Institution:	**The University of Manchester**
Unit of Assessment:	UoA12a Chemical Engineering
Title of case study:	MULTISENSORS – Noncontact water pollution monitoring

1. Summary of the impact

Research at the University of Manchester has led to the provision of cost effective instruments for monitoring water, industrial and environmental pollution. The underpinning research on chemical sensors conducted in the unit was protected by patent, and in 2007 Multisensor Systems Ltd was spun-out in-order to meet the needs of the water industry and has grown to employ 6 people in 2013. Currently this is the only commercially available instrument sensitive enough to monitor low concentrations of hydrocarbon pollution and is used by major UK water companies to prevent risk of environmental pollution hazards with mitigated losses valued at more than £100m.

2. Underpinning research

The impact is based on research conducted in the University since 1993

The key researchers at Manchester were:
Professor Krishna Persaud (1988 – present, Principal Investigator)
Professor Peter Payne (1988 – 2000, Co-Investigator)
Dr Soad Mohaldin-Khaffaf (1993 – 1996, PDRA)
Dr. Richard Dowdeswell (1994 – 1996, PDRA)
Dr. Peter Wareham (2000-2007, PhD student, PDRA)
Dr. Neville Christopher Woodyatt (2004-2010, PhD student, PDRA)

The main aim of the research was to develop measurement systems that were able to detect, monitor and predict odour concentrations that could be directly correlated with human panel assessments of the odour. Manchester's research, focussed on gas sensing array systems, has adopted a novel approach with the design and development of an online system using non-contact technology for the *in-situ* detection of trace gases in the process industries. This has enabled the sensors to operate across diverse sectors; water, manufacturing, construction, oil & gas and the environment.

Research findings:
1. We showed, for the first time, that a single sensor could be used to measure the proportion of three- and four-component mixtures of volatiles without the need for any separation process [1].

2. The single-point electronic nose technology used in [1] was further developed to a non-contact volatile chemical sensing system [2] and the invention of a new device (E-nose) for the remote detection of trace volatiles was successfully patented in 2004 in GB, Europe and USA [3].

3. We showed that the stand-alone array based gas sensing system [3] that was primarily used by water companies could be further developed to an *in-situ* online system to identify odours from foods [4] and to observe the dynamic changes in gas emissions from landfill sites [5].

3. References to the research

The research was published in prestigious peer reviewed international journals, presented at international conferences, and the intellectual property was protected by patents. In recognition of his research on monitoring systems, Persaud received the Royal Academy of Engineering Silver Medal in 1999 for "*an outstanding and demonstrated personal contribution to British engineering, which has led to market exploitation*".

Key Publications

[1] Amrani M, Dowdeswell R, Payne P, Persaud K. An intelligent gas sensing system. *Sensors and Actuators B-Chemical.* 1997; 44(1-3) 512-516 DOI: 10.1016/S0925-4005(97)00240-2,
[2] Persaud K, Wareham P, Pisanelli A, Scorsone E. 'Electronic Nose' - New Condition Monitoring Devices for Environmental Applications *Chemical Senses*. 2005; 30: i252-i253 DOI: 10.1093/chemse/bjh210
[3] Method and apparatus for detection of trace volatiles (2004) WO/2004/097376 Inventors WAREHAM, Peter, Darren; (GB). Persaud, Krishna, Chandra; (GB)

Other Relevant Publications

[4] Stinson J, Persaud K, Bryning G. Generic system for the detection of statutory potato pathogens. *Sensors and Actuators B-Chemical*. 2006; 116(1-2): 100-106. DOI: 10.1016/j.snb.2005.12.061,
[5] Krishna C. Persaud, Neville C.P. Woodyatt, Robert W. Sneath, (2008) Development of a perimeter odor monitoring system for landfill sites. *Sensors IEEE*, 2008 1360-1363 DOI 10.1109/ICSENS.2008.4716698

4. Details of the impact

Context

Chemical sensors for process industries including water, oil & gas and manufacturing are prone to failure due to the harsh environments in which they have to operate. Environmental managers are increasingly required to detect and quantify trace gases and vapours of land, air and water sites in-order to meet the regulatory and legal requirements concerning environmental pollution. Prior to our research, industry was unable to monitor trace levels of gaseous contaminants, odours, or other chemicals as available instrumentation was not sufficiently sensitive to detect the low concentrations involved. Our research led to the introduction of a new non-contact technology, based on monitoring the headspace vapours and provided the relevant industries with a viable solution. The non-contact approach is vital to providing the highest level of protection of plant, equipment, customers and the environment. Furthermore it decreases dramatically (by a factor of 12) the service costs associated with the use of other technologies involving direct contact with the media.

Pathways to impact

The research was published in leading journals (see Section 3) and presented at international conferences, where it was possible to demonstrate the advantages of the instrument over existing technology. This exposure generated significant interest within the UK and from international countries including USA, Korea and Japan. Proof of principle funding from The University of Manchester allowed the E-nose sensor to be patented, developed, tested and endorsed. Testing and endorsement was carried out by the Water Research Council UK. The E-nose was subsequently spun-out as Multisensor Systems Ltd in 2007.

Reach and Significance of the Impact

Multisensor Systems Ltd

From 2008 pilot sales of E-nose to UK Water companies generated sales revenue worth £150k. Achieving CE marking & compliance testing certification led to sales of instruments (ca. 60) to companies including the major UK water companies and the US Airforce. In 2010, independent investor funding allowed the hiring of the first full time employees, and today 6 people are employed. Multisensor Systems Ltd began to subcontract instrument manufacture, which provided two further positions within a small company based in Yorkshire. During this time more than 200 units are now in use with turnover for financial year 2012/2013 (31/7/13) reaching £435k. Currently,

distribution networks exist in Asia, USA and Canada. With plans to expand into Australasia and South America, it is anticipated that sales will continue to grow rapidly [i].

Impact on Users:

Water Industry

Clean and waste-water monitoring is essential for the water industry to protect the environment and comply with regulations. From 2005 to 2010 the UK water and sewerage utilities collectively invested a total of £20bn in their infrastructure and will invest a similar amount in the period 2010 to 2015. E-nose provides an effective, on-line, real-time monitoring and alarm generation for the protection of raw water intakes, alerting users to fuel leaks by monitoring oil levels in water. In 2008 Multisensor Ltd collaborated with Yorkshire Water to develop the Volatile Organic Compound (VOC) sensor system which can be used on both wastewater and water treatment plants. Following the successful implementation of the sensor in North Yorkshire, the major UK water companies now use this sensor.

Anglian Water Services Ltd is the largest water and wastewater company in England and Wales servicing six million domestic and business customers and delivering ca. 1.2 billion litres of water each day. It uses several VOC monitoring systems originally developed using the innovative E-nose research carried out at The University of Manchester. Peter Barratt, senior water quality specialist, says "*The E-nose technology we use has provided a significant reduction in risk to plant and customer water supplies; intake protection on higher risk lower abstraction cost sources will save operational expenditure and may prevent or delay capital expenditure.*" [ii]. In addition, per installation, the costs of servicing a conventional monitoring unit would be typically around £4,800 compared with just £400 for the Multisensor system. With more than 200 units currently installed, the savings in servicing alone are considerable [i].

Regulations limiting the levels of Trihalomethanes (THMs), a carcinogenic by-product of disinfectants, in drinking water have made it essential, throughout the distribution network, to have the ability to measure low levels of these compounds. Multisensor's THM monitor provides that facility efficiently and accurately, with users in the UK, Europe and the rest of the world. Mejoras Energeticas, a major water quality control company in Spain, refer to the impact of the Multisensor system in process analysis: *"being able to measure online makes it possible to control the process and the risk. The non-use of chemicals means zero waste and maintenance free technology* [iii]. Heyward Inc., USA, have also used Multisensor's THM monitor since 2010 throughout their distribution network (the entire southeast and mid-Atlantic United States) to ensure that their clients are meeting the regulatory and legal requirements. Michael Ping, Heyward Inc. Engineer, says "*The E-nose technology is used to monitor and minimise chemical dosage at our water treatment plants. This reduces our potential liability as we meet regulations and the system offers effective cost savings to our company*" [iv]. Energy savings in THM reduction systems, brought about through the use of the THM monitor, are estimated to be in excess of £300k per annum for each system. Associated reductions in chemical usage are estimated to be 31% (equivalent to ca. £45k per year). In addition to these direct savings, the value of regulatory compliance is clearly significant [i, v].

Manufacturing Industry

In 2010 Cummins Engineering Company, a global diesel engine manufacturer implemented Multisensor System's VOC detection instrument at their Darlington engine test facility. Paul Malpass Technical Specialist at Cummins' engine test facility said "*The new emergency spillage containment system using Multisensor's VOC detection instrument provides the security which Cummins demands to protect the local environment and infrastructure to the highest level."* [vi]. In 2012 the VOC instrument saved Cummins' Diesel in excess of £50k as there was a fuel line failure during the Christmas shutdown. Cost savings are associated with clean up and fuel (ca. £20k), fines from Environmental Agency (tens of thousands), and legal costs (ca. £20k) [i].

The E-nose instrument can provide early detection and potential future losses have been mitigated by improved methods of risk assessment and management avoiding scenarios such as; in 2010 an

Insulation Firm was fined £12,000 after washing spilt oil down the drains (Barbourne Brook at Gheluvelt Park and into the River Severn) [vii], in 2012 Bradford Council were fined £250k following a Diesel Spill [viii] and Enbridge Energy incurred a record fine of US$3.7m in 2012, for crude oil leakage during 2010 in Marshall USA where an undetected malfunction resulted in 877,000 US gallons of oil reaching a river. The clean-up operation is still on-going with costs already in excess of $765m [ix]. With 50 VOC units active, if each unit has prevented just one incident, the value to the water companies has been at least £100m [i].

5. Sources to corroborate the impact

[i]. Letter from CEO Multisensor Systems Ltd corroborating factual information presented in this case

[ii]. Letter Senior Water Quality Specialist – Anglian Water – impact on non-contact monitoring techniques in the water industry.

[iii]. Impact Questionnaire. Manuel del Rio – Mejoras Energeticas, Spain – Water Quality Engineering Company and Distributor – beneficial impacts on the environment

[iv] Letter from Heyward Inc., USA, Water Quality Engineering Company – impact on environmental compliance

[v]. Environmental Science & Engineering Magazine Article, March 2013, "Controlling trihalomethane levels in dynamic water treatment systems"

[vi]. Paul Malpass, Technical Specialist, Cummins Engineering Company. Press release (2010) http://www.multisensor.co.uk/blog/multisensor-and-cummins-work-to-protect-the-environment-against-fuel-spillage/

[vii]. Press release "Insulation Firm fined £12,000 after washing spilt oil down the drains" http://www.edie.net/news/3/Firm-washed-oil-down-drains-and-into-rivers/19003/

[viii]. Press release "£250,000 bill for Bradford Council following Diesel Spill" http://www.thetelegraphandargus.co.uk/news/10016110.Council_facing___250_000_diesel_leak_bill/

[ix]. Press release "Record fine for Enbridge Spill" http://www.spill-international.com/news/id985-Record_Fine_for_Enbridge_Spill.html