Institution: University of Chester		
Unit of Assessment: B8 Chemistry		
Title of case study: Graphene Nanoflake Manufacture and Commercialisation by Ultrasonic Cavitation		
Period when the underpinning research was undertaken: October 2014 to June 2019		
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:**
Trevor Davies	Dr, Senior Lecturer	2014 – 2018
Graham Smith	Professor, Acting Dean	2014 – ongoing
Period when the claimed impact occurred: 2018 – present		
Is this case study continued from a case study submitted in 2014? No		

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

This research has led to the identification of ultrasonic cavitation as a practical means of production of graphene nanoflakes. Acoustic cavitation offers the potential of an alternative to the usual top-down (e.g. exfoliation) or bottom-up (e.g. CVD) approaches that is conceptually simple, and scalable. The method will help in bringing the benefits of graphene technology to market in a more efficient and cost-effective manner. The method is the subject of a patent, owned by start-up company Kainos Innovation Ltd. and now licensed to First Graphene Ltd.

2. Underpinning research (indicative maximum 500 words)

The work described here was carried out in the Department of Mathematical and Physical Science at the University of Chester by Dr Richard Price (Visiting Research Fellow, Kainos Innovation Ltd.), Dr Trevor Davies (Senior Lecturer to 2018, now Innovyn Chlorvinyls Ltd) and Professor Graham Smith. Initial commercial exploitation was through Paul Ladislaus (Project Engineer, Thomas Swan Ltd). The work was carried out at the University of Chester from October 2014 through to February 2019 with funding from Kainos Innovation Ltd.

Graphene was first produced and identified in 2004 by Geim and Novoselov, for which the Nobel Prize was awarded in 2010. One of the biggest challenges to the successful future application of graphene in new devices is the need to develop commercially viable production methods. Typically, current methods are “top down” involving breaking bonds in stacked layers of graphite. Alternatively, they may be “bottom up” methods of synthesis for example by Chemical Vapour Deposition (CVD) requiring thermal decomposition of carbon-containing gases and subsequent deposition on a suitable substrate. The method escribed here provides an alternative approach that is relatively simple and can produce graphene platelets in functionalised and non-functionalised forms.

The work builds upon previous knowledge of the effect of cavitation in diesel fuel injector systems on the build-up of unwanted carbonaceous deposits [1]. The investigation team realised that the effect could be exploited under controlled conditions to produce thin multi-layer graphene-like flakes with consistent and well-characterised properties [2], provided proper selection of energy density and materials properties were made.

Following successful demonstration of the principle and patenting [3] by Kainos Innovation Ltd, efforts were made to seek a commercial sponsor. Thomas Swan Ltd were found to have been developing a related means of graphene nanoflake production using a hydrodynamic cavitation technology, and were a natural partner for development. Further funding was provided by Thomas Swan Ltd for a comparison of the methods and characterisation of the materials produced [2].

3. References to the research (indicative maximum of six references)

1. “Understanding the Impact of Cavitation on Hydrocarbons in the Middle Distillate Range” R.J. Price; D. Blazina; G.C. Smith; T.J. Davies.

Fuel, **156**, 30-39 (2015); DOI.10.1016/fuel.2015.04.026.
https://www.sciencedirect.com/science/article/pii/S001623611500424X

2. "A novel 'bottom-up' synthesis of few- and multi-layer graphene platelets with partial oxidation via cavitation", Richard Price, Paul Ladislaus, Graham C. Smith and Trevor Davies, Ultrasonics Sonochemistry **56**, 466-473 (2019) DOI: 10.1016/j.ultsonch.2019.03.020
https://www.sciencedirect.com/journal/ultrasonics-sonochemistry/vol/56/suppl/C

3. Kainos Patent "Improvements related to graphene nanomaterials" International Publication Number WO2018/020247. Subsequent patents:
Australia, AU201733764A1
China, CN110072808A
Europe, EP3490932A2
United States of America, US20190161352A1

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

Impacts on commerce and the economy

Through work initiated at the University of Chester and developed to the proof-of-principle stage, a start-up company [1] has been able to licence a new technology to a major UK based materials science company [2]. The underpinning research collaboration between the University and the start-up company has led to the design and evaluation of a novel process of manufacturing graphene nanoflakes from pure hydrocarbon source material. The method, acoustic cavitation, is an alternative to the more common exfoliation or synthesis routes and is conceptually simple, and scalable. It has the advantage that both functionalised and non-functionalised graphene flakes can be produced.

The collaboration has involved knowledge transfer from the University to the start-up company Kainos Innovation Ltd. and the end-licensee Thomas Swan& Co. Ltd. on ultrasonic cavitation technology and graphene materials characterisation. Unfortunately, and as a result of the business impact of the coronavirus situation alongside other changes within their business, Thomas Swan have not proceeded with commercialisation of the process. Therefore, the licence has been rescinded and the technology re-licensed to First Graphene Ltd. who have subsequently won Innovate UK funding in partnership with Kainos Innovation Ltd to develop the method further [3].

Impacts on the environment

Graphene nanoflakes are widely reported to have applications in environmental remediation and ground-water clean-up, among others. This provision of an alternative means of manufacture will enhance the take-up of these technologies, leading to environmental benefit.

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

1. Visiting Research Fellow, Kainos Innovation Ltd.

2. Project Engineer, Thomas Swan & Co. Ltd.

3. Press release from First Graphene & Kainos Innovation: https://firstgraphene.net/new-route-to-hydrogen-and-graphene-based-battery-materials-funded-by-uk-government/