Institution: University of Sussex

Unit of Assessment: UoA 8 Chemistry

Title of case study: Improvements to biogas extraction

1. Summary of the impact

The anærobic production of gas from waste – or biogas – is an important renewable energy source and means to prevent the release of methane, which is a powerful greenhouse gas. Exploitation of biogas is hampered by traces of siloxanes and H_2S, which damage engines through the formation of SiO_2, SO_2 and H_2SO_4 during combustion. Research at Sussex in collaboration with PpTek Ltd (engineers of purification technology) has expanded the scope of current purification technology, meaning that biogas systems can be installed in a range of new sites. This has led to a strong increase in the commercial activity of the company, with turnover increasing from £910,000 in 2008 to £1.95m in 2012-13 and half year figures suggest turnover of at least £3m 2013–14 with £4.3m predicted for 2014–15.

2. Underpinning research

The strong relationship between Chen and Turner at Sussex and PpTek Ltd is based on research to underpin the development and deployment of the photocatalytic purification of biogas streams for renewable energy generation. Collaborative research between PpTek and Sussex has been focused on deploying an optimised photocatalytic system as the successor technology for PpTek's current absorption process. Such an approach has many advantages, not least in the energy requirement for purification, which will be much lower than the current thermal-regeneration methods. The capture of solar energy by semiconductors, whereby hole-electron pairs are generated and can then be used, either as charge carriers for electricity generation or directly harnessed in chemical transformations, is well known. Optimisation of the spectrum captured, through a combination of the control of morphology at the nanoscale, layering or doping, is an attractive method of effecting the redox transformations of components of gas streams. Moreover, in an industrial setting where gas flows are of the order of 10^3 m^3 hr^{-1} and where the duty cycle of a catalytic bed is measured in days or months, the physical nature of the catalyst is critically important. Focusing on TiO_2 as a base material for the morphological manipulation of the band gap and chemical doping, Turner and Chen have developed and optimised the generation of physically robust mats and beds of nanofibres [see Section 3, R1] that display strong photocatalytic properties. This applied and collaborative research is based on more-fundamental studies of nanostructured TiO_2 [R2] and its photocatalytic properties [R3,R4].

Initially funded by EPSRC through a CASE award to PpTek and Sussex, we demonstrated the oxidative power of TiO_2 in the removal of volatile organic compounds from a gas stream under laboratory conditions. This EPSRC-funded work secured the basis for a grant from the Technology Strategy Board (TSB) for the production of a pilot-scale prototype that will be capable of operating under the conditions in the field and over a variety of different biogas sources – including sewage plants, digestors and landfill sites.

A key strand of both the EPSRC- and the TSB-funded research has been an analysis of the current processes of purification and regeneration, as the successor technology under development must be deployed with minimum disruption to the current installations. The results of this process of research and analysis have directly affected PpTek's current practice and the current IP under development has been a significant asset in adding value to the company, leading to acquisition talks with a major multinational that are currently on-going.

3. References to the research

R1 Bedi, J.S., Lester, D.W., Fang, Y.X., Turner, J.F.C., Zhou, J., Alfadul, S.M., Perry, C. and Chen, Q. (2013) 'Electrospinning of poly(methyl methacrylate) nanofibers in a pump-free process', *Journal of Polymer Engineering*, 33(5): 453–461.

R2 Al-Abdullah, Z.T.Y., Shin, Y., Kler, R., Perry, C., Zhou, W. and Chen, Q. (2010) 'The influence of hydroxide on the initial stages of anodic growth of TiO_2 nanotubular arrays', *Nanotechnology*, 21(50): 505–601.

R3 Papageorgiou, C., Beglitis, N.S., Pang, C.L., Teobaldi, G., Cabailh, G., Chen,Q., Fisher, A.J., Hofer, W.A. and Thornton, G. (2010) 'Electron traps and their effect on the surface chemistry of TiO_2(110)', *Proceedings of the National Academy of Sciences of the United States of America*, 107(6): 2391–6.

R4 Shahzad, N. and Chen, Q. (2013) 'Nanofibers: a simple and practical way forward for air pollution abatement', *Materials Science Forum*, 756(): 225–30.

Outputs R2 and R3 best indicate the quality of the underpinning research.

Outputs can be supplied by the University on request.

Grants awarded

EPSRC CASE Award: *Photocatalytic Oxidation of Volatile Organic Compounds in Doped Zeolites*
EPSRC Reference EP/H501614/1
October 2009–September 2014
Total award value: £195,882

PpTek CASE Award (industry element): *Photocatalytic Oxidation of Volatile Organic Compounds in Doped Zeolites*
October 2009–March 2013
Total award value: £21,765

TSB Award with PpTek: *A Green Approach to Biogas Purification with Nanomaterials*
TSB reference 101255
1 October 2012–30 September 2015
Total award value: £216,600

4. Details of the impact

As part of the EPSRC CASE award and the current TSB-funded second stage of the PpTek–Sussex collaboration, close examination of the current technology and processes that are deployed in the UK biogas market by PpTek (which currently has an 80 per cent market share) was undertaken. In 2008, PpTek's technology was adequate to remove siloxanes from the relatively consistent composition of biogas emitted from landfills. As a result of Sussex research, a new process has been developed which allows expansion of PpTek's commercial activity to biogas sources with more chemically difficult and variable gas compositions emitted from anærobic digesters and sewage treatment works. Previously, application of this technology in these chemical conditions was problematic and, in some cases, required the replacement of parts under a contractual obligation.

There are a number of beneficial outcomes from the Sussex research work that has been brought to market through PpTek. One beneficial impact is that 81 additional biogas installations have been deployed on sites that generate on average 2–3 MW of green energy per year each, enabling the

UK to better meet its target under the Climate Change Act of 2009 [see Section 5, C1].

There are also economic benefits in a number of areas, such as growth in turnover, increased graduate-level employment with accompanying HMRC returns, reduction in the balance sheet provision PpTek has to make for replacement parts, increased income from servicing and expansion of the client base overseas.

In 2008, the turnover of PpTek was £910,000. In 2013/14, turnover will rise to £3M – an increase of 233 per cent. The company has grown from 3 employees to 15, all of whom are employed as engineers working on product development or electronic/process engineering. This expansion in staff numbers at the company has had a substantial effect on the benefits to HMRC [SENTENCE REDACTED]

According to the Technical Director [C1], the changes that have effected this increase have depended critically on the research and analysis conducted by Sussex and would not have been possible in its absence. Following analysis of biogas at Sussex, the company has been able to successfully deploy its technology into some highly contaminated landfill sites by filtering some components from the gas before the siloxanes removal system, thus avoiding media failure before end-of-life expectancy. In 2008, PpTek was required to make financial provision for the failure or recall of part of their systems [PHRASE REDACTED] for the five UK installations. By 2012, provision by PpTek had fallen to [PHRASE REDACTED] for 11 units installed.

This fall in the provision is due to the analysis at Sussex and in particular the complex analysis of the compounds blinding the media from the incoming biogas. The resulting changes in processes and equipment design by PpTek has enabled them to argue scientifically the case that the cause of failure was the species contained in the biogas stream and not the failure of the media. In product design, PpTek have been able to reduce the amount of media used in each system, giving savings in its large systems [AMOUNT REDACTED].

Similar improvements have taken place in the income derived from servicing installations: [PHRASE REDACTED]. Without the ability to deploy on progressively more chemically difficult sites, these increases would not have materialised. As of June 2013, PpTek purification systems are now deployed in sites owned by CLP Envirogas (Bolton), Southern Water (Worthing), Wessex Water (Bath), Coxhoe Landfill (Durham), United Utilities (Manchester) and Severn Trent Water (Nottingham), amongst others.

The collaborative research between PpTek and Sussex formed the technical core of negotiations with [REDACTED] in 2012–13, the result of which was the award of contracts to PpTek with a value in excess of £1M during 2012–13, where four systems were sold [REDACTED PHRASE] Chile, [REDACTED AMOUNT], and two systems to [REDACTED PHRASE] in Argentina [REDACTED AMOUNT]. Importantly, these contracts are serviced in South America and constitute the first expansion of PpTek outside the UK and into South America.

5. Sources to corroborate the impact

C1 Technical Director, PpTek Ltd.

C2 Engineering Director, PpTek Ltd.