Institution: University of Essex

Unit of Assessment: 5 – Biological Sciences

Title of case study: Commercialising innovations in optical devices for environmental and agricultural applications to boost business performance

Period when the underpinning research was undertaken: Jan 2000 – June 2020

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:
Tracy Lawson	Professor	1999 - present
Philippe Laissue	Lecturer	2009 - present
Neil Baker	Professor	1976 - 2011
Richard Geider	Professor	1999 - 2020
David Suggett	Senior Lecturer	2001 - 2013
Kevin Oxborough	Senior Research Officer	1994 – 2006

Period when the claimed impact occurred: August 1st 2013 – December 31st 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research at Essex enabled the development, production, commercialisation and validation of eight instruments for optical, non-invasive analysis of photosynthetic organisms. This research led to new developments for four companies, Technologica (UK), PhotoSystem Instruments (Czech Republic), Chelsea Technologies Ltd. (UK) and Cairn Research (UK), enabling them to break into new markets, expand their instrument portfolios, widen their customer base and reputation for innovation, create new jobs internally and generate over GBP3,300,000 in sales. The specialist instruments are sold in Europe, USA, Middle East, China and Australia to world-leading agricultural companies (e.g. Syngenta), core facilities and research laboratories.

2. Underpinning research

Essex Biological Sciences researchers have an extensive body of work **[R1- 6, P1]** in acquiring and analysing fluorescence data, ranging from the underlying theory and development of instrument technology to experimental validation. This work was proactively shared with four commercial companies, contributing to innovation and improving their business performance through the introduction of new instrumentation and analysis methods. The instruments and methods are used to measure plant and algal productivity and to non-invasively image delicate organisms.

Chlorophyll Fluorescence Imaging (Technologica Ltd. and PhotoSystem Instruments): Chlorophyll fluorescence imaging (CFI) enables measurements of plant photosynthetic efficiency. It has become an important tool for assessing the effects of various chemical, genetic and environmental impacts on plant performance and productivity and is widely used in plant screening and phenotyping. The first instrument prototype was designed and produced by Baker and Oxborough at Essex, along with Bartington, for rapid screening of multiple plant seedlings in one

image. They filed a patent **[P1]** and the University set up the spinout company Technologica Ltd to market the commercial version, the CFImager. Its use and suitability for commercial applications, published in **[R1]**, helped to establish CFI as a mainstream screening tool. The Technologica instrument has been purchased and used in many research groups around the world as well as commercial enterprises (e.g. Syngenta) for assessing plant performance. Lawson at Essex then extended CFI theory to include thermography and produced the first instrument capable of measuring intrinsic water use efficiency **[R2]**. Lawson's pioneering work and close working relationship with PhotoSystem Instruments (PSI) enabled the company to develop a new commercial system capable of dual measurements of photosynthetic processes and stomatal responses by combining CFI and thermal imaging. This has greatly benefitted the company's strategy of constant product development and helped to maintain its position as a market leader in phenotyping.

Single Turnover Active Fluorescence (Chelsea Technologies Ltd.): Marine phytoplankton contribute approximately half of Earth's photosynthetic primary production. Reliable assessment of phytoplankton primary productivity is crucial to understanding the global carbon cycle and pelagic ecosystem function, validating climate change models and monitoring important phenomena such as harmful algal blooms. Research by Geider, Lawson and colleagues at Essex led to the formulation and validation of a new approach for using Single Turnover Active Fluorescence (STAF) to measure primary productivity of algal suspensions. The resulting paper **[R3]** contained a new equation and new algorithms for determining primary productivity using STAF, and the approach was validated using data previously collected by Suggett **[R4]** on NERC grants **[G1 & G2]** held at Essex. This significant innovation allows the determination of absolute photosynthetic electron transfer rates using a single instrument and led to a NERC-funded equipment development project with Moore (University of Southampton), Geider (Essex) and Oxborough at Chelsea Technologies Ltd (CTL) as a named industrial subcontractor **[G3]**. More recently, Geider at Essex, with Oxborough at CTL, further improved the STAF approach for measuring marine primary production by providing correction factors for naturally occurring variability in fluorescence yield of phytoplankton **[R5]**. These innovations were first incorporated into the operating software for CTL's existing FastOcean fluorometer increasing its marketability, and subsequently incorporated in CTL's most recent STAF systems: the benchtop LabSTAF and deployable AutoSTAF.

Light-sheet fluorescence microscopy (Cairn Research Ltd.): For marine research on light-sensitive, photosynthetic and ecologically highly relevant corals, Laissue at Essex designed and produced an instrument prototype for non-invasive light-sheet fluorescence microscopy. It enables harmless, nontoxic fluorescence imaging of large, living, light-sensitive microscopic samples at high resolution and over long time periods. Novel features of the instrument were two wide, uniform light-sheets, which were overlapping to reduce shadowing. The fact that the instrument could be adapted for use with *any* microscope was also novel. Laissue then collaborated with Cairn Research to commercialise the instrument, supported by a Royal Society Industry Fellowship **[G4]**. Instrument design and demonstration of its non-invasiveness using light-sensitive corals were published thereafter **[R6]**. The watershed product led to the development, production and validation of three additional light-sheet instruments for Cairn in collaboration with Laissue.

3. References to the research [can be supplied by HEI on request]

P1 Patent: Baker NR, Bartington JK, Oxborough KM (2004). UK Patent No. GB2380790. Newport, Wales: The Patent Office. https://www.ipo.gov.uk/p-ipsum/Case/PublicationNumber/GB2380790

R1 Barbagallo RP, Oxborough K, Pallett KE, Baker NR (2003). Rapid, Noninvasive Screening for

Perturbations of Metabolism and Plant Growth Using Chlorophyll Fluorescence Imaging. Plant Physiology, 132: 485–493. DOI: 10.1104/pp.102.018093

R2 McAusland L, Davey PA, Kanwal N, Baker NR, Lawson T (2013). A novel system for spatial and temporal imaging of intrinsic plant water use. Journal of Experimental Botany. 64: 4993-5007. DOI: 10.1093/jxb/ert288

R3 Oxborough K, Moore CM, Suggett DJ, Lawson T, Chan HG, Geider RJ (2012). Direct estimation of functional PSII reaction centre concentration and PSII electron flux on a volume basis: a new approach to the analysis of Fast Repetition Rate fluorometry (FRRf) data. Limnology and Oceanography Methods 10: 142-154. DOI: 10.4319/lom.2012.10.142

R4 Suggett, DJ, MacIntyre, HL, Kana, TM, Geider RJ (2009). Comparing electron transport with gas exchange: parameterising exchange rates between alternative photosynthetic currencies for eukaryotic phytoplankton. Aquatic Microbial Ecology 56: 147-162
DOI: https://doi.org/10.3354/ame01303

R5 Boatman TG, Geider RJ, Oxborough K (2019). Improving the Accuracy of Single Turnover Active Fluorometry (STAF) for the Estimation of Phytoplankton Primary Productivity (PhytoPP). Frontiers in Marine Science 6, 319, 1-16. DOI: 10.3389/fmars.2019.00319

R6 Laissue PP, Roberson L, Gu Y, Qian C, Smith DJ (2020). Long-term imaging of the photosensitive, reef-building coral *Acropora muricata* using light-sheet illumination. Sci Rep. 2020; 10 (1):10369. DOI:10.1038/s41598-020-67144-w

G1 Geider RJ, Baker NR. NERC. Evaluation of the fast repetition rate fluorescence technique for measuring primary productivity. 6/2001 – 9/2004. Value: £181,581.

G2 Suggett DJ. NERC. Closing the gap between light energy and CO_2 fixation in phytoplankton photosynthesis. Duration 11/2004 – 11/2007. Value: £137,501.

G3 Moore CM, Hickman AE, Bibby T, Geider R. NERC. Single Turnover Active Fluorometry of Enclosed Samples for Autonomous Phytoplankton Productivity (STAFES-APP). 07/2017 – 07/2017. Value: £525,650.

G4 Laissue PP. Royal Society Industry Fellowship. Lightsheet illumination modules for low-phototoxicity fluorescence microscopy. Duration: 10/2015 – 09/2018. Value: £90,650.

4. Details of the impact

Essex research has supported the development and commercialisation of novel advanced chlorophyll fluorescence and microscopy instruments for the assessment of organisms by 4 companies (UK and international) resulting in significant growth in sales and profits in the period from August 2013. This has led to combined sales of approximately GBP3,300,000 for all 4 companies.

Technologica Ltd., UK The chlorophyll fluorescence imaging system, the CF Imager, was developed at Essex in 2001. Technologica, a University of Essex spin-out company, was established in 2001 to market this and other Essex-led optical instruments. Essex research demonstrated the potential commercial value of the instrument **[R1]** and enabled the functionality of the instrument to be extended **[R2]**. This has resulted in commercial success for Technologica Ltd. The Managing Director (MD) of Technologica Ltd confirms that from August 2013 to January 2018, the company sold 33 CF Imagers, totalling a turnover of GBP458,000 and net profits of GBP210,441 **[S1]**. The MD of the company states: '*The research and development work carried*

out in Biological Sciences at Essex was vital to the success of the system and the resulting commercial impact" **[S1]**. The CF Imager has been sold to plant research laboratories, university departments and – importantly, outside of academia - to world-leading commercial firms such as Syngenta **[S1]**, whose technical specialist states: *"Essex's research and its resulting instrumentation has had an important and long lasting effect: new protocols and procedures which further advanced Syngenta's chlorophyll fluorescence screening approaches and their market leading CF Imager which remains in broad use in our commercial screening."* **[S2]** For a large tender in 2016, Technologica was able to certifiably demonstrate that the CF Imager had the highest performance specification compared to all competitors. As a result of this Technologica won the bid to supply instruments throughout China in early 2016 which contributed to growth of the company **[S1]**. Technologica's MD states '*the CF Imager and Technologica's very existence was entirely the result of pioneering work in Biological Sciences at the University of Essex. Furthermore the research of Professors Baker & Lawson and colleagues at the University of Essex from the plant science research perspective was essential for Technologica's unprecedented success in the four years since August 2013 when our sales rates (across the world incl. Europe, China, Australia and Israel) increased year on year, totalling approximately GBP500,000*.' **[S1]**.

PhotoSystem Instruments (PSI), Czech Republic: Over the past 25 years, PSI has developed and manufactured advanced high-end instrumentation, particularly in the field of chlorophyll fluorescence techniques for plants and algae. Many aspects of their work have been underpinned by Essex research, as their CEO and President explains: "*The research of you and your colleagues at the University of Essex has informed our knowledge and awareness of chlorophyll fluorescence, plant responses to dynamic light and imaging approaches for many years. The research undertaken in the School of Life Sciences at Essex has led to the development of both novel tools and concepts that have been implemented into our chlorophyll fluorescence imaging systems as well as helped us develop new instrumentation."* This is highlighted later on: "*In the last two years we have worked even more closely with you and your fellow researchers at Essex to develop a combined chlorophyll fluorescence and thermal imaging system to enable dual measurement of photosynthetic processes and stomatal responses"* **[S3]**. Using this novel design developed at Essex **[R2]**, PSI has produced a commercial instrument. So far, one prototype instrument has been sold for USD92,000 (07-2020) **[S3]**. PSI's CEO & President states: *"The FluorCam range is an important part of PSI's activities and our fluorescence imaging solutions account for a significant share of this market. The development of this new product has helped maintain our position as a market leader in phenotyping technology and is the only commercially available combined chlorophyll fluorescence and thermal imaging system on the market. We anticipate sales of these instruments to be in the region of about $1 200 000 and provide a profit of $300 000. Due to the COVID-19 restrictions further development of the system has been delayed which had delayed the full launch of this product. Had it not been for the research, undertaken at the University of Essex, the benefits outlined here could not have been achieved"* **[S3]**.

Chelsea Technologies Ltd. (CTL), UK: CTL is a leading UK-based sensor design and manufacturing company specialising in instruments incorporating Single Turnover Active Fluorometry (STAF) for monitoring oceanographic and freshwater environments. Essex research, describing and validating a novel approach to directly measure photosystem II photochemistry and photosynthetic electron transfer rates of algal suspensions, was incorporated into CTLs FastOcean fluorometer and Act2 laboratory system which according to CTLs chief scientist "…*triggered a steady increase in the adoption of this technology, mostly within the academic community. To date, CTL has sold well over 100 FastOcean sensors and associated equipment, generating income in excess of £2 M."* **[S4]**. Further research by Geider & Oxborough led to the development of a practical method for increasing the accuracy of STAF by accounting for the impact of 'the package

effect' on light absorption **[R5]** and contributed to the development of a new product for CTL, the LabSTAF Single Turnover Fluorometer system, supported by a GBP500,000 contract to CTL as part of NERC funding **[G3]**. The instrument was announced on their website on October 31, 2019 **[S5]** and to date CTL have sold 20 LabSTAF instruments across Europe, the United States, China and Israel, generating GBP480,000 in income **[S4]**. The Essex research has enabled CTL to maintain market dominance in providing active fluorescence technology for use in the marine environment as evidenced in the testimonial from the Chief Scientist at CTL who states: *"The novel STAF-based approach for assessing phytoplankton primary productivity, developed through the collaboration between CTL and the University of Essex, has been of great importance to the development and maintenance of CTL's dominance of the academic market for STAF instrumentation."* **[S4]**.

Cairn Research Ltd., UK: Cairn is a UK SME specialising in microscopy solutions for the Life Sciences, whose instruments are sold globally including in North America, Europe, China, India and Russia **[S6]**. In 2014, Laissue proactively established collaboration with Cairn to commercialise his light-sheet prototype developed at Essex which led to the adoption of the new light-sheet technology. Cairn Research's MD confirms **[S6]**: *"Laissue's instrument, concept and timing were a perfect fit for our company. At the time, we did not have experience or expertise in the area of light-sheet microscopy. Laissue however did, and embedded his knowledge and expertise in the company."* Work on a commercial version of Laissue's prototype light-sheet instrument, the L-SPI **[S7]**, began in March 2015 and continued during Laissue's Royal Society Industry Fellowship **[G4]**. The L-SPI was Cairn's first light-sheet product on the market; indeed the first produced in the UK, and enabled Cairn to expand their instrument portfolio and customer base **[S6]**. Cairn Research's MD emphasizes **[S6]**: "*Through our collaboration with the University of Essex, Laissue's research in Biological Sciences has provided new instrumentation and expertise which enabled Cairn to break into the fast-growing light-sheet microscopy market at the right time."* Building on the L-SPI Cairn added three further light-sheet instruments to their range. *"We could not have produced and validated these new instruments without Laissue's research. These four light-sheet systems, of which in total 74 units were sold, have generated overall sales worth GBP 305,000 since September 2016."* These new products have contributed to Cairn's position *"as a market leader for innovative fluorescence microscopy solutions".* **[S6]**. Cairn Research's MD also confirms: *"As a consequence of our establishment in the light-sheet segment of the market, we have appointed a full-time application specialist for our light-sheet products in April 2019*."**[S6]**.

5. Sources to corroborate the impact

S1 Testimonial and sales information from MD of Technologica Ltd.
S2 Testimonial from Technical Specialist, Syngenta.
S3 Testimonial from CEO and President of PSI.
S4 Testimonial from Chief Scientist of CTL.
S5 CTL LabSTAF product pages:
https://chelsea.co.uk/introducing-the-all-new-labstaf-single-turnover-active-fluorometer-system/
S6 Testimonial sales information from MD of Cairn Research Ltd.
S7 Cairn Light-sheet Product Pages: https://www.cairn-research.co.uk/products/lightsheet/