Institution: Lancaster University		
Unit of Assessment: UOA8, Chemistry		
Title of case study: Lancaster University research results in a step change in UK and global battery insurance policy, practice and understanding		
Period when the underpinning research was undertaken: 2015-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): • Professor Harry Hoster • Professor Plamen Angelov • Dr Denes Csala • Professor Robert Young	**Role(s) (e.g. job title):** • Professor of Physical Chemistry and Director of Energy Lancaster • Professor of Intelligent Systems • Lecturer in Energy Storage Systems Dynamics • Professor of Physics	**Period(s) employed by submitting HEI:** • 1/1/2015– • 1/6/2003– • 17/10/2016– • 1/9/2009–
Period when the claimed impact occurred: 2019 - Dec. 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Lancaster University's research on lithium-ion battery degradation directly led to the formation of the spin-out company Altelium in 2019, [redacted] with **first–year trading income of GBP121,000**. Backed by Lloyd's of London, Altelium insures energy storage containers based on used electric vehicle batteries. This is a rare instance of the financial services sector becoming a beneficiary of a strategic technology research programme aligned with the Government's "Batteries for Britain" initiative. The availability of Altelium's insurance–based battery warranty has enabled SMEs in the UK's emerging battery industry, such as Connected Energy, AMTE Power (formerly AGM Batteries), Delta Motorsports, and Brill Power to enter the rapidly growing energy storage market. Connected Energy rolled out their first batch of Mega-Watt (MW)-level energy storage systems with an Altelium warranty, and AMTE are growing their larger-scale cell manufacturing provision.

2. Underpinning research

Impact has arisen from lithium-ion-batteries (LIBs) research by the interdisciplinary team at Lancaster University's Battery Laboratory (BatLab), led by Hoster. The research has directly enabled a new method of informing insurance risk calculation, with potential global reach.

Battery warranty presented two novel challenges for the insurance market: (i) chemically driven performance loss (typical for batteries), which had not been encountered as a basis for insurance risk calculation (the main ones being mechanical fatigue and electronic failure), and (ii) historical data on battery performance had been too scarce, given that EV mass production only started in 2010 and the pace of new battery cells entering the market.

The lack of historical data was tackled by scientifically informed battery lifetime predictions along with real-time monitoring of batteries in the field. The underpinning research has made three distinct contributions:

1. A robust model to predict battery degradation, accounting for cycles and time [G1-G3];
2. A new cell model based on lab performance tests and identification of the internal chemical processes that cause performance fade (see Section 4 and [G2]);
3. Data encryption and machine learning capabilities for battery remote monitoring and the interpretation of incoming real-world data ('battery status estimation'), which validates and improves prior risk calculations [G3].

This approach begins with fundamental battery research and then relies on multi-scale modelling and model parameterisation [G1] to turn those insights into prognostic tools. Via two Innovate UK projects [G2-G3], those tools were validated in commercial battery cells and then utilised to address performance and capacity fade.

Batteries from fundamentals to applications.

The atomistic understanding of processes occurring in battery cells [3.2, 3.6] allowed the BatLab team to improve non-intrusive diagnostics of LIBs [3.1, 3.3-3.6]. This fundamental research is part of the Multi-Scale Modelling consortium funded by the Faraday Institution [G1]. It includes modelling the spatial distributions of Li atoms in LIB electrodes using electron structure theory and Monte-Carlo simulations [3.2]. These simulations explain the changes in LIB cell voltage

during charge and discharge [3.2], which is the feature most used to track battery state-of-charge and state-of-health [3.1, 3.3, 3.5]. Improvements were also made in the method of 'entropy profiling', which measures the changes of free energy, entropy, and enthalpy in a LIB during charge and discharge. By reducing measurement time from weeks to hours, the method was made viable for diagnostics of commercial cells [3.6]. In a recent study [3.2], entropy profiling enabled us to shed new light on the well documented but poorly understood phenomenon of voltage hysteresis at graphite electrodes, which is crucial for the reliable estimation of battery status.

In a 2015 project with BMW [3.4], Hoster et al. also studied the formation of the solid electrolyte interphase, an electrochemical process that is necessary for the stabilisation of the graphite electrode after manufacturing but also leads to long-term degradation [3.4].

Commercial battery cells and their diagnosis [3.1, 3.3, 3.5, and 3.6] became the focus through a 2015 collaboration with Technical University Munich [3.5 and 3.6]. That opened the door for Innovate UK funded industry-oriented projects [G2, 3], starting with the 'UK Niche Vehicle Battery Cell Supply Chain' [G2] consortium led by AMTE power (formerly AGM Batteries). Here, important trends in how battery operation influences the pace of battery degradation were found. For instance, if two battery cells are left on 'idle' for 12 months, both will lose capacity due to so-called calendar ageing [3.1]. If one cell is charged to 70% and the other is fully discharged (0 %), then the former will lose 4 times more capacity than the latter; a third cell charged to 100% may even develop internal short-circuits. Likewise, it was possible to quantify how battery degradation is impacted by charge/discharge rates, upper and lower voltage limits, and temperature [3.1, 3.3 and 3.5]. Those insights formed the basis of the algorithms and parameters behind Altelium's battery insurance products.

Project Pozibot: battery data capturing, authentication, and analysis.
Early in the Niche Vehicle Battery project [G2] (July 2018), LU hosted a meeting with AMTE Power (lead partner and a battery manufacturer), Delta Motorsports, and the insurance company CNC Asset Ltd. AMTE power and Delta Motorsports stated an urgent need for insurance-based warranties for battery packs, and CNC Asset confirmed that no such products existed so far. Hoster then led a consortium to tackle that challenge, via the Innovate UK funded project 'Pozibot' [G3], in response to the call 'Transforming Accountancy, Insurance and Legal Services with AI and Data'. Pozibot not only addressed battery diagnostics, but also topics like quantum-based data encryption and asset tagging (Robert Young and QuantumBase), risk calculation (Hoster group and Altelium), machine learning (Plamen Angelov), and algorithm-based decision making (Hoster group and Altelium). This paved the way for an algorithm-driven 'insuretech' platform that detects faults automatically from remote data, offers predictive maintenance as a service to warranty clients and updates and adjusts risk and pricing models automatically for future contracts. Altelium Ltd. was created in May 2019, i.e., shortly after project Pozibot was awarded.

A parallel collaboration with Prof Katy Mason from the Lancaster University Management School involved the supervision of one PhD student and one Masters-by-Research student on the topic of energy-storage systems based on second-life electric vehicle batteries (see reference 5.4). That collaboration helped identify the immediate market opportunity and further potential customers, which triggered the founding of Altelium Ltd. and the first client services agreements.

In summary, the research in the Lancaster BatLab (spanning a broad research area, from atomic scale phenomena, to lifetime predictions of commercial batteries), funded via the Faraday Institution and Innovate UK within the strategic Batteries for Britain initiative, has resulted in new 'extended warranty' products in the global insurance market. The impact of this strategic research funding has therefore boosted not only the science and technology sector, but also the financial services industry.

3. References to the research

3.1 Communication—Identifying and managing reversible capacity losses that falsify cycle ageing tests of lithium-ion cells. Burrell, R., Aragon Zülke, A., Keil, P., **Hoster, H.**, 15/10/2020 Journal of The Electrochemical Society 167, 130544, https://doi.org/10.1149/1945-7111/abbce1

3.2 Voltage hysteresis during lithiation/delithiation of graphite associated with meta-stable carbon stackings. Mercer, M.P., Peng, C., Soares, C., **Hoster, H.**, Kramer, D., 27/11/2020 Journal of Materials Chemistry A, https://doi.org/10.1039/D0TA10403E
3.3 Communication—Why high-precision coulometry and lithium plating studies on commercial lithium-ion cells require thermal baths. Aragon Zülke, A., Li, P., Keil, P., **Hoster, H.**, 26/08/2019 Journal of The Electrochemical Society 166, A2921, https://doi.org/10.1149/2.0841913jes
3.4 Solid electrolyte interphase: Can faster formation at lower potentials yield better performance? Antonopoulos, B.K., Stock, C, Maglia, F., **Hoster, H.**, 04/2018 Electrochimica Acta 269, p. 331-339. 9 p. https://doi.org/10.1016/j.electacta.2018.03.007
3.5 Simulation and measurement of local potentials of modified commercial cylindrical cells: I. Cell preparation and measurements. Osswald, P.J., Erhard, S.V., Wilhelm, J., **Hoster, H.**, Jossen, A. 5/08/2015 Journal of the Electrochemical Society 162, 10, p. A2099-A2105. 7 p. https://doi.org/10.1149/2.0561510jes
3.6 Fast and accurate measurement of entropy profiles of commercial lithium-ion cells. Osswald, P.J., del Rosario, M., Garche, J., Jossen, A., **Hoster, H.** 20/09/2015 Electrochimica Acta 177, p. 270-276. 7p https://doi.org/10.1016/j.electacta.2015.01.191

The battery-related publications out of the Hoster group since 2015 have so far attracted **>450 citations**. **Awards:** 'Most innovative project' prize by *The Faraday Institution* on 2018-11-07 for the presentation 'Atomistic modelling and experimental validation of voltage and entropy profiling in Li-ion cells' (Dr Michael Mercer).

Grants:

G1. *Multi-scale modelling*, since 2018, consortium led by Imperial College, one of four fast-start projects funded by *The Faraday Institution*. Lancaster Academics: Harry Hoster (Chemistry) and Denes Csala (Engineering). Grant: GBP1.821million.
G2. *UK Niche Vehicle Battery Cell Supply Chain* (led by *AGM Batteries*), *Innovate UK* project No. 104183, Competition title 'Faraday Challenge Batteries Innovation Batteries Phase 2 - Growth (Challenge Led Funding).' Lancaster share of grant: GBP601,000.
G3. *PoziBot: Insure-tech solutions for Extended Battery Warranty* (led by CNC Asset and Altelium Ltd.), Innovate UK project No. 104815. Lancaster share of grant: GBP527,000.

4. Details of the impact

4.1. Impact on the financial services and insurance industry, and the creation of a new spin-out company Altelium:

Lancaster University (LU) spin-out Altelium Ltd. was founded in 2019 in response to an early market opportunity identified in the preparation phase of project Pozibot (section 3). Altelium Ltd. interfaces the chemically driven uncertainties about battery degradation to risk calculations as common at the London insurance market. That interface is reflected by the three founding directors and their backgrounds Prof Harry Hoster (Lancaster Chemistry), Charley Grimston (CNC Asset, insurance), and John Pesmazoglou (Helestia, insurance).

The novelty of battery warranty to the insurance market is down to two facts (see statement 5.5):

(i) Chemically driven performance loss, as typical for batteries, was not established as a basis of insurance risk calculation (as opposed to mechanical fatigue or electronic failure).
(ii) Historical data on battery performance was too scarce, given that EV mass production only started in 2010, and given the pace of new battery cells entering the market.

Altelium Ltd. brought a new 'extended warranty' product (Battery Energy Storage System Warranty) [5.1] to the London Insurance Market. The underpinning risk calculations are based on the Lancaster BatLab's research results about the chemical processes of battery degradation [3.1-3.4] in combination with the jointly developed data science and machine learning tools [G3]. The UK Faraday Institution stated in a recent report: "*through the creation of Altelium, the power of battery data can now be harnessed. Real time information about battery State of Health, enhanced by AI technology, has been packaged together in a secure platform, which is accessible and practical for customers who need to make investment or operation decisions about Electric Vehicle batteries*" [5.1, 5.6].

As of November 2020, Altelium has 20 employees. Data experts Judith Elgie and Jazz Kirkwood are co-located in the premises of Energy Lancaster and are thus embedded in the research activities of the Lancaster BatLab. Battery experts Prof Harry Hoster (Altelium co-founder) and Dr Alana Aragón Zülke are affiliated with LU and Altelium. All other employees (software, operations, claims handling, finances, business development) are based in Finmere, Buckinghamshire.

Since its founding, Altelium has raised **investments worth GBP390,000 from its founding shareholders** and won **GBP806,560 of research grants**. As of November 2020, income from first customers (*Connected Energy* and *AMTE power*) **has been GBP121,000**. [redacted] [5.5]. Altelium is determined to position itself to grow in support of UK and worldwide green energy initiatives and is poised to expand its team to maintain growth in line with international momentum. From 2021 onwards, Altelium expects income to reach GBP590,000, GBP2.117 million, and GBP4.095 million per annum, respectively [5.5]. Altelium's income projections ("Net Worth Premium") are GBP0.7million, GBP4million, and GBP13million for years 2021, 2022, and 2023 [5.1, 5.5]. Altelium's Battery Energy Storage System Warranty is continuously improved to meet the demands of customers. Those demands grow and diversify, given the rapid growth of the Energy Storage market (also due to the UK's Green Growth strategy) and the rising wave of used electric vehicle batteries that become available for stationary energy storage ('second life').

On the Lloyd's of London side, work is progressing toward securing the first capital provider to financially underwrite the new insurance product created by the LU team and Altelium - an extended warranty for a set of energy storage containers based on used electrical vehicle batteries ('second life'). Negotiations started in November 2019 and are ongoing, with the aim of creating the foundations for a co-designed battery warranty underwriting model. This represents a first of its kind *globally* and is a crucial milestone in the wider roll out of green technology [5.2].

The Lancaster BatLab underpins trust relationships between Altelium and their customers and capital providers by ensuring that Altelium's algorithms and assumptions are founded on world-leading research. This includes the provision of informed modifications of the warranty products as required for new battery cell models or different battery usage patterns.

4.2. Supporting SMEs into the electric vehicles and stationary battery storage markets: Insurance-backed extended warranty allows SMEs to offer their customers longer (e.g. five-year) warranties on their products (e.g. energy storage containers that contain second-life electric vehicle batteries). Without such warranty, their products are not eligible for many B2B procurement processes, thus limiting their market chances. SMEs (with their rather slim balance sheets) can offer longer term ('extended') warranties only when backed by an insurance company with access to sufficient capital. Companies like Altelium and CNC Asset act as translators between warranty needs of technically oriented businesses and the large-capital insurers (e.g., in the Lloyd's of London syndicates) by creating technically informed risk calculation and pricing.

The creation of Altelium and much of the work conducted by the LU team was motivated initially by the desire to provide support to those SMEs and green-tech start-ups with which it was engaged [G2-G3], including: Connected Energy, AMTE Power (formerly AGM Batteries), Delta Motorsports, and Brill Power. For AMTE Power as an emerging player in battery cell manufacturing in the UK, the availability of insurance-based battery warranty is essential *"if AMTE are to leverage the output of the Innovate UK funded project and establish a successful and commercially viable niche cell manufacturing facility in the UK"* [5.3]. Connected Energy (www.c-e-int.com) is a UK SME, specialising on the utilisation of second-life battery packs in stationary energy storage solutions. Connected Energy confirmed that Altelium's 'Battery Energy Storage System Warranty' removed the principle roadblock from their entry into the energy storage market: *"Our collaboration with Altelium and Lancaster University was critical for achieving an extended warranty that satisfies our customers' needs to evaluate our products as a desirable investment case. This has already led to a successful bid for a large, 2nd-life ESS*

and we expect more to come soon" [5.4 and 5.5]. The fast adaptation of that product for the special demands of second-life batteries was only possible via (i) **a Client Services Agreement worth GBP95,000** signed between Altelium and Connected Energy in April 2020 and (ii) underpinning contract research and consultancy by the Lancaster BatLab team funded by Altelium and CNC Asset. Connected Energy and other Altelium clients expect to install several thousand second-life battery packs (with a total power of more than 250 MW) in the next three years [5.5], which could not proceed without the new warranty product.

4.3. Environmental impact:

The new battery warranty product and the work of LU and Altelium, has enabled companies and investors to more easily venture into the battery market, leading to enhanced growth and better market access for Electric Vehicle (EV), energy storage, and green technology producers [5.1-5.6].

A faster deployment of energy storage solution and of clean transport in business setting has an even bigger environmental impact than the electrification of private cars. Whereas the latter are typically parked for 90% of their time, energy storage systems and business-related vehicles are constantly in use. Clean air in ports, warehouses, and airports will strongly benefit from that transition. The UK's GBP2.5 billion 'Green Growth Strategy' (announced in November 2020) will further boost the deployment of solar and wind energy installations, whose power variability is a key driver for energy storage installations. Our enabling of faster deployment of 'second-life' battery storage systems is essential for the circular economy of Li ion batteries, where maximising the useful life is an important component.

As the Faraday Institution's Head of Engagement has stated with regards to the hurdles facing the transition to green energy sources: *"Major barriers... hold back battery producers and electric vehicle (EV) manufacturers from having the confidence in the state of battery health to a level that can be warranted. The depth of information needed around battery history, changes to the battery chemistry and the impacts on future performance to underpin a battery warranty – or investment decisions in them – has not been readily available"* until now, thanks to research by Lancaster University and Altelium [5.6]. Empowering new players on the second-life market (including SMEs) will ensure that battery packs with their expensive and partially hazardous components are accounted for throughout their life cycle, and eventually feed into verified and clean material recycling processes [5.4]. Lastly, our newly created link between battery science and technology on the one hand and financial services on the other will ensure that the 'Green Growth Strategy' will not only benefit the environment and the technical sector of the industry, but also the financial services sector, the central economic stronghold of the United Kingdom [5.1].

5. Sources to corroborate the impact

5.1 Altelium website explaining the products and services provided and their importance to the battery and green energy markets: https://altelium.com/what-we-offer/.
5.2. Corroboration from Managing Director of Insight Risk Consulting, a general insurance actuarial consultancy linked to Lloyd's of London (Contact details provided).
5.3. Statement from 'AMTE power', a new battery cell manufacturer in the UK (2020).
5.4. Statement from 'Connected Energy', highlighting that Extended Warranty is a game changer for their business with second-life batteries (2020).
5.5. Statement from CNC Asset Ltd. and Altelium Ltd. on the relevance of Lancaster's battery research for their business (2021, Letter from the Chairman of the board of Altelium Ltd., Hon. Gerald Charles Walter Grimston).
5.6. Statement from the UK Faraday Institution on the quality of LU Chemistry's battery research and the significance and uniqueness of warranty products as a technology transfer output in battery research (2020).