Institution: University of Bath		
Unit of Assessment: B12 Engineering		
Title of case study: Improving the efficiency and reliability in transportation systems using adsorption media tubes		
Period when the underpinning research was undertaken: 2000 - 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:**
Semali Perera	Professor, previously Senior Lecturer, Lecturer	April 1989 - present
Barry Crittenden	Professor	September 1973 - August 2016
Y.M. John Chew	Professor, previously Senior Lecturer, Lecturer	September 2010 - present
Period when the claimed impact occurred: 29 October 2013 to 31 July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Adsorption Media Tube (AMT) technology based on University of Bath's research on structured adsorbents is now used for the drying of air by the rail industry for diverse applications such as air braking, pneumatically operated doors, self-levelling suspension systems, pantographs, train horns, couplers and toilets in 12 countries including the UK and USA.

From its original research, Bath created a spin-out company (n-psl) which was sold to FTSE-100 listed IMI plc for GBP6,100,000 on 29 October 2013 (inside the census period for this REF). Manufacturing by subsidiary IMI Norgren Ltd. has been created at two sites: in Leeds, for the structured adsorbent components, and at Fradley, Lichfield, for the complete AMT rail units. Four jobs have been created and three preserved at Leeds, four jobs have been preserved at Fradley and ten additional sales, marketing and technical support jobs have been preserved within IMI plc.

With a value of GBP2,250,000 per year, 700 live AMT systems are now being sold to the rail sector each year by IMI Norgren Ltd., benefitting not only the railway companies themselves but also their passengers who demand reliability in their rail journeys.

2. Underpinning research

Results from fundamental materials research by Perera and Crittenden on structured adsorbents in 2000 [1] revealed considerable promise for new ways of making materials with much lower pressure drops than existing ones. This is important as it leads to savings in energy and cost, whilst maintaining high separation performance. University of Bath research by Crittenden and Perera was initially focused on monoliths (funded by EPSRC), and development was supported financially by the TSB (K3510G) and KTP (TP No 4211) programmes. The projects then stimulated further research which led to the patented invention of adsorbent hollow fibres incorporating functional materials for different applications [2, 3]. This research focussed on creating novel fibres with straight channels providing good access to the adsorbent while reducing skin friction and form drag so as to keep the pressure drop low. This research further led to the invention of (i) an electrically regenerable adsorption unit, for both air purification and volatile organic chemical removal/recovery, and (ii) a pressure swing adsorption unit for air drying. The patent rights were assigned by the University to n-psl (nano-porous solutions ltd), a spin out company. n-psl's main use of the fibre technology was in the treatment of compressed air (used in a very broad range of applications) where the potential exists to reduce energy consumption by

50% compared with existing methods, because the pressure drop of air flowing through the fibres is so low. Indeed, a Carbon Trust project (Ref No: 075-048) with Bath and n-psl in 2008-09 concluded that the reduced energy consumption would translate into a minimum accumulated saving of $4MtCO_2$ by 2050.

Research on developing novel structured adsorbents continued to progress further by Perera and Crittenden, responding to specific industrial needs for low pressure drop, high performance materials [e.g. 4]. For example, research funded by Air Products focused on making novel adsorbents known as 'miniliths'. These are adsorbent pellets of relatively large size to minimise pressure drop, whilst providing them with multiple straight channels of low diameter, to enhance diffusional mass transfer performance [5]. According to Prof M Kalbassi (Global Lead Emerging Separations, Air Products) the minilith mass transfer coefficient is 1.5 times greater, and the flow resistance is 48% lower, compared with current extrudates. Accordingly, use of such miniliths offers the prospect of a 10% reduction in total cost. Further research, funded by Dstl, Innovate UK and Jaguar Land Rover, focused on incorporating adsorbent materials into polymeric foam structures, that can be formed *in situ* in either simple or more complex geometric shapes, for air purification [6]. Further research looks at the incorporation of metallic species with the adsorbent materials, so that microbial species can be destroyed *in situ*.

3. References to the research

[1] Lee, LY, Perera, SP, Crittenden, BD & Kolaczkowski, ST 2000, 'Manufacture and characterisation of silicalite monoliths', *Adsorption Science & Technology*, vol. 18, no. 2, pp. 147-170. https://doi.org/10.1260/0263617001493350

[2] Nevell, JM & Perera, SP 2011, 'Novel adsorbent hollow fibres for oxygen concentration', *Adsorption*, vol. 17, no. 1, pp. 273-283. https://doi.org/10.1007/s10450-011-9323-9

[3] Jeffs, C, Smith, MW, Stone, CA, Crittenden, B & Perera, S 2013, 'Low pressure drop respirator gas filters using adsorbent hollow fibres as an alternative to granular adsorbents', *Journal of the International Society for Respiratory Protection*, vol. 30, no. 1, pp. 12-29. [Available on request]

[4] Jeffs, CA, Smith, MW, Stone, CA, Bezzu, CG, Msayib, KJ, McKeown, NB & Perera, SP 2013, 'A polymer of intrinsic microporosity as the active binder to enhance adsorption/separation properties of composite hollow fibres', *Microporous and Mesoporous Materials*, vol. 170, pp. 105-112. https://doi.org/10.1016/j.micromeso.2012.11.039

[5] Omojola, T, Cherkasov, N, Rebrov, E, Lukyanov, D & Perera, S 2018, 'Zeolite minilith: A unique structured catalyst for the methanol to gasoline process', *Chemical Engineering & Processing: Process Intensification*, vol. 131, 131, pp. 137-143. https://doi.org/10.1016/j.cep.2018.07.016

[6] G, R, Crittenden, B, Smith, M, Camus, O, Chew, Y-M & Perera, S 2019, 'Synthesis of Novel Regenerable 13X Zeolite-Polyimide Adsorbent Foams', *Chemical Engineering* Journal, vol. 361, pp. 736-750. https://doi.org/10.1016/j.cej.2018.12.096

4. Details of the impact

A spin-out company, n-psl (nano-porous solutions ltd), was created by the University of Bath following the award of the prestigious Royal Society Brian Mercer Award for Innovation to Professor Perera in 2007, for her research and development with novel adsorption fibres. By 28 October 2013, the financial turnover of n-psl had increased to over GBP1,000,000 per year and the company had created 24 new jobs. On 29 October 2013 (inside this REF's period for impact), n-psl was acquired by the FTSE 100 listed international engineering group IMI plc for GBP6,100,000 [A]. The adsorbent fibre technology created and patented by

Perera, and marketed by n-psl, is now incorporated in the Adsorbent Media Tube (AMT) technology (Figure 1) that is marketed and sold by IMI Precision Engineering under its IMI Norgren® Rail Dryer brand [B].

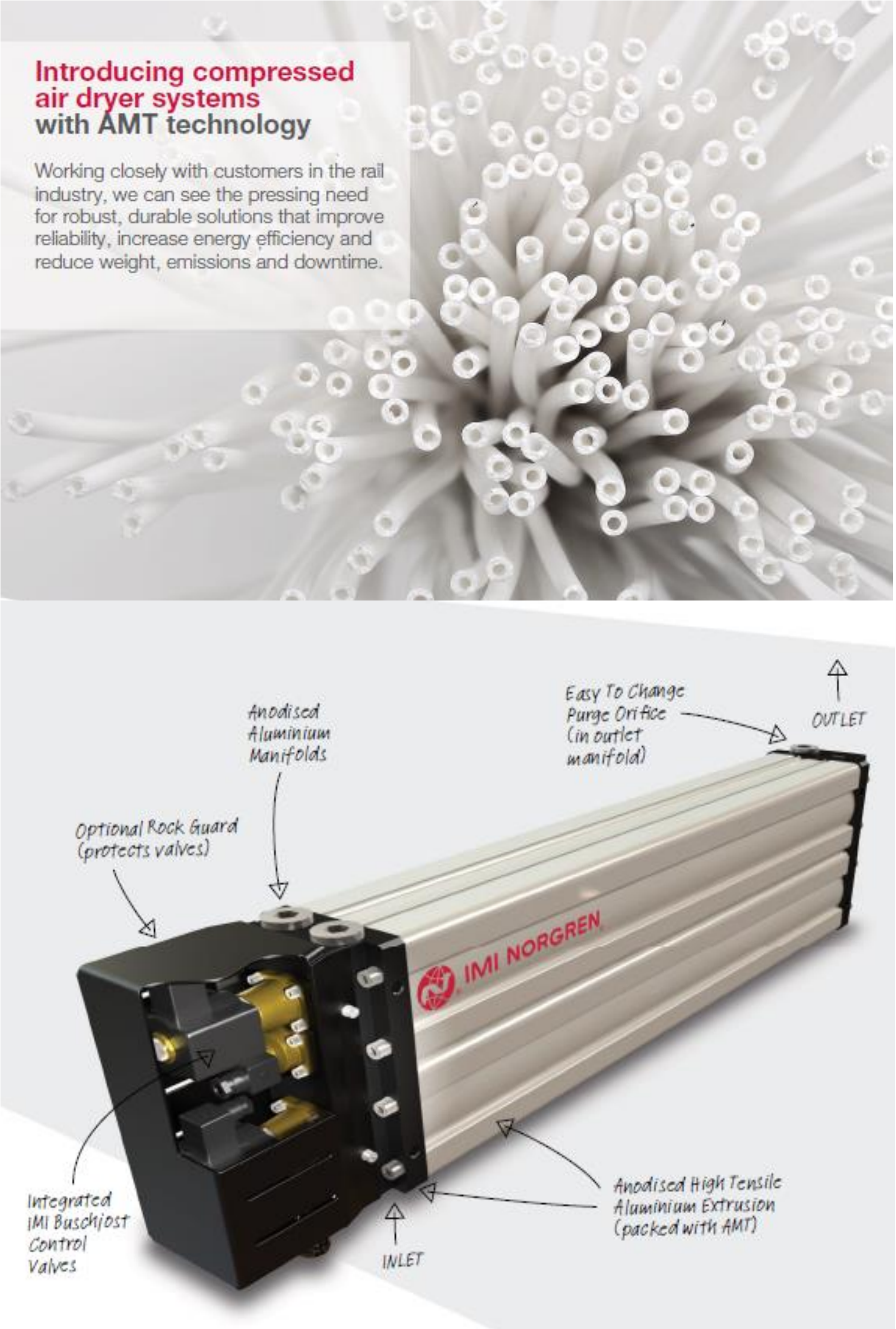

Figure 1: Adsorbent fibres invented by Perera (top) incorporated into an IMI Norgren® twin-tube AMT module for the rail sector, 2m in length (bottom).

In terms of reach, the AMT technology, which produces dried air using Bath's adsorbent fibres, is applied in railway applications across the world including in braking systems, pneumatically operated doors, self-levelling suspensions, pantographs, train horns, step control, couplers and toilets. There are usually up to four compressor/dryer sets spread out along the length of the train providing dry air to all connected equipment with the exception of the pantograph, which has its own local compressor. The AMT adsorbent fibre technology has been incorporated as an essential system component to provide dry and contaminant-free compressed air systems in rail transportation systems in Australia, China, Czech Republic, Finland, Germany, Russia, Singapore, South Korea, Spain, Thailand, the UK and the USA [B]. Since 2014, more than 700 live AMT systems are now being supplied each year around the world with a value of approximately GBP2,250,000 per year. This has resulted in high quality jobs in the UK, as reported by the Senior Mechanical Engineer and Team Leader NPD at IMI, who stated in December 2019 that [C]:

> *"The technology has directly created 4 jobs and the preservation of at least 3 jobs at IMI's Leeds site and the preservation of 4 jobs at IMI's Fradley (Lichfield) site, together with the further preservation of 10 sales, marketing and technical support jobs".*

Being more reliable than previous drying systems, the AMT technology arising from Bath's research means that railway rolling stock needs less maintenance, thereby leading to less downtime. As an example, the AMT Team Leader comments that [C]:

(i) "*Sydney Trains reported a 21% improvement in pneumatic door reliability, on its DDS/DDIC trains after installing our 3-stage filter system and 80mm Twin AMT dryer. They installed 210 sets 2 years ago, and they are working very well with RH <15% since installation*." (n.b. RH is relative humidity, a key moisture parameter);

(ii) "*The AMT technology provides better drying compared to existing systems based on adsorbent beads, now lasting up to 7 years compared with 6 to 24 months with alternative systems. Being more reliable means that railway rolling stock needs less maintenance, thereby leading to less downtime".*

The AMT Team Leader refers [C] to another important example of the use of AMT technology to replace an existing system and hence solve a major practical problem in the USA:

> "*The principal beneficiaries of Perera's original research accordingly include not only the rail transportation companies themselves but also their customers (passengers) who demand reliability in their rail journeys. As an example, the New York City Transit (one of the largest in the world with over 1,700,000,000 passenger journeys each year) experienced a problem with its existing dryers because moisture in compressed air was causing mechanical problems including preventing the brake trip valve from resetting and door actuation on subway cars.*" Previously, "*New York City Transit has to change its desiccant canisters every 6 months at a cost of USD200 each, the AMT dryer was fitted for 7 years without a media change*".

The AMT Team Leader concludes that [C]:

> "*Currently, the Norgren financial position is healthy, more than 700 live systems are being supplied by IMI Norgren each year to the rail sector with an annual value of around GBP2,250,000. We could not have achieved our market position in air purification in the rail industry firstly without Professor Perera's award-winning invention at the University of Bath of the hollow fibre adsorption system which lies at the heart of the AMT technology and secondly without her dedicated and ongoing collaboration with IMI*". He also added that: "*As a result of original Bath research which developed into AMT technology, we are able to provide more environmentally friendly solutions, low pressure drop, improved sustainable greener products, consequently increased profits and energy savings for our customers*".

5. Sources to corroborate the impact

[A] IMI plc Annual Report and Accounts, 2014, p.108.
[B] IMI Norgren, AMT Rail Dryer brochure, 2014.
[C] Testimonial letter from Senior Mechanical Engineer and Team Leader NPD, IMI Precision Engineering, 17 December 2019.