Institution: University of Bedfordshire		
Unit of Assessment: UoA12 - Engineering		
Title of case study: Optimised Powertrain Technologies for Low/Non Emissions Vehicles		
Period when the underpinning research was undertaken: Since Jan 2007		
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:**
Prof Jun Peng	**Professor in Engineering**	**Since Jun 2017 – to date**
Dr Tahmina Ajmal	**Senior Lecturer in Engineering**	**Since Oct 2010 – to date**
Dr Vladimir Dyo	**Senior Lecturer in Computer Networking**	**Since Mar 2009 – to date**
Dr Xiang Li	**Research Fellow**	**Since Aug 2018 – to date**
Period when the claimed impact occurred: Since Jan 2012		
Is this case study continued from a case study submitted in 2014? N		

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

Our game-changing research, led by Professor Peng, is significantly influencing the design of engines for vehicles, boats and ships internationally, optimising their performance and reducing CO2 emissions. Studies into diesel engine fuel injection optimisation have helped shape the design of new Ford and Jaguar cars, cutting CO2 emissions by 15% and other harmful emissions by 20%.

We have developed solar boats and also pioneered the use of carbon capture and storage (CCS) for boats powered by internal combustion engines. This has paved the way for thousands of boats to be retrofitted with new technology, with a potential reduction of 21000t of CO2 emissions every year **[Refs 5.1,5.2].** Our ground-breaking research around optimising engine intake systems has also influenced new engine designs in both the UK and in China.

2. Underpinning research (indicative maximum 500 words)

The research described has been led by Professor Peng. The studies aimed to explore and develop new technologies that both enhance performance and reduce harmful emissions from vehicles and inland ships and boats. This is helping to develop boats of zero carbon emissions and will contribute to a non-carbon water transport.
Research focused on three key areas - low temperature combustion for internal combustion engines; internal combustion engines and carbon capture and storage; and fuel cell electric powertrain technology.

1. Low Temperature Combustion for Internal Combustion Engines

Working alongside industry partner AVL Powertrain UK, the largest privately owned company for the development of powertrain systems, Professor Peng and his colleagues carried out

investigations and numerical simulations to deliver more precise air-fuel mixing for diesel engine combustion, optimising the fuel delivery process and injection strategies **[Refs 3.1, 3.2]** and leading to a reduction of CO2 and other harmful emissions.

Direct contributions to performance optimisation and emission reduction are evident in investigation results on HCCI, combustion or low temperature combustion for which fuel delivery process and injection strategies have been optimised.

Several research projects have been conducted with the State Key Laboratory of Engines of China and Beihang University into optimising engine intake systems with VVT/VVA technology and applying biofuel to reduce emissions **[Ref3.3]**, and relevant outputs from this research have been applied to new engine designs in both China and the UK.

2. Internal combustion engines and carbon capture and storage

Professor Peng's research with Dr Tahmina Ajmal into internal combustion (IC) engines has made significant progress towards applying CCS to water vessels that are powered by internal combustion engines with conventional liquid fossil or biofuel fuels **[Ref3.4]**.

By developing oxyfuel combustion (burning fuel with pure oxygen) combined with HCCI (homogeneous charge compression ignition) combustion in IC engines, CO_2 can be filtered out and stored, so that the powertrain can achieve zero greenhouse gas emissions. Working with a consortium from five European countries - France, Netherlands, Germany, Luxembourg and the UK - promising results have been achieved on inland boats, indicating that the technology has massive potential to reduce emissions if retrofitted to vessels.

3. Fuel cell electric powertrain technology

Professor Peng and Dr Vladimir Dyo conducted research on fuel cell electric powertrain technology for achieving zero emissions, including zero CO_2 emissions. The research includes the optimisation of fuel cell internal flows of PEMFC (proton exchange membrane fuel cell) by optimising gas flow channel geometry and configurations and the development of a PEMFC dynamic model which is suitable for designing fuel cell powertrains for heavy duty vehicles **[Ref3.5]**. Both Research areas are aiming to improve the power density and energy efficiency of fuel cell stacks.

4. Solar boats without carbon emissions

Professor Peng has previously participated an InnovateUK granted research project, investigating a high efficiency solar PV system **[Ref3.6]**. Relevant outputs have underpinned the design and funding of a demonstrator boat in a recent collaboration with Mothership Marine Ltd for developing zero-emission, solar-powered inland boats.

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

[Ref3.1] Zhong, S., Peng, Z., Li, Y., Li, H. et al., Direct Numerical Simulation of Methane Turbulent Premixed Oxy-Fuel Combustion, *SAE Technical Paper,* 2017-01-2192, 2017.

[Ref3.2] S. Thiyagarajan, M.R. Herfatmanesh, V. Edwin Geo, Z. Peng, Experimental investigation into the effect of magnetic fuel reforming on diesel combustion and emissions running on wheat germ and pine oil, *Fuel Processing Technology*, Volume 186, 2019, Pages 116-124.

[Ref3.3] Zhichao Wang, Yuzhen Lin, Jianchen Wang, Chi Zhang, Zhijun Peng, Experimental study on NOx emission correlation of fuel staged combustion in a LPP combustor at high pressure based on NO-Chemiluminescence, *Chinese Journal of Aeronautics* (SCI-E), Vol.33(2)):550-560, 2020.

[Ref3.4] Li Xiang, Zhijun Peng*, Ajmal Tahmina, AITOUCHE Abdel, Mobasheri Raouf, Pei Yiqiang; Gao Bo, Wellers Matthias, A Feasibility Study of Implementation of Oxy-fuel

Combustion on a Practical Diesel Engine at the Economical Oxygen-Fuel Ratios by Computer Simulation, *Advances in Mechanical Engineering (SCI)*, AME-20-1054, accepted on 18/11/2020.

[Ref3.5] Wei Liu, Zhijun Peng*, Bo Gao, Bill Kim, Yiqiang Pei, Development of a PEMFC dynamic model and the application to the analysis of fuel cell vehicle performance, 4th ICEMA (International Conference on Energy Materials and Applications), Beijing, China on May 11-13, 2019. IOP Conf. Series: Materials Science and Engineering **628** (2019) 012006, doi:10.1088/1757-899X/628/1/012006.

[Ref3.6] Zhijun Peng* (*corresponding author), Mohammad R Herfatmanesh, Yiming Liu, Cooled Solar PV Panels for Output Energy Efficiency Optimisation, *Energy Conversion and Management (SCI)*, Vol.150, PP.949-955, 15/10/2017.

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

Our research reduces greenhouse gas emissions in roadgoing and marine transport sectors. Leading automotive companies are already reaping the benefits of improved designs to enhance vehicle performance whilst substantially reducing carbon emissions. Similarly, our work in China alongside Beihang University has far-reaching implications, with recent results from industry showing our new engine designs save up to 20% in fuel. In the water transport sector, our developed solutions place us at the forefront of an initiative to reduce carbon emissions from narrowboats by 100,000 tonnes a year. Full details follow:

4.1 Internal Combustion Engines: Impacts on Technology Development and Emissions Reduction

Our numerical simulations and experimental investigations have delivered fuel injection optimisation strategies. As a close industry partner of the University of Bedfordshire, AVL Powertrain UK Ltd has applied these findings to its work on developing, calibrating and integrating combustion engine powertrains for its prestigious clients, including Ford Motor Company and Jaguar Land Rover. The research has also helped AVL expand its own business **[Ref5.6].**

An international collaboration with the State Key Laboratory of Engines of China and Beihang University has led to findings being applied to new engine designs in China and the UK. For instance, a new design of RTO (Regeneration Thermal Oxidizer) combustor has been used by Yunhui Technology Ltd for their new system for processing VOC (Volatile Organic Compound) emissions. “Their test results show the new design can save fuel (natural gas)… (by)… more than 20%. This is really a great achievement from our collaboration,” Prof Yuzhen Lin, School of Energy and Power Engineering, Beihang University in a letter to Prof Peng **[Ref5.3].**

The results of our work enhancing in-cylinder air flows and improving air-fuel interaction in diesel and gasoline engines have been applied by the State Key Laboratory of Engines to diesel engines for the Guangxi Yuchai Machinery Company; and in gasoline engines for the Changan Automobile Company. Alternative fuels, including biofuel, have also been explored with the aim of directly improving the combustion processes and reducing fuel consumption and CO_2 emissions **[Ref5.3]**.

Our research on engine combustion (including low-temperature combustion) has been carried out with financial support from the Engineering and Physical Sciences Research Council (EPSRC), the Royal Academy of Engineering and AVL Powertrain UK Ltd, and has involved substantial international and industrial collaborations. Research outputs have also been adopted by AVL for commercial application. **[Refs 5.3, 5.6].**

4.2 Impacts on Non-carbon Internal Combustion (IC) Engine Combustion Technology Development with CCS

The research on non-emission water vessels powered by oxyfuel combustion IC engines and fuelled with conventional fossil or biofuel hydrocarbon fuels is financially supported by the European Interreg funding. Our research outputs are being applied by industry partners and were also disseminated at the SAE (Society of Automotive Engineers) (https://www.sae.org/) international annual congress in April 2020, where researchers and developers across the world joined to exhibit the latest technologies **[Refs 5.1,5.2]**.

By developing oxyfuel combustion (burning fuel with pure oxygen) combined with HCCI combustion in IC engines, CO_2 can be filtered out and stored, enabling the powertrain to achieve zero greenhouse gas emissions, even though the engines are still fuelled with liquid hydrocarbon fuels (fossil fuels or biofuels).

A consortium from five Northwest European countries is working with the Canal and River Trust (https://canalrivertrust.org.uk/) to improve emissions from boats. The results from a single boat already demonstrated it is possible to reduce or eliminate the pollutants from the polluting vessel engines. At the end of the project, results on the demonstration vessel showed that Nitrogen Oxide (NO_x) emissions can be reduced by 194 kg per year and 24 tonnes/year on each narrowboat, and CO_2 emissions can be avoided altogether. In the next 20 years, a European campaign through the network linked to this technology, involving inland water operators, national authorities and engine manufacturers, can potentially ensure that thousands of boats of various sizes are retrofitted with the technology, leading to a total reduction of up to 100,000 tons per year of CO2 emissions **[Refs 5.1,5.2]**. "We believe that the collaboration will not only benefit…..our business development, and the university's research output, but also will make (a) remarkable impact on saving carbon emissions from water transport," Chris Barnett, Enterprise Manager (EU Projects), Canal & River Trust, canalriverttrust.co.uk **[Ref 5.4]**. As a result of this narrowboat experience, Professor Peng went on to work with Mothership Marine (see (4.4) on a commercially available combustion-free narrowboat.

4.3 Impacts on Non-carbon Fuel Cell Electric Vehicle Powertrain Technology Development

Future forecasts of CO2 emissions from the commercial sector are alarming**.** The sector's share is predicted to increase from 27% in 2015 to around 40% in 2030. Professor Peng, Dr Dyo and Dr Gao's research is significantly contributing to reducing CO2 emissions in the sector and is providing industry partner AVL Powertrain UK with opportunities to grow its business in the rapidly expanding electrified and fuel cell vehicle market, in particular in the electrified commercial vehicle sector.

We have been researching how to optimise fuel cell internal flows of PEMFC (proton exchange membrane fuel cell) by improving gas flow channel geometry and configurations and developing a PEMFC dynamic model that is suitable for designing the fuel cell powertrain of heavy-duty vehicles. The research aims to improve the power density and energy efficiency of fuel cell stacks. With a collaborative project supported by Innovate UK, industry partner AVL is applying the results and designing improved fuel cell powertrains for heavy duty commercial vehicles.
AVL is also seeking to expand its business, engaging with commercial vehicle original equipment manufacturers (OEMs), supporting them to develop fuel cell hybrid commercial vehicles from concept definition and fuel economy assessment to implementation. AVL expects to secure a project with an OEM within two to three years based on the outcome of our research, which will have a commercial value of several million pounds **[Ref5.6]**.

4.4 Impacts on Non-carbon Boats Powered by Solar Energy
30,000 UK narrowboats are powered by diesel combustion motors, with resulting greenhouse gases. Prof Peng has partnered with Mothership Marine (http://mothershipmarine.com/motor/), providing direct technical support for replacing these – designing, optimising and integrating a linked power ecosystem of E-motor, gearbox and

propeller and building this into a pilot boat. Tim Knox of Mothership Marine reports "Initial results have led to increases in confidence with our customers. As a result, we have a full orderbook for the final product even before it has been demonstrated, and now need to take on more permanent staff to keep up with the demand" **[Ref5.5].**

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

[Ref5.1] RIVER - Non-Carbon River Boat Powered by Combustion Engines project news, https://www.nweurope.eu/projects/project-search/river-non-carbon-river-boat-powered-by-combustion-engines/
[Ref5.2] Letter from Prof Abdel Aitouche, JUNIA Institution. *Provided as PDF*
[Ref5.3] Letter from Prof Yuzhen Lin of Beihang University. *Provided as PDF*
[Ref5.4] Letter from Chris Barnett, Canal and River Trust. *Provided as PDF*
[Ref5.5] Letter from Tim Knox, Mothership MarineLtd. *Provided as PDF*
[Ref5.6] Letter from Dr Matthias Wellers AVL Powertrain UK Ltd. *Provided as PDF*