the impact

1. Green Chemistry Workshops in Ethiopia (information supplied by Dr Nigist Asfaw, Addis Ababa University)

2. Letter from Dr Nigist Asfaw, Addis Ababa University

3. British Council (2010): Development Partnerships in Higher Education – case study of Green Chemistry in Ethiopia
   http://www.britishcouncil.org/delphe-case-studies-2010.pdf

4. Letter from Director of Science, British Council

5. Letter from Ambassador, Embassy of the Federal Democratic Republic of Ethiopia, London

6. Letter from Chief Executive, Royal Society of Chemistry

7. Royal Society of Chemistry (2011): Wealth Not Waste: Green Science and Engineering for Sustainable Growth in Africa