Institution: University of Strathclyde		
Unit of Assessment: B9 - Physics		
Title of case study: Economic and environmental impacts from laser spectroscopy spinout		
Period when the underpinning research was undertaken: 2000-2013		
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:**
Dr Nigel Langford	Reader	01/01/1990 – present
Prof Geoffrey Duxbury	Professor; Emeritus Professor	01/01/1981 - 30/09/2006; 2006-present
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? Yes		

1. Summary of the impact

Cascade Technologies Ltd is a spinout from the Department of Physics at the University of Strathclyde. Using a new approach to mid-IR spectroscopic gas sensing patented by Strathclyde, Cascade Technologies manufactures a range of gas sensors for both environmental and process monitoring that are sold either globally through Emerson or as original equipment manufacturer (OEM) systems to other manufacturers. These sensors are used in a range of gas sensing markets, including the shipping, car manufacturing, aerosol and food packing industries, where they have contributed to improved environmental pollution monitoring and food quality assurance. From 2014 to 2020 Cascade Technologies increased annual turnover from GBP5,800,000 to GBP10,300,000, and now employs 85 highly skilled staff, an increase of 42 from 2014.

2. Underpinning research

Context

The growing awareness of the negative effects of climate change and environmental pollution, demonstrated through international commitments to reduce emissions of key atmospheric pollutants and greenhouse gases (including carbon dioxide, methane, nitrous oxide and sulphur hexafluoride), has led to an increasing demand for instrumentation capable of detecting and quantifying the concentrations of such pollutants, be they environmental or related to manufacturing processes such as aerosol production. Laser spectroscopy for trace gas detection has been shown to be a suitable basis for such instrumentation.

Key Research Findings

From 1999, Dr Langford and Prof Duxbury established a research programme, supported initially by EPSRC funding, to investigate the potential of pulsed distributed feedback quantum cascade lasers (DFB-QCL) for trace gas detection. The mid- to long-infrared emission of these devices makes them of particular interest for atmospheric trace gas detection. Further, their physical compactness and robust nature make them suitable for practical application. The key outcome from this research was the development of a new type of laser-based spectrometer using intra-pulse spectroscopy, which combined DFB-QCLs with multi-mirror long path gas cells for the rapid detection and quantification of trace gases [**R1**, **R2**].

This intra-pulse spectroscopy approach was significantly different from the methodology used by other researchers for the detection of trace gases. In contrast to other research groups who utilised short duration (<20ns) optical pulses to detect trace gases, the Strathclyde approach used long duration optical pulses (0.3-2μs). A consequence of operating a DFB-QCL in pulsed mode is that it causes temporal variation of the laser frequency, known as a chirp. This frequency chirp is important as it (i) eliminates optical interference effects in the multiple mirror cell (these interference effects impose sensitivity limits on multiple mirror cell spectrometers using fixed frequency sources) and (ii) allows the absorption spectrum of the trace gas to be written onto the time profile of the pulse, giving a simple way of observing the spectrum.

Furthermore, the frequency windows generated by the intra-pulse approach using longer pulses up to 2µs, as in the Strathclyde work, are large enough (typically 100GHz) to observe multiple species of gases, or multiple lines of the same species simultaneously. This gives the user the ability to determine the concentration of a single gas using several different absorption lines, or to monitor the variation in concentrations of multiple gases. Application examples include in industrial processes such as monitoring changes in acetylene in the growth of synthetic diamond, or tracking changes in methane and nitrogen dioxide in the atmosphere for environmental monitoring.

Initial research focussed on the demonstration of the technique in a laboratory setting [**R1**, **R2**] and established detection sensitivities of the order of 500 parts in 10^9, equating to the measurement of absorptions of less than 1%. While a useful tool for fundamental studies of molecular species, the main focus of the next phase of research was the further refinement of the approach and testing in practical settings. This was supported by a range of funders including the National Environment Research Council (NERC) and the Atomic Weapons Establishment (AWE), enabling investigation of the intra-pulse spectroscopy technique in a range of settings:

- In-flight measurements made on a NERC-supported airborne survey and research facility (ASRF) aeroplane demonstrated the detection of atmospheric methane, nitrous oxide and water on flights from Oxford to Wales; results were related to possible sources in the flight path. [**R3**]
- Real-time diagnostics of the amounts of carbon monoxide, carbon dioxide, and water, in the exhaust of an aero gas turbine (turbojet) engine operated in a sea level test cell demonstrated the monitoring of the time evolution of exhaust gases from combustion processes. [**R4**]
- Real-time detection and observation of the evolution of carbon dioxide and ethylene in the exhaust by-products from several cars demonstrated the applicability of the technique to the automotive industry. [**R5**]

These practical demonstrations of the effectiveness of the intra-pulse spectroscopy approach for trace gas detection set the scene for the commercial application of the technique.

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **Normand E.**, **McCulloch M.**, **Duxbury G.** and **Langford N.** (2003). Fast, real-time spectrometer based on a pulsed quantum-cascade laser. *Optics Letters* 28(1): 16-18. DOI: https://doi.org/10.1364/OL.28.000016 [FWCI: 3.12]

R2 **McCulloch M.**, **Normand E.**, **Langford N.**, **Duxbury G.** and Newnham D. (2003). Highly sensitive detection of trace gases using the time-resolved frequency downchirp from pulsed quantum-cascade lasers**.** *Journal of the Optical Society of America B* 20(8): 1761-1768. DOI: https://doi.org/10.1364/JOSAB.20.001761 [FWCI: 3.03]

R3 **Hay K.**, **Wright S.**, **Duxbury G.** and **Langford N.** (2008). In-flight measurements of ambient methane, nitrous oxide and water using a quantum cascade laser based spectrometer. *Applied Physics B* 90, 329–337. DOI: https://doi.org/10.1007/s00340-007-2926-x

R4 **Duxbury G.**, **Hay K.**, **Langford N.**, Johnson M. and Black J. (2011). Real-time diagnostics of a jet engine exhaust using an intra-pulse quantum cascade laser spectrometer. *Molecular Physics* 109(17-18): 2131-2142. DOI: https://doi.org/10.1080/00268976.2011.610367

R5 **McCulloch M., Langford N.** and **Duxbury G**. (2005). Real-time trace-level detection of carbon dioxide and ethylene in car exhaust gases. *Applied Optics* 44, 2887-2894. DOI: https://doi.org/10.1364/AO.44.002887 [FWCI: 1.48]

Notes on the quality of research: The field-weighted citation impact (FWCI) at 02/02/2021 is included above to highlight publications that have had a higher than average influence on the academic field. From 2000 - 2013, the work was supported by research funding from a range of sources, including competitively won research council funding (both EPSRC and NERC) together with industry-supported research studentships.

4. Details of the impact

From research to impact

The intra-pulse spectroscopy technique described, allowing for interference-free operation to be achieved in multi-pass optical cells, was patented by the University of Strathclyde in 2003 (*A semiconductor diode arrangement*, GB0208100.8, *Semiconductor diode laser spectrometer arrangement and method*, US Patent 7,283,243, 2007). The patent was subsequently assigned to Cascade Technologies Ltd, a company established by Erwan Normand, a former doctoral student of Langford's, in 2003 [**S1**]. As noted by Cascade Technologies' Lead Technologist:

> '*This allowed Cascade Technologies to become the first supplier of quantum cascade laser-based spectrometers capable of making trace gas measurements.*' [**S2**]

The company went on to develop instrumentation that has been applied to many different gas sensing markets. During the period 1 August 2013 – 31 December 2020, a range of impacts have been realised:

- Economic impact of Cascade Technologies – new product development, sales turnover, creation of high-quality high-tech jobs and market development via trade sale of company
- Adoption of Cascade Technologies emissions monitoring products by customers across a range of industry sectors, with associated economic and environmental impacts.

Impact 1: Economic impact of Cascade Technologies

Cascade Technologies' strength in a variety of different markets contributed to the decision of US-based electronics manufacturer Emerson to purchase the company in 2014 for GBP37,000,000 [**S3**]. This gave Emerson access to a range of sensors operating in the mid-infrared, a wavelength range that their existing products didn't cover, thereby strengthening their position as a manufacturer of sensing systems. The purchase has also granted Cascade Technologies, as a subsidiary of Emerson, further access to global markets, increasing the reach of the technology underpinned by Strathclyde research.

The growth of Cascade Technologies has benefitted the UK economy and led to the employment of highly skilled graduate-level staff. Table 1 shows the company's growth from March 2013 to September 2020 [**S4a**,**b**]. Note the 18-month reporting period from March 2015 to September 2016 and that figures for year to 30 September 2020 are estimates. Aggregated turnover in the period amounted to approximately GBP62,500,000, with staff doubling from 43 in 2014 to 85 in 2019.

Table 1:

Year to	Turnover (GBP)	Gross profit (GBP)	Staff at end date
31/03/2014	5,801,500	2,574,590	43
31/03/2015	6,474,663	2,970,917	49
30/09/2016	13,252,621	7,534,577	64
30/09/2017	8,623,478	4,533,237	78
30/09/2018	11,807,794	5,511,445	80
30/09/2019	6,262,337	1,414,897	85
30/09/2020	10,300,000 (est)	3,600,000 (est)	Not available

Table 2, provides a representative breakdown of Cascade Technologies' turnover by geographical region for the financial year ending September 2018 [**S2**], illustrating the global reach of the company's products.

Table 2:

Area	Turnover, 2017/18	% of total
Europe including UK	3,299,719	31%
Asia Pacific	5,684,734	53%
North America	1,345,203	13%
Rest of World	364,256	3%

For the same period, two key market sectors were [Text removed for publication] (turnover GBP4,723,800) and aerosol leak detection (turnover GBP2,237,881), with sales into marine contract equipment manufacturers an emerging market sector for the company. In addition, approximately GBP3,000,000 of turnover related to service and maintenance contracts [**S2**]. The impact that these sales enable for Cascade Technologies' customers are discussed further in the following section.

Impact 2: Impacts realised by Cascade Technologies' customers

The compact nature, sensitivity and speed at which signals are generated (<0.1s) by Cascade Technologies' sensors have seen these instruments sold to a variety of different markets, including the shipping, automotive, aerosol and food packing industries, where they are used to ensure that companies meet the strict emission guidelines set out by EU and US regulatory bodies. In this way Cascade Technologies' products contribute to effective environmental pollution and manufacturing process monitoring, with resulting positive impacts on production, on compliance with environmental regulation and on the environment.

Automotive industry: monitoring vehicle emissions

With the rise of global environmental consciousness, including the need to restrict greenhouse gases, global regulations on vehicle exhaust emissions have become more stringent, demanding reductions of several pollutants notably nitrogen oxides (NOx including NO, NO_2 and N_2O) and ammonia NH_3. Industry therefore has a need for easy and accurate measurement of these gases in vehicle emissions.

The ease with which Cascade Technologies' frequency chirped system can be integrated with gas handling lines has seen this instrumentation become an integral component of combustion engine exhaust monitoring systems [Text removed for publication]. [Text removed for publication] [**S5**] systems, which utilise multiple QCL sources of varying mid-IR wavelengths to provide simultaneous analysis of the multiple NOx pollutants, are sold to a range of companies across the automotive supply chain including all global car manufacturers, tier one suppliers, fuel companies and catalyst manufacturers that perform engine tests [**S6**]. [Text removed for publication]

Maritime industry: monitoring pollution from ships

Emissions associated with global shipping fleets are significant contributors to global warming. The ability of the intra-pulse spectroscopy technique to give rapid species-specific information in a compact footprint has seen the technology adopted for the monitoring of smoke stack emissions from ships. The sensors developed by Cascade Technologies are used to ensure that the companies that have purchased the instrumentation meet the strict emission guidelines set out by EU and USA regulatory bodies.

To this end, in September 2019 Cascade Technologies signed an original equipment manufacturer (OEM) agreement with [Text removed for publication] [**S2**], one of the world's largest maritime emissions monitoring companies, to provide instrumentation capable of the simultaneous detection of emissions from up to eight species including SO_2, CO_2, NO, NO_2, CH_4, CO, O_2 and NH_3. The resulting [Text removed for publication] systems incorporating Cascade Technologies products are recognised and accepted by various bodies, including the American Bureau of Shipping, the Korean Register, Lloyds Register, DNV-GL (a major industry accredited registrar and classification society) and the European Union for its Monitoring, Reporting and Verification (MRV) requirements [**S7**].

Manufacturing process monitoring

In addition to the OEM supply of spectroscopy components for emissions monitoring described above, Cascade Technologies also develops full monitoring systems primarily for environmental process monitoring. The company's CT2210 Micro Leak Detector system offers a simple cost-effective approach to detecting defective aerosol cans when compared with the competing approaches of monitoring bubbles in water baths, using acoustic sensors or flame ionisation detectors. It can operate on production lines running at up to 500 cans per minute compared with

the 200 cans per minute limitation of conventional systems. The system satisfies the leak detection performance requirements as specified by the Fédération Européenne des Aérosols (FEA) in its FEA Waterbath Alternative Guidelines, and has been certified to comply with EU transport regulations [**S8**].

With some 3 billion aerosol cans produced annually in the US alone, the success of the CT2210 Micro Leak Detector in improving the productivity of aerosol manufacturers has led to this technology becoming embedded in the production lines of all major aerosol manufacturers [Text removed for publication] [**S2**]. The system was highly commended in the Process Safety and Training category of the British Aerosol Manufacturers' Association annual awards in 2019 [**S9**].

Furthermore, the simplicity and robustness of the instrumentation makes it well suited for use in the food packing industry, where concerns about food quality, level of ripeness and the airtightness of packaging have led to the adoption of Cascade Technologies' instrumentation in this sector. The Rosemount CT 4215 Packaging Leak Detection System marketed by Emerson [**S10**] is a modified version of the Cascade Technologies CT2211 Microleak Detection System and has been used for leak detection in a variety of food processing industries ranging from brewing to dairy at speeds of up to 200 packs per minute. The primary market is food packaged in a protective atmosphere, such as fresh meat, dried meat (for example beef jerky) and cheese [**S2**].

In summary, the impacts realised in the period 1 August 2013 – 30 December 2020 encompass not only the economic impacts of Cascade as a successful technology company – new products, sales and employment – and the economic impacts of both their OEM and end-product customer companies, but also the efficiency and cost savings, plus the safety, regulatory compliance and environmental improvements that result from the use of Cascade products.

5. Sources to corroborate the impact

S1 Licence and Assignation Agreement between the University of Strathclyde and Cascade Technologies Ltd

S2 Corroborating statement from Lead Technologist, Cascade Technologies Ltd (20/11/2020)

S3 Articles related to Emerson's purchase of Cascade Technologies

a. Laser Focus World, *Emerson acquires Cascade Technologies to expand gas emission monitoring portfolio*, 2 January 2015. https://bit.ly/3oaz8N2 (accessed 26/08/2020).

b. Pitchbook. Emerson Acquires Cascade Technologies, 31 December 2014. https://bit.ly/3kLMq2l (accessed 02/03/2021).

S4 Information relating to Cascade Technologies Ltd financial performance,

a. Cascade Technologies Ltd company accounts 2013-2019.

b. Information on financial performance 2019/20 provided by Lead Technologist, Cascade Technologies Ltd.

S5 [Text removed for publication]

S6 [Text removed for publication]

S7 [Text removed for publication]

S8 Emerson. *Cascade Technologies Aerosol Leak Detection*. Video at https://bit.ly/2Mehbj1 (accessed 02/03/2021).

S9 British Aerosol Manufacturers' Association Annual awards 2018 https://bit.ly/3uUqgzr (accessed 24/02/2020).

S10 Emerson Cascade Technologies Rosemount CT4215 Leak Detection System Product Data Sheet https://bit.ly/2MV5oXS (accessed 02/03/2021).