Institution: University of Warwick		
Unit of Assessment: B8 - Chemistry		
Title of case study: Interface Polymers		
Period when the underpinning research was undertaken: 2006 – 2018		
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:**
Peter Scott	Professor of Chemistry	1997 – Present
Period when the claimed impact occurred: 2016 – 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Professor Peter Scott's team has developed a new class of block copolymer which modifies the surface and interfacial properties of polyolefins, thereby enabling the mixing and adhesion of otherwise incompatible materials, including recycled plastics. Scott and co-inventors Dr Christopher Kay (Warwick PhD graduate) and Ken Lewtas (Visiting Professor) established the spin-out company Interface Polymers (IPL) in 2016 to develop these Polarfin® additives and bring them to market. IPL has secured over GBP4,000,000 in investment and currently employs 11 FTE staff. IPL has established pilot production facilities and has supplied international customers in the packaging, construction, agriculture, automotive and recycling sectors. Polarfin-containing recycled packaging products reached consumers in 2019 and requests for industrial manufacturing-scale materials were received in 2020.

2. Underpinning research (indicative maximum 500 words)

Scott's research group has been concerned with the mechanistic study of homogeneous Ziegler-Natta catalysis since 2002. In 2006 he began work with Infineum UK Ltd–one of the world's leading formulators, manufacturers and marketers of fuel and lubricant additives–initially addressing the long-standing problem that addition of styrenic monomers to Ziegler-type olefin polymerisation reactions leads to lowering of catalyst activity, with low incorporation rates of the styrene. Catalyst and monomer design led to improved understanding and performance **[3.1-3.3]**.

A detailed study by Scott's group revealed that a previously reported mechanism for ethylene polymerisation in the presence of styrenes and dihydrogen was incomplete. This led to the *de-novo* design of a new efficient catalytic process for catalytic end-capping of polyolefins with α-methylstyrenes and the establishment of a new mechanism **[3.4]**. The use of bifunctional α-methylstyrenes such as readily available 1,3-diisopropenylbenzene allowed the catalytic synthesis in one pot of olefin polymers and copolymers that are end-functionalised with reactive α-methystyrene units. Further, simple radical copolymerisation of these macromonomers with conventional styrenes, acrylates, methacrylates, vinyl esters and other monomers allowed efficient, direct synthesis of amphipathic block copolymers *via* another new mechanism. The materials produced were either new, or had hitherto only been accessible by circuitous or expensive routes such as multi-step or anionic polymerisation processes **[3.4-3.7]**. Small quantities of these polymer additives were shown to modify the surface and interfacial properties of plastics **[3.4, 3.7]**.

In 2016 the Warwick team was an awardee in the RSC Emerging Technologies competition for the development of this new block copolymer technology.

Research continues at Warwick to support the synthesis, analysis and testing of new materials of this class to enable the use of recycled polymers in high-value applications, simplification and improvement of recyclability of packaging, modification of mechanical properties, and improved and environmentally less costly application of adhesives or paints.

3. References to the research (indicative maximum of six references) **Warwick = bold**

All research papers were published in peer-reviewed journals

[3.1] Theaker, Giles W., Morton, Colin and **Scott, Peter** (2008) *Awakening a dormant catalyst : salicylaldimine systems for ethene/tert-butylstyrene copolymerization.* Dalton Transactions (No.48). pp. 6883-6885. doi:10.1039/b818829g

[3.2] Theaker, Giles W., Morton, Colin and **Scott, Peter** (2009) *Substituent effects in ethene/styrene copolymerization: dormant state destabilization?* Journal of Polymer Science Part A- Polymer Chemistry, Vol.47 (No.12). pp. 3111-3117. doi:10.1002/pola.23417

[3.3] Theaker, Giles W., Morton, Colin and **Scott, Peter** (2011) *Zirconium-catalyzed polymerization of a styrene: catalyst reactivation mechanisms using alkenes and dihydrogen.* Macromolecules, Vol.44 (No.6). pp. 1393-1404. doi:10.1021/ma102835p

[3.4] Kay, Christopher, **Goring, Paul D.**, **Burnett, Connah A.**, Hornby, Ben, Lewtas, Kenneth, **Morris, Shaun N.**, Morton, Colin, **McNally, Tony**, Theaker, Giles W., Waterson, Carl, Wright, Peter M. and **Scott, Peter** (2018) *Polyolefin–polar block copolymers from versatile new macromonomers.* Journal of the American Chemical Society, 140 (42). pp. 13921-13934. doi:10.1021/jacs.8b09039

[3.5] Waterson, Carl, Lewtas, Kenneth, Theaker, Giles, Wright, Peter, **Scott, Peter** and **Kay, Christopher** (2014) *Additives for fuels and oils comprising functionalised diblock copolymers*, EP2684940

[3.6] Hornby, Ben, Wright, Peter M., Theaker, Giles W., **Kay, Christopher J.** and **Scott, Peter** (2017) *Additives for fuels and oils comprising functionalised diblock copolymers,* CA2942275 (A1)

[3.7] Scott, Peter, **Kay, Christopher J**. and **Lewtas, Ken** (2017) *Use of polymers comprising two segments as polymer additives*, WO2017046009 (A1)

Research grants & investment

[G1] Scott, Peter, EPSRC Collaborative Training Account studentships (part of EPSRC GR/T11371/01) with Infineum, 2006-10 (GBP50,000) and 2010-13 (GBP50,000).

[G2] Scott, Peter, Proof of Concept grant (Warwick Ventures, HEIF), Jan-June 2014, GBP30,000.

[G3] Scott Peter, ICURe programme (SETSquared, Innovate UK), Oct-Dec 2016, GBP35,000.

[G4] Scott, Peter, Innovate UK, Materials & Manufacturing 2 (part of *Manufacturing process to produce additives with enhanced functional performance- Polarfin-Green*, Oct 2017-Sept 2018, Warwick GBP115,374; Total GBP542,829

4. Details of the impact (indicative maximum 750 words)

The Warwick spin-out Interface Polymers Ltd (IPL) has demonstrated economic impact through securing investment of over GBP4,000,000 and generating employment for currently 11 FTE employees **[5.1]**. The business has established pilot scale facilities in the USA for production of its patented materials. It has collaborations with over 80 companies, who have variously performed research and production trials, purchased materials or services, or produced materials incorporating IPL products **[5.1]**. Warwick sold its share of the company in 2017 to private investors for an undisclosed sum. In 2020, a number of large international companies indicated that commercial Proof of Concept had been demonstrated and that the purchase of materials on a large commercial scale was intended as soon as available.

In 2013, a patent with Infineum and Warwick as co-inventors **[3.5]** described the synthesis of polyolefin macromonomers, their conversion to copolymers via an anionic route, and the results of work by Infineum on copolymer performance in applications. Research continued in both Warwick and Infineum laboratories on synthesis and laboratory proof-of-concept studies on potential applications. In September 2015, the Warwick team including Scott and colleagues from Warwick Ventures (Warwick's research commercialisation department) secured ICURe funding for Dr Kay to undertake an intense period of market validation **[5.2]**. The team established the substantial unmet needs in respect of the interfacial properties of polyolefins for over 100 industrial companies. This formed the basis of a business plan pitch in December 2015 to a panel of business leaders at Innovate UK. Recommendation was made for the establishment of IPL as a spin-out from Warwick University in February 2016, and a grant from Innovate UK of GBP500,000 was awarded as a result in March 2016 **[5.3]**.

Patents filed concurrently in 2016 from Infineum (with Warwick co-inventors) **[3.6]** and from Warwick **[3.7]** described new radical polymerisation routes to block copolymers, alongside the results of performance testing of these materials in Warwick and Infineum laboratories. The Warwick patent, **[3.7]** transferred to IPL as part of the purchase of the University's shares, focussed on applications in solid materials. An experienced business and technical employee team (3.5 FTE) was established at IPL, and Kay became the full-time Chief Scientific Officer – a post he still holds. Dominique Fournier, former CEO of Infineum, was appointed Chair of IPL's Board of Directors with Scott as board member. Sven Royall, formerly VP Shell Chemicals, was appointed as a Board Member in 2017. In the same year, IPL secured two significant private investment rounds, including GBP2,000,000 from the private capital investment group 24Haymarket **[5.4]**; Jean-Lou Rihon, a Director at 24Haymarket joined the team.

IPL engineers and scientists led by Kay co-developed scale-up of production to 30t per annum capacity with MATRIC, a process development organisation based in West Virginia, USA. This required an investment by IPL of ~GBP500,000 for personnel, installation of large plant, process control and safety features **[5.1]**.

Multi-kg quantities of materials originating in the above facility have been sampled or sold to over 80 collaborating businesses who conducted extensive work on their own applications, leading to commercial proof of concept (see below for examples).

In 2017, a second Innovate UK Grant (GBP543,000) under the Materials and Manufacturing initiative allowed the development of a new product variant and refinement of production process to improve the performance of crop protection coverings **[5.5]**.

In 2018, a third investment round was closed and the business and technical team was expanded.

In 2019, IPL secured a third Innovate UK grant (GBP638,000) **[5.6]** to develop additives for higher value recycling of mixed plastic waste, and the employee team expanded to 10 FTE. In the same year, IPL won the AkzoNobel 'Paint the Future' Award and secured an agreement to co-develop new enhanced-functionality polymer-based coatings **[5.7]**.

Laboratory-scale trials with a leading international packaging manufacturer indicated the possibility that IPL products could enable them to achieve an ambitious target for incorporation of mixed plastic post-industrial recyclate (PIR) in a key product. Following this, an extensive engagement with the business led to changes in their process conditions and raw materials, as well as incorporation of IPL products as recyclate compatibilisers. Weeks of plant trials in 2019-

20, where production facilities in the UK were taken offline to conduct tests, led to a process in which an unprecedented 40% mixed-plastic PIR could be incorporated into their packaging materials despite the inclusion of only 0.2% IPL polarfin product. In this work, over 40,000m^2 of such packaging material was successfully manufactured and product was shipped to customers across Europe. IPL continues active engagement with this business.

A large (>GBP10,000,000,000 revenue) US-based fibre and fabric company wants to incorporate a mixed polyolefin waste stream into a polar polymer for use in a wide variety of commercial and domestic products **[5.1]**. Various conventional recycling options have been evaluated, but up to now all tested additives did not give processable materials. However extensive trials using Polarfin additives in 2020 showed that mixed waste can be efficiently reprocessed on existing production-scale equipment and recycled or even upcycled into higher-value products. The concentration of Polarfin additive needed is very small, and the stated demand from this company alone corresponds to 30,000t per annum of finished product, and will save 6,000t per annum from landfill **[5.1]**.

In 2020 a mainland Europe-based international speciality chemicals manufacturer reported commercial Proof of Concept for the use of Polarfin in the recycling of multilayer plastic film from packaging applications back into multilayer film without significant loss of properties. Critically, the Polarfin additive, even at low addition levels, has been shown in trials to eliminate gels – visual defects which also disrupt production and reduce customer acceptance **[5.8]**. Gel formation is a very common problem for polyolefin films using recycling mixed plastics, which up to now has restricted their recyclability.

A further two large international businesses (Europe and Japan) have demonstrated Proof of Concept in their applications and stated a desire to move toward commercial development once Polarfin materials are available on commercial (multi-tonne) scale **[5.1]**.

Following the securing of this large-scale commercial demand for IPL products, the development of a commercial manufacturing process has been accelerated with a number of potential partner manufacturers. In 2020 IPL commissioned a report on scale-up feasibility, lab work was performed by partners, and it was determined that the products could be made in their plant at commercial scale (500t decrper annum) **[5.1]**. IPL is now in the process of securing further investment partners to finance the move to this position.

Governments around the world are incentivising plastic recycling. In the UK for example a GBP200 per tonne tax will be levied from April 2022 on plastic packaging with less than 30% recycled material. The purpose is "a clear economic incentive for businesses to use recycled material in the production of plastic packaging, which will create greater demand for this material and in turn stimulate increased levels of recycling and collection of plastic waste, diverting it away from landfill or incineration." (gov.uk, 2020). Similar incentives will apply in the EU (European Council, 2020). Correspondingly, all major producers in the global USD300,000,000,000 polyolefin market have strategies for recycling. IPL's Polarfin additives will allow business like those described above to recycle plastics into high quality products, and more generally will allow the modification of surface and interfacial properties of polyolefins for high value applications.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Statement from Chair of Board of Directors at Interface Polymers.

[5.2] Interface Polymers Case Study, *Set Squared Partnership, Market validation through the ICURe programme*, https://www.setsquared.co.uk/case-studies/interface-polymers/

[5.3] Innovate UK grant - *ICURe Aid for Start Ups Cohort 4 - Interface Polymers Limited,* GBP500,000, https://gtr.ukri.org/projects?ref=900035

[5.4] Press release - *Interface Polymers today announced that it has closed a £2m investment round led by private capital investment group 24Haymarket*, 29.09.2017, https://interfacepolymers.com/2017/09/

[5.5] Innovate UK grant - *Manufacturing process to produce additives with enhanced functional performance,* GBP543,000, https://gtr.ukri.org/projects?ref=103754

[5.6] Innovate UK grant - *Polarfin-Blue: compatibilization of polymers to enable recycling,* GBP638,000, https://gtr.ukri.org/projects?ref=104684

[5.7] Press release - British Plastics and Rubber Magazine, *Interface Polymers Wins AkzoNobel Paint the Future Award,* 14.06.19, https://tinyurl.com/suctwp9v

[5.8] Press release – *Interface Polymers, Interface Polymers secures LOI and POC commitments for its Polarfin® additive technology to recycle mixed plastic waste*,15.12.2020, https://tinyurl.com/4ymbjcxr