The Mathematical Sciences and the ISCF

Workshop Summary

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Contents

Forewords

The Mathematical Sciences is a subject of great intricacy, elegance and utility. The UK punches above its weight, by all metrics, in regard to the scale and quality of its research. It is also a subject which has exceptional breadth. Hence, in many UK mathematical sciences departments we pride ourselves in undertaking study in topics such as industrial mathematics, applied statistics and operational research in addition to the more traditional pure and applied mathematical. There is a general recognition in our community of the value of our interaction with cognate areas, such as physics and computer science, as well as increasing value to subjects further afield in the humanities and social sciences.

In recent years, there has been an increasing focus on technological solutions to complex global and societal issues. This has translated into a greater importance places on the impact of the research that governments support. The UK is at the vanguard of this drive to ensure that research groups within academia better recognise and exploit their activities and build partnerships both to other disciplines and to industry and Government.

As the UK Mathematical Sciences research community already works with many sectors outside one may conclude that it is relatively easy to scale up the community's activity in impactful areas. However, this is not the case for a variety of reasons, not least the 'impedance mismatch problem' – as coined by Professor Peter Grindrod CBE - and our inability to engage easily with stakeholders to define and develop fertile areas of common interest. A number of enthusiastic members of our community, together with national and the Knowledge Transfer Network, have worked tirelessly to encourage debate about the way ahead for knowledge exchange in the mathematical sciences, to enable greater scale-up through collaborations, to break down barriers impeding interdisciplinary interactions, and to facilitate fuller engagement with the significant funding opportunities introduced in recent years.

As Director of the Isaac Newton Institute (INI), and its knowledge exchange arm, the Newton Gateway to Mathematics, I see it is as my role, in partnership with the International Centre for Mathematical Sciences, to facilitate and focus the efforts of the community to the above ends. Together, we are the independent UK research infrastructure for the mathematical sciences and so our role is to provide support, expertise and encouragement to our academically and geographically diverse community. A little over a year ago we ran a workshop for the community on the Global Challenges Research Fund (GCRF) from which came a dedicated EPSRC call. This report arises from another such activity, a three-day workshop organised by the KTN and a team of academics, and supported by both INI and ICMS. Its purpose was to analyse and explore the various aspects of the Industrial Strategy Challenge Fund (ISCF) and thus minimise the 'impedance mismatch' between researchers within the mathematical sciences community, with their traditional capability-led research programmes, and the broader challenge-led multidisciplinary opportunities. This report is an aide-memoire for participants at that event, and a useful introduction to ISCF for those who could not take part. I believe that it will provide a valuable future resource for those seeking to engage in the ISCF.

I am grateful to Dawn Wasley and the rest of the team at ICMS for their hosting of the workshop in Edinburgh and to the organising committee for their time and energy on this project. I extend special thanks to Jo Jordan (Freelance KE Consultant) and Matt Butchers

(KTN) for the successful running of the meeting and for the production of this excellent report.

Professor David Abrahams – Director, Isaac Newton Institute.

Since the Industrial Strategy was launched in 2017, it has been a busy and exciting time for KTN, Innovate UK and UKRI. With its ambition to reach 2.4% of GDP spend on R&D, the Industrial Strategy is a step change in innovation funding in the UK. The Industrial Strategy Challenge Fund (ISCF) is a major part of this ambition. By tackling some of the largest and hardest challenges UK businesses have, the ISCF will position the UK as global leaders in new and emerging markets.

Engagement with the excellent UK research base isn't just a nice-to-have but an underpinning principal of the ISCF. The ambition can only be achieved by delivering the science that business needs, whilst maintaining the UK's world leading position in research and innovation.

One thing that you may notice in the ISCF is the diversity of challenges topics being funded, from healthy ageing, construction, plastics to quantum technologies. The mathematical sciences is almost unique in its ability to contribute to many if not all of them. What is needed is for mathematical sciences to reach out and engage with challenge holders and across research fields. It is encouraging to see this initiative as the beginning of such an approach, and I commend the Isaac Newton Institute and International Centre for Mathematical Sciences for its delivery.

During my many conversations at the ICMS in Edinburgh, it was enlightening for me and the various UKRI representatives to engage with the mathematical science community on their research and share in their positivity in engaging in this programme. I look forward to seeing future challenges and projects enriched by the power of the mathematical sciences.

Sue Dunkerton OBE – CEO Knowledge Transfer Network

Mathematical sciences is at the heart of solving some of the world's most complex issues. From fundamentals of machine learning and artificial intelligence to disease outbreak or climate change, mathematical sciences has a key role to play. This is a discipline which truly cuts across the breadth of UKRI's remit.

I see the formation of UKRI as a huge opportunity for mathematical sciences research. Never before has there been access for mathematicians to engage with such large-scale multidisciplinary funds. However, for the potential of the mathematical sciences contribution to areas such as those funded through the Industrial Strategy Challenge Fund to be truly realised, collaboration with problem owners is crucial.

This workshop has been a fantastic platform to discuss how we can achieve this wider collaboration, and I would like to thank the Knowledge Transfer Network for organising this event. I hope this will only be the start of the discussions on how mathematical sciences can engage with this Fund, and I look forward to seeing an increased understanding of how this discipline can impact on key government priorities.

Dr Katie Blaney – Head of Mathematical Sciences, UKRI EPSRC

Executive Summary

Awareness should be raised within the mathematical sciences community of wider research challenges and societal challenges (including the sustainable development goals addressed by the Global Challenges Research Fund, GCRF) and deeper integration of mathematics should be promoted within industrial challenges (including the **Industrial Strategy Challenge Fund, ISCF**).

The Era of Mathematics. An Independent Review into Knowledge Exchange in the Mathematical Sciences. Professor Philip Bond (2018) [1]

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This document outlines the efforts of the mathematical science community to engage, understand and articulate the mathematical science offering, and the points of intellectual interest to be found inside the Industrial Strategy Challenge Fund (ISCF). Background to the ISCF can be found in Section 1.

This engagement was primarily through a three-day workshop in Edinburgh funded by the Isaac Newton Institute (INI) and the International Centre for Mathematical Sciences (ICMS) with support from the Knowledge Transfer Network (KTN). The details of this workshop are shown in Section 2.

Over the course of the three days, the assembled mathematical science community heard from senior UKRI representatives, who outlined the ISCF purpose, process and various challenges for consideration. The mathematical science community then discussed with

[1] https://ktn-uk.co.uk/news/the-era-of-mathematics-review-findings-on-knowledge-exchange-in-the-mathematical-sciences-published

these representatives the areas of mathematical innovation they felt underpinned the challenges [2]. These responses can be found in Section 3 and 4.

Further to this, the delegates considered how the community might engage with senior business delegates in co-creating such challenges. By discussing the requirements for a ‘good’ ISCF challenge, and with priming talks on global industry trends, templates were worked on which might be considered mathematically-inspired ISCF challenges. Brief descriptions for these can be found in Section 5.

By demystifying the process, discussing the challenges and their aims, this document sets out the beginning of a roadmap for how the mathematical sciences can better engage with the ISCF process. We present ideas for the areas of mathematical science innovation for each of the challenges, and the best way (using tried and tested mechanisms) the mathematical sciences can be far more successful in engaging in this unique opportunity for UK science and innovation in the future.

2 It should be noted that this document contains a mathematical science community response to the ISCF challenges as they perceived it. It therefore does not necessarily indicate the current plan or future strategy for the challenges.

1. Background

1.1 UKRI, the Industrial Strategy, and the Challenge Fund

Research and Innovation is central to the UK's 2017 Industrial Strategy [3]. By increasing investment in R&D to 2.4% GDP by 2027 (from 1.7% in 2016), the Industrial Strategy aims to create an economy that boosts productivity, jobs, and earning power, enabling the UK to become the most innovative country in the world. A major component of the strategy is in challenge-led research awarded via the Industrial Strategy Challenge Fund (ISCF) which provides funding for academic researchers and industry partners to collaboratively address major industrial and societal challenges of our time.

The ISCF:

- Focuses on the four Grand Challenges of **AI and Data Economy, Future of Mobility, Clean Growth, and Ageing Society**.
- Builds on the UK's world-class research base and delivers the science that business needs to transform existing industries and create new ones.
- Accelerates commercial exploitation of the most exciting technologies the UK has to offer the world to ensure that scientific investment truly delivers **economic impact, jobs, and growth right across the country**.
- Is **industry-led** and powered **by multi-disciplinary research** and business-academic collaboration.
- Is part of the government's £4.7 billion increase in research and development over 4 years.

The ISCF is delivered by UK Research and Innovation (UKRI), the single voice for the UK's research and innovation landscape. Established in 2018, UKRI brings together the seven Research Councils, Innovate UK, and Research England. With an annual budget of £7bn, UKRI is responsible for ensuring the UK maintains its world leading position in research and innovation.

3 Industrial Strategy white paper https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future (published 27 November 2017)

1.2 Structure and Timeline

To date, the funding for ISCF has been announced in annual waves. This timeline is pictorially shown in Figure 1.

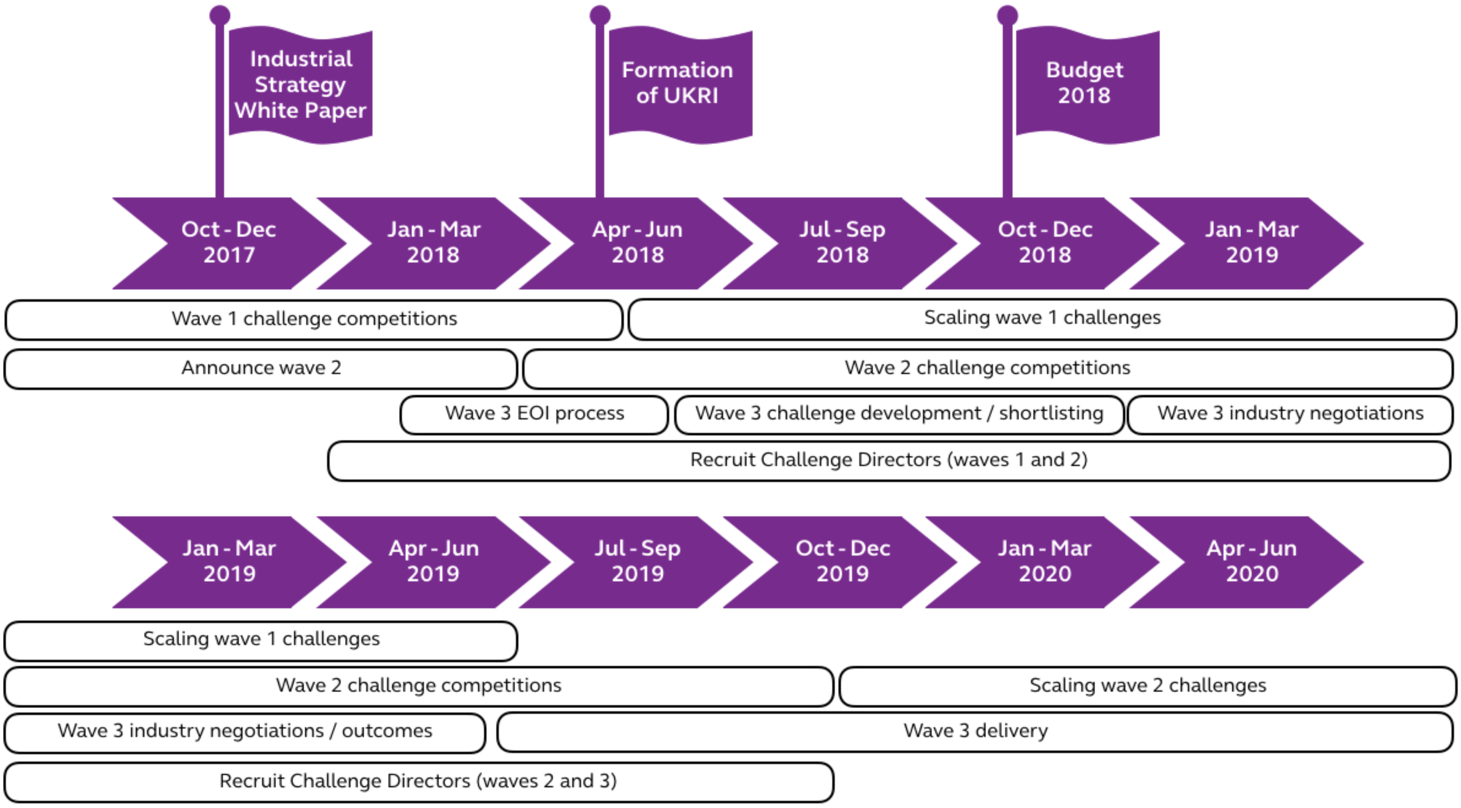

Figure 1. Timeline for the ISCF thus far

Wave 1 challenges were announced in April 2017, and were based on topics where the UK already has world-leading research and businesses that are ready to innovate, and the global market is large or fast-growing and sustainable.

Wave 2 followed a year later in April 2018, and comprised challenges developed from existing knowledge of where there was a strong industry pull.

Challenges in Waves 1 and 2 represent a funding allocation of around £2bn. They are scoped and competitions are currently at various stages of delivery [4]. They all have their own delivery mechanisms and structures, and some, for example the Faraday Institute, are creating institutions to position the UK as a global leader.

4 For funded projects, refer to https://gtr.ukri.org/

Inspired by the US Defence Advanced Research Projects Agency (DARPA) model, each challenge has a Challenge Director who sets strategic direction, UKRI representatives to manage the process, and a KTN representative is assigned to each challenge. The full list and contact details for these people can be found in Annex 2.

Wave 3 has followed a different set up to previous waves, and sought challenges developed from the community. An Expression of Interest (EoI) process ran between February and April 2018 where 252 EoIs were received. Nine challenges, subject to business case approval and industry co-funding, were approved between November 2018 and January 2019. These Challenges are scoped, but delivery mechanisms and funding competitions are still under development, and thus opportunities to engage are at an earlier phase.

There has not yet been an announcement on funding beyond Wave 3. This presents a potential opportunity for mathematical sciences to build industrial support and prepare a clearly articulated offer to new or emerging challenges. This is further explored in Section 5.

1.3 ISCF Challenges

Below is a list of the challenges thus far announced [5] in bold are the ISCF challenges considered at workshop. The challenges considered were 'down-selected' based on the amount of funding still available, variety of topics, and potential opportunities to get involved in funded programmes / demonstrators / pilots etc.

Wave 1 challenges

- Leading-Edge Healthcare Challenge (up to £188m)
- **Faraday Battery Challenge (up to £246m)**
- Next Generation Affordable Lightweight Materials Mfg (up to £26m)
- Autonomous Vehicles (CCAV projects) (up to £38m)
- Robotics & AI in extreme environments Challenge (up to £93m)
- National Satellite Test Facility (up to £99m)

5 As of 21st April 2019. Waves 1 and 2 can be found here: https://www.ukri.org/innovation/industrial-strategy-challenge-fund/ and the Wave 3 information can be found here: https://innovateuk.blog.gov.uk/2019/02/05/industrial-strategy-challenge-fund-wave-3-shortlist/

Wave 2 challenges

- Audience of the future (up to £33m)
- Next generation services (up to £20m)
- **Prospering from the energy revolution (up to £102.5m)**
- **Transforming construction (up to £170m)**
- **Data to early diagnosis and precision medicine (up to £196m)**
- Quantum technology (up to £20m)
- **Healthy ageing (up to £98m)**
- **Transforming food production (up to £90m)**

Wave 3 challenges (subject to business case and successful negotiation)

- **Commercialising Quantum Technologies (up to £70m*)**
- **Digital Security by Design (up to £70m)**
- Accelerating detection of disease (up to £79m)
- **Industrial Decarbonisation (up to £170m)**
- **Manufacturing Made Smarter (up to £121m*)**
- **Smart Sustainable Plastic Packaging (up to £60m)**
- **Transforming Foundation Industries (up to £66m)**
- **Driving the Electric Revolution (up to £78m*)**
- **Future Flight (up to £125m)**

1.4 The Mathematical Sciences and the ISCF

To the best of our knowledge, engagement of mathematical scientists directly in ISCF projects is very limited. One rare example of engagement is with the Universities of Oxford and Southampton. They are contributing a combination of PDE modelling, asymptotic, and numerical methods to describe different lithium batteries at cell level over medium and long timescales to the **Faraday Battery Challenge**: Batteries for Britain. Their models incorporate the interacting physics: electrochemistry, solid state transport, reaction kinetics, mechanical deformation, thermal generation and expansion in a highly convoluted porous geometry.

However, there are many mathematical scientists who are *already* working on ISCF challenge topics, although we believe most are unaware of this overlap, and / or these are not coordinated into the ISCF in any strategic sense. There are major investments across the UK into mathematical sciences research areas which are hugely relevant to the ISCF programme. Workshops and research programmes in areas pertinent to the challenges also appear as a regular occurrence in the mathematical sciences research calendar. The following examples are intended to be illustrative, rather than exhaustive.

In 2013, EPSRC invested £3.5m in six *Future Manufacturing with Mathematical Sciences* projects, in **Manufacturing Made Smarter** topics including automated manufacturing and inverse problems in machining [6].

Directly relevant to the **Data to Early Diagnosis and Precision Medicine** challenge, EPSRC funded five Mathematics Sciences in Healthcare Research centres in 2015, including precision healthcare and predictive modelling, totaling an investment of £10m [7].

Mathematical scientists are currently working in several areas in relation to the **Future Flight** challenge. Two example projects include a large industry-funded project run by the University of Bristol, and an EPSRC Programme Grant led by Lancaster University. T-B PHASE (Thales-Bristol Partnership in Hybrid Autonomous Systems Engineering) [8] is a 5-year project which targets fundamental autonomous system design problems in Hybrid Low-Level Flight, Hybrid Rail Systems, and Hybrid Search & Rescue. Whilst OR-MASTER (Operational Research - Mathematical models and algorithms for allocating scarce airport resources) is a six-year £2.3m EPSRC Programme Grant involving several airlines and airports [9]

Back in 2000, three back-to-back one-week meetings were held at the Isaac Newton Institute on *Free Boundary Problems in the Glass, Food and Metal Industries,* which directly sits within the remit of the **Transforming Foundation Industries** challenge. Highlights included *Float glass stability, Chocolate coating, boluses*, and *Blast furnace design.* See further [10].

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6 https://gow.epsrc.ukri.org/NGBOViewPanelROL.aspx?PanelId=1-14M44A&RankingListId=1-14O96L.
7 https://epsrc.ukri.org/newsevents/news/newmathscentres/
8 https://www.bristol.ac.uk/engineering/research/t-bphase/about-us/
9 https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/M020258/1.
10 https://www.newton.ac.uk/files/reports/scientific/fbp.pdf

An invitation-only workshop on efficiency, capacity and safety in air traffic operations, organised for NATS by the Smith Institute in 2017, identified the key fields of research for future investment, directly relevant to the **Future Flight** challenge [11].

In the last 18 months alone there have been three workshops in areas of the **Prospering from the Energy Revolution** challenge. In 2018, the KTN and the ICMS ran a three-day *Management of energy networks* meeting [12] and a Study Group focused on the Mathematics in Energy Systems [13]. There is currently a four-month programme on the *Mathematics of Energy Systems* taking place at the Isaac Newton Institute [14], including topics such as operational planning under uncertainty and pricing.

In March 2019, the KTN and the Newton Gateway to Mathematics brought together academic and industrial practitioners in the **Quantum Technology** space to explore how quantum computing can be employed in the pharmaceutical industry [15].

A browse of the Mathematics in Industry Study Group archive [16] reveals many problems which have been investigated at Study Groups over the years that overlap with the ISCF challenges. A similar overlap is found by searching the database of Mathematical Sciences Impact case studies submitted to REF 2014 [17]. In Sections 3 & 4 of this report, we have tried to identify one illustrative Impact case study for each challenge.

Dedicated projects at the Alan Turing Institute (for example the AI for precision mental health [18]), Centres for Doctoral Training (such as UCL's CDT in Delivering Quantum Technologies [19]), and the Heilbronn Institute for Mathematical Research [20] provide a critical mass of research focus, students, and research staff who could transform many of these challenges through the disruptive approach mathematical science brings.

11 https://www.smithinst.co.uk/wp-content/uploads/2018/03/Smith-Institute-Brochure.pdf (p16)
12 https://www.icms.org.uk/energynetworks.php
13 https://www.icms.org.uk/KTN_Energy_SG.php
14 https://www.newton.ac.uk/event/mes
15 https://gateway.newton.ac.uk/event/tgmw69
16 http://www.maths-in-industry.org/miis/view/subjects/
17 https://impact.ref.ac.uk/casestudies/Results.aspx?UoA=10
18 https://www.turing.ac.uk/research/research-projects/ai-precision-mental-health
19 https://www.ucl.ac.uk/quantum/study-here/cdt-delivering-quantum-technologies
20 https://heilbronn.ac.uk/

It is our goal that the result of this workshop is to both raise awareness of the opportunities for mathematical scientists to engage with the ISCF, and to facilitate coordination with existing activity in a strategic way.

1.5 What is in the ISCF for the mathematical sciences?

It should be noted that the ISCF is a new way of delivering innovation funding, and as such is unfamiliar for many both within and outside of the research community. It is reasonable to ask why would / should UK academic researchers wish to engage. Borrowing words from mathematicians already engaged in the ISCF challenges [21]:

> [The] ISCF provides huge opportunities for mathematicians to exploit their ability to gain understanding and to **provide disruptive thinking on critical issues** by providing novel theoretical frameworks for understanding behaviour.
>
> Engagement requires mathematicians to be involved in **large consortia across disciplines and in collaboration with end users**
>
> Benefits include support **of high quality research staff, novel questions to explore, time to dig deep into the underlying theory, ability to make future mathematicians** who can apply their talents to practical problem of great importance.

21 C. Please. Summary. A Mathematician's Experience with the ISCF (2019)

2. ISCF and the UK Mathematical Sciences

In 2018, a group of interested parties from within the mathematical science community applied to the ICMS for a *Strategic Workshop* to explore where and how mathematical scientists could get involved in the ISCF. With matched funds from the INI, a steering committee (listed below) was established to ensure representation from all sub-disciplines of the mathematical science community

David Abrahams	Isaac Newton Institute
Martine Barons	University of Warwick
Collin Bleak	St Andrews University
Matt Butchers	Knowledge Transfer Network
Jo Jordan	Consultant
Colin Please	University of Oxford

The workshop held at the ICMS, Edinburgh between the 20th – 22nd February 2019 attracted over 70 representatives from across Government, academia, and business. The meeting was a unique opportunity to discuss ISCF challenges with senior UKRI representatives including Sir Ian Diamond, Mike Biddle, various challenge leads and innovation leads across Innovate UK, and EPSRC.

The final day was structured around writing our own mathematical science inspired ISCF "bids". Conversations were prompted by senior business representatives; PepsiCo, National Grid, Dstl, GlaxoSmithKline and Rolls-Royce. The detailed agenda and participants can be found in Annex 1.

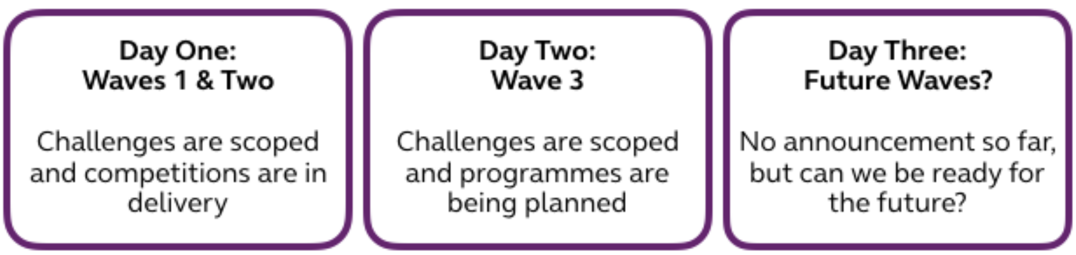

Figure 2. Brief outline structure of the workshop

3. Waves One & Two (Day One)

Day One focussed on Waves One and Two challenges. The challenges discussed were down-selected from the complete list based on availability of future funds in the challenges, and variety of topics (i.e. the balance between the Grand Challenges). Brief presentations were given on the topics, the 70 delegates then self-organised into working groups to discuss the following questions:

- What are the mathematical sciences doing already in relation to this challenge, and the names of industrial organisations who are involved?
- What (more) could the mathematical sciences bring to the challenge and how does it relate to the challenge objectives?
- Names of UK mathematical scientists to ‘champion’ the communities interaction with this challenge
- Examples of relevant case studies
- ‘Bullet point statements’ which could be included in call scopes

The output of these discussions form the basis of the next two sections. We report here firstly, a reiteration of the challenge statement followed by the mathematical areas and application which are felt to be relevant to the challenges, and finally – where available and appropriate - an example of cutting edge research used as an exemplar to highlight what benefit the mathematical sciences can have against such a challenge.

It is felt that some of these challenges and responses are well formed (often where there is a mathematical heritage in the challenge already), the work that follows can then be used by the UKRI challenge teams as a reference for where and how to engage the mathematical sciences, and also by the community itself to realise where the research topics they work in fit into the ISCF.

There are also those which are less well-defined, and require further engagement to unpick the challenge and the mathematics, These less well-defined challenges are indicated in their titles with the symbol: ‡. Ideas for how to improve this are detailed in Section 7.

3.1 Faraday Battery Challenge

Challenge

More and more people are making the switch to fully electric and zero emission vehicles. As petrol and diesel cars come to be phased out this market is only going to grow - to an estimated £5 billion in the UK and £50 billion in Europe by 2025.

The £246 million Faraday battery challenge will invest in research and innovation projects and establish new facilities in **battery production, use and recycling.**

These batteries will be more **cost - effective, durable and lightweight** than ever before, with improvements to their **performance, safety and sustainability.**

Their use will go beyond the automotive sector, crossing over into other applications within the low carbon, electrified economy.

Response:

- Physical, electrochemical models for predicting solid state transport, reaction kinetics, mechanical deformation, thermal generation, and expansion in a highly convoluted porous geometry.
- PDE modelling, asymptotic methods and numerical methods to describe different batteries and varying timescales.
- Data science and AI combined with first-principles models to identify mechanisms and correlations associated with (i) battery materials health; (ii) electrode formulations and structures; and (iii) cell ageing to design and control novel battery architectures for maximal lifetimes, and minimal failure rates.
- Economic modelling / option pricing for storage and charging.
- Economics for servitisation model for batteries.
- Dynamical networks models of modules, cells etc., and management.
- Use of robust UQ methods for linking multiple scales (lengths and time).
- Inverse problems; in particular this could be applied to: (i) electrode manufacture, (ii) cell performance (given electrode characteristics and cell design); (iii) ageing.

3.2 From Data to Early Diagnosis & Precision Medicine

Challenge:

Identifying diseases and conditions early is usually the best way to contain them later on. They can be **mitigated, managed and made to have a less serious impact** on a patient's quality of life.

Once diagnosed, it's important that a patient gets the right treatment. Through an improved understanding of a disease and its characteristics, it means that the **best treatment for the individual** can be selected first time.

Through this challenge the government will fund industry and research to **combine data and real-world evidence** from our health service and create new products and services that **diagnose diseases earlier and more efficiently.**

Response:

- Pattern recognition, topological data analysis for tumour detection, links with mathematical oncology.
- Quantitative challenges in regenerative medicine, such as metrology and automation.
- Asymptotic models of cartilage deformation.
- Bayesian analysis of electronic health records.
- Data science and tomography applied to MRI scans of patients with dementia.
- Design and analysis of randomised trials.
- Data-driven analysis of genotype-phenotype relations.
- Predictive mathematical models for managing and treating chronic health conditions.
- Dynamical systems models for understanding antimicrobial resistance.
- Multiscale soft-tissue modelling of cancer and cardiac disease.
- Multiscale networks for unifying patient-level precision medicine with behavioural and social contexts.
- Operational research for analysis of immunisation programmes, and wider delivery and planning of services.
- Mathematical methods for combining large longitudinal studies.

Case Study:

Around 3-5% of the population suffer from epilepsy. Selecting the most appropriate treatment for an individual is of paramount importance for the patient's quality of life. Mathematical Scientists from the University of Liverpool carried out competing risks data analysis of randomised control trials to identify the most appropriate first-line treatment. Their analysis took both the efficacy and the cost of the drug into account. The results showed that the standard treatment drug is most effective for generalised epilepsy, whilst a new drug is as effective for newly-diagnosed localised seizures, has fewer adverse effects, and is cheaper.

Their work provides the best evidence globally to inform treatment decisions in newly-diagnosed epilepsy patients and triggered an update to the NICE (National Institute for Clinical Excellence) clinical guidelines on epilepsy in 2012. More details are described in the REF 2014 impact case study *Informing clinical policy on epilepsy treatment*

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=5569.

3.3 Healthy Ageing

Challenge:

The number of people over 75 in the UK today is one in 12. By 2040, it will rise to one in 7. We're also living for longer and a third of children born now are expected to live to 100.

This presents a challenge to health services, but it is also an opportunity for businesses and researchers who can help **people to stay active and productive as they age.**

This challenge will support UK government's mission to ensure people can enjoy **at least 5 extra healthy, independent years of life by 2035**, while narrowing the gap between the experiences of the richest and poorest.

Through the challenge, government will bring together UK businesses and researchers to support people to **stay in their homes for longer, tackle loneliness, and increase independence and wellbeing.**

Response:

- Network analysis to understanding the provision of service for different communities / demographics and health and social care.
- Real-time analytics for monitoring people in their homes to reduce reliance on GPs / hospitals.
- Financial mathematics for the modelling and design of future financial products (pensions, insurance etc), robust and appropriate for the ageing population.
- Natural language processing (NLP) for inferring behaviour from speech or written documentation.
- Image recognition for recognising mental health issues through integration with smart phone technology.
- Agent based modelling and collective dynamics for the design of future community spaces to tackle lonliness.
- Graph theory applied to social media networks to predict at-risk groups.
- Machine learning, and AI for personalised nutrition for ageing communities, improving 'wellness' and fitness.

- Quasi-Economic models about extending life.
- Modelling of digestive processes, and pharmaceutical release systems.

Case Study:

Mobile technologies offer new opportunities for prospective, high resolution monitoring of long-term health conditions. The opportunities seem to be of particular promise in psychiatry where diagnoses often rely on retrospective and subjective recall of mood states.

A signature-based learning method was used to capture the evolving interrelationships between the different elements of mood and exploit this information to classify participants' diagnosis and to predict subsequent mood.

The three participant groups could be distinguished from one another on the basis of self-reported mood using the signature methodology. The signature method provided an effective approach to the analysis of mood data both in terms of diagnostic classification and prediction of future mood. It also highlighted the differing predictability and the overlap inherent within disorders.

https://www.ncbi.nlm.nih.gov/pubmed/30546013

3.4 Prospering from the Energy Revolution

Challenge:

Smart energy systems can intelligently **link energy supply, storage and use, and power heating and transport** in ways that dramatically improve efficiency. It's a huge market opportunity, with $2 trillion a year estimated to be invested in global energy infrastructure.

The government is enabling the UK to take advantage of this by funding industry and researchers to create new systems. They will provide **cleaner, cheaper energy,** while creating high value jobs for the UK.

Doing so will meet government's priorities set out in the Clean Growth Strategy, the Smart Energy Systems and Flexibility Plan and Industrial Strategy's clean growth pillar. It will help the UK to meet **air quality targets** at **lower investment costs, avoid power cuts** and ensure its compliance with the fifth carbon budget (from 2028).

Response:

- Stochastic models of distributed supply and demand, which are required for both system operation, control and planning.
- Probabilistic modelling of capacity markets to reduce the risk of capacity shortages.
- Design of new materials to improve solar panels.
- Smart meter data analysis.
- Novel forecasting methods (classification, unsupervised learning) for understanding the variability, volatility, seasonality, and diversity of renewable energy sources.
- Scheduling maintenance.
- Design and operation of local energy markets and peer-to-peer trading.
- Forecasting pricing, incentive modelling, and dynamic pricing including vehicle to grid (V2G).
- Modelling demand for electric vehicle charging, including access to off-street parking including accounting for uncertain uptake in innovative technologies.
- Optimising asset management.
- Arbitrage and demand-side management of energy storage.

- Optimal control of networks with low inertia.
- Modelling domestic heating and behavioural / consumption for distinct dwelling-types.

Case Study:

To avoid blackouts, it is vital that demand for electricity does not exceed supply. Mathematical scientists from the Universities of Durham and Heriot Watt were commissioned by the National Grid to assess the risks of generating capacity shortages over a period of five winters. The researchers used a probabilistic approach, combined with sensitivity analysis, to analyse uncertainties related to intermittent wind generation, power plant closures, and overall electricity demand.

Their results are published in Ofgem's publicly-available Electricity Capacity Assessment 2012 and 2013 reports, which have provided a key input to government policy on security of electricity supply. Their work is further described in a REF 2014 Impact Case, *Supporting the GB Electricity Market: Capacity Assessment and Capacity Market Design.*

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=11796.

3.5 Transforming Construction ‡

Challenge:

The UK needs more affordable places for people to live and work that are safe, healthy and energy efficient.

To create better buildings and deliver the £650 billion worth of projects planned under the national infrastructure programme, the construction industry needs to become more **productive, competitive and sustainable.**

This challenge will invest £170 million - matched by £250 million from industry - to modernise construction processes and techniques, such as using **digital design and standardised, modular components for offsite manufacture**.

Response:

- Stochastic processes models of portfolio management.
- Computational statistics – Bayesian inference, financial maths, stochastic processes – for distributed decision making.
- Uncertainty modelling and game theory of contractual negotiation.
- Physical modelling, decentralised control, and optimal placement of sensors and smart houses.
- Resilience, robustness, and quality of manufacturing supply networks.
- Stochastic networks of industrial scheduling problems.
- Optimisation of construction costs.
- Fluid mechanics of building environments.
- Digital twins / BIM, for example for modelling building efficiency.
- Big data analytics and machine learning for handling uncertainty in manufacturing.

Case Study:

Previous models of building ventilation were limited by the assumption that each zone within a building was at a single uniform temperature. Inspired by laboratory experiments, mathematical scientists at the University of Cambridge developed fluid mechanics models to describe ventilation flows within buildings, including for buildings which are naturally ventilated (i.e., do not rely on air conditioning). These buildings are significantly more energy efficient, typically having carbon emissions of around 25% of fully air conditioned buildings.

The US Department of Energy has incorporated the algorithms developed into their whole-building simulation code EnergyPlus. This code is used around the world, and has optimised the design and energy performance of several high-profile buildings such as the headquarters of the New York Times. For more details, see the REF 2014 impact case study *Low-energy buildings*

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=17232.

3.6 Transforming Food Production

Challenge:

To transform food production systems so that by 2030 UK agricultural productivity is market leading and environmental impacts have **reduced by 40%, waste across food supply chains** is minimised and the UK is a leading exporter of **data-driven solutions supporting food production**.

Response:

- Modelling of climate for decision support in precision agriculture.
- Optimisation of energy & water use, nutrients and fertilisers for crop production.
- Building resilience and robustness into UK supply chains by modelling provenance of food.
- Multiscale physical modelling of soil quality, biodiversity and natural capital.
- Real-time data collection and analysis of production to ensure welfare, quality and value.
- Modelling of ‘what-if’ scenarios for experimentally inaccessible events, i.e pandemic planning.
- Continuum modelling of novel production processes.
- Data analysis to support genotyping / phenotyping for maximising desirable qualities in livestock / crops / aquaculture.
- Linking data, operational research and growth models to provide personalised nutrition for animals.
- Image analysis for use in agricultural robotics for precision agriculture.

Case Study:

Phytoponics is an ‘AgTech’ start-up based in Wales. Their vision is to innovate the food chain by facilitating the mass adoption of Hydroponic technology, so that a market sustainable agriculture can tackle this century’s food, land and water challenges. Hydroponics is the best way to grow fruit and veg, using 10 times less land and water than a traditional field.

The challenge addressed is to understand the process by which dissolved oxygen enters into the water within Phytoponics Hydrosac^{TM} system. The mathematical approach revolved around the way bubbles are formed from the pores within the aeration strip at the bottom of the sac.

Using simple experiments and mathematical analysis, a basic understanding of the bubble dynamics was obtained. In particular, a model is constructed for the diffusion of dissolved oxygen from the bubbles. From this model, operating recommendations are made on the key design parameters. In particular, a tentative recommendation is that the pressure in the aerator strip and pore diameters are both minimised, while the number of pores is allowed to be as large as is necessary to achieve the required level of dissolved oxygen for minimum energy cost.

4. Waves Three (Day Two)

Day Two focussed on the recently announced challenges for Wave Three, it followed the same structure and format as Day One with discussions taking place after brief UKRI presentations introducting the challenge. Again, a ‡ symbol is used to indicate a challenge and response which needs further work.

4.1 Commercialising Quantum Technologies ‡

Challenge:

This challenge will use the UK's global strength in quantum technologies to radically transform **computing, sensing and communications**. This new technology promises to provide **secure connectivity, safe autonomous mobility** and address currently **intractable data analysis opportunities.**

Response:

- Information theory and quantum error correcting codes.
- Abstraction, using the mathematical sciences as a language to describe problems on which a quantum computer can be used.
- Quantum-limited sensing – error bounds – characterising quantum states using classical information theory or graph theory.
- Quantum key distribution and post quantum algorithms for next generation cryptographic systems.
- Mathematical image analysis used for in-situ metrology using quantum sensors and imaging.
- Using quantum simulation and computational methods to model biological processes for use in pharmaceutical industries, mathematical language to describe the novel computational paradigm.
- Optimisation of large problems with many parameters for climate science, financial services etc.

Case Study:

The past two years have seen rapid advances in building increasingly large-scale quantum computers. It is now widely expected that there will be a demonstration, within the coming months, of a device that cannot be simulated by any classical computer (so called 'quantum computational supremacy').

The prospect of a relatively near-term device capable of a quantum advantage has sparked a huge amount of excitement both in academia and in industry. The conference will cover the central questions in this emerging field, focusing on how to use quantum computers to solve some of the grand challenges of our time, such as drug discovery or the development of energy-efficient industrial processes or new catalysts.

https://heilbronn.ac.uk/2018/10/26/quantum-computing-theory-in-practice/

4.2 Digital Security by Design ‡

Challenge:

This challenge will radically **update our insecure digital computing infrastructure** by developing and applying hardware innovation.

It will boost productivity and halve cybersecurity costs to businesses, and mean that connected and **autonomous vehicles, IoT and other digital services are intrinsically safe.**

Response:

- Formal methods for software verification and validation to engineer in security.
- Sensible policy suggestion – open source code. For security purposes.
- Establish sensible supply chain for hardware upgrade. Made designs and software upgrades are always sufficient for security adjustments in lifetime of objects.
- Policy / ethics: software upgrades / security. System needs to be modular so it can be replaced even if company disappears.
- Managing credentials in a sensible way.
- Cryptography, number theory – graph theory / synchronisation for secure communication.
- Using mathematical models to communicate complex maths / security points.
- Side-channel analysis using Maxwell’s equations

4.3 Driving the Electric Revolution ‡

Challenge:

Also announced at Budget 2018, this challenge will allow the UK to seize the economic opportunities from the global **transition to clean technologies and electrification**. The programme will help businesses across seven different sectors to invest and work together to capitalise on the UK's strengths in this technology.

Subject to business case and match funding from industry, government has announced that it is prepared to invest up to £78 million in this challenge

Response:

- Continuum models of thermal management, heat generation, and removal to inform choice of coolant and use of heat pipes in electric motors. Electromagnetic interference management
- Models for accurate simulation – including design and multi-physics modelling for example, improved design for magnetic components etc taking into account material sustainability and supply chain resilience.

Case Study:

Researchers from the University of Sunderland's Institute for Automotive and Manufacturing Advanced Practice have modelled, and developed, a novel ultra-high efficient gearbox control system for electric vehicles.

Using computer simulation and a full-scale prototype rig, they have modelled a geared transmission in an electric vehicle to investigate efficiency gains. Their results indicate that by using a variable ratio gearbox within an electric vehicle it is possible to improve overall energy consumption levels by around 5 – 12% depending on the driving cycle used.

For more details, see the REF 2014 impact case study *New Technologies for Electric Vehicles.*

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=27378

4.4 Future Flight

Challenge:

Announced as part of Industrial Strategy One Year On events, this challenge will show how innovative flight solutions, such as **electric planes with vertical take-off capability, goods and service drones** will radically transform how we fly by 2023. It will also make sure we are able to **manage this newly congested airspace safely and reduce its environmental impact.**

Subject to business case and match funding from industry, government has announced that it is prepared to invest up to £125 million in this challenge.

Response:

- Statistical modelling, for example model order reduction (reducing computational complexity of mathematical models in numerical simulations), of airport capacity.
- Understanding and communicating – especially to the public – varieties of risk, for example of unmanned aerial vehicles.
- Optimal control of hybrid-electric vehicles.
- Data assimilation, combining theory with real-time observations of aircraft trajectories.
- Productivity and lifecycle analysis of aircraft.
- Uncertainty quantification of air traffic management.
- Collective dynamics of autonomous-human hybrid systems.
- Operations Research for demand, routing, and logistics of aircraft.
- Filtering and tracking algorithms for tracking autonomous vehicles.
- Time series prediction, probabilistic prediction of aircraft movement.
- Multi-objective optimisation with real-time updating of on-board air vehicle data and related ground infrastructure.
- Certifiable robustness of flexible systems.
- Game theory for autonomous swarms and airspace management.

Case Study:

Being able to make a decision in real time is vital in many different safety-critical aerospace applications, for example if a component fails or if there is a sudden change in weather. Traditionally, methods, such as Fault Tree Analysis, have been used to predict the likelihood of failure in complex engineering systems. However, for large-scale systems these methods are computationally intensive, so approximations of the calculations are required, resulting in loss of accuracy.

Mathematical scientists at Loughborough University have developed new computational methods for real-time mission planning, based on Binary (true or false) Decision Diagrams, which use exact calculations. These algorithms can be used to diagnose in-flight faults in unmanned aerial vehicles more accurately, and more quickly, than existing methods, and thus can be used in decision making. This research has been integrated into major industrial trials and proprietary software products, including at BAE Systems.
For more details, see the 2014 REF impact case study *Fast binary decision algorithms to enable real time diagnosis of in-flight faults in Unmanned Aerial Vehicles* https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=36084.

4.5 Industrial Decarbonisation ‡

Challenge:

Announced at COP24 climate talks, this challenge will develop and **deploy low carbon technologies** and enabling infrastructure in one or more heavily industrialised areas and aims to create at least one low carbon cluster by 2030. Subject to business case and match funding from industry, government is prepared to invest up to £170 million in this challenge.

Response:

- Decision making under uncertainty, probabilistic assessments for carbon capture and storage technologies.
- Models of geological risk of leakage of captured carbon.
- Modelling, risk and economics of manufacturing processes.
- Continuum models of fluids, chemistry, heat involved in the sequestration process.
- Cost / benefit analysis – of retrofit carbon capture equipment or of new-build power stations.
- Game theory – one industry gains, one loses, understanding the relationship between oil price and plastic manufacture.
- Economic modelling of costs of captured carbon dioxide transport versus utilisation.
- Mapping and inventories of stored carbon.

Case Study:

Carbon sequestration is the process involved in carbon capture and long-term storage of carbon dioxide, and is a vital tool in climate change mitigation.

Informed by novel laboratory experiments, mathematical scientists at the University of Cambridge developed fluid dynamics models to describe the spread and leakage of carbon dioxide injected into a porous medium. They successfully validated their models against field data collected in the North Sea.

The lead researcher was invited to Chair the European Academies' Science Advisory Council (EASAC) Working Group on Carbon Capture and Storage (CCS) which published a report on the potential and challenges of CCS for the European Parliament in 2013. This research has also made an important contribution to the Australian Government's policy on CCS.

For more details, see the University of Cambridge's REF 2014 impact case study *Carbon dioxide sequestration.*

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=22417.

4.6 Manufacturing Made Smarter ‡

Challenge:

Made Smarter will support the transformation of UK manufacturing through **industrial digital technologies,** such as the **Internet of Things and virtual reality**. This will ensure the long term prosperity of UK Manufacturing, raising total productivity by 30% by 2030, making the UK a global leader of the 4th Industrial Revolution and delivering clean growth.

Response:

- Data assimilation and related analytics for the optimisation of manufacturing efficiencies by incorporating real-time monitoring and control i.e., a Digital Twin.
- "Smart Design" - is it buildable? Using physical models to explore more fully available design spaces and predict output qualities and manufacturability.
- UQ for making processes robust, dealing with random component variability, and uncertainties arising from lack of process knowledge.
- Statistical approaches to sampling and quality control.
- Blockchain and distributed ledger technologies for supply chain analytics and their integration into manufacturing processes.
- 3D printing – bringing continuum mechanisms into 3D printing to bring down material costs and time.
- Operational research aspects to distributed manufacturing.

4.7 Smart Sustainable Plastic Packaging ‡

Challenge:

This challenge will develop a new generation of **advanced and sustainable plastic packaging** to **reduce single-use plastics, increase recyclability and the amount of plastic packaging that is recycled and ultimately reduce the amount of plastic waste entering the environment.**

The challenge will develop **new forms of plastic and consumer-friendly packaging** formats that can contain more recycled material and are **easier to recycle** and find n**ew ways of recycling plastic packaging** that is currently wasted or ends up in the environment.

Response:

- Game theory for modelling circular economy and sustainability; using incentivisation schemes.
- Mathematical modelling of reaction kinetics for plastic breakdown pathways; for natural breakdown and assisted breakdown.
- Data mining and inference of chemical databases to find candidate material for plastics for synthesizing new materials.
- Modelling possible migration from a plastic materials over a range of timescales.
- Modelling energy efficient plastic extrusion processes, for next generation materials.
- New mathematical techniques, image recognition for example to aid technologies for recycling plastics

Case Study:

The production of plastic (polymer) waste and the difficulties associated with its disposal is a major environmental challenge. Many polymer food packaging structures are made using thermoforming processes in which hot thin oil-based polymer sheets are forced under pressure into moulds and then cooled to become thin-walled packaging structures. These structures are not eco-friendly and do not degrade after use. Thus unless they are recycled, which is a complicated process and mostly does not happen, these structures cause major environmental problems worldwide.

Researchers in Brunel Institute of Computational Mathematics (BICOM) have undertaken extensive computational modelling of the thermoforming of packaging structures made from bio-materials (thermoplastics). This computational work, together with the necessary laboratory experiments which were executed by Brunel engineers, has contributed to a far better understanding of the behaviour of starch-based biodegradable food packaging. In turn, the availability of such knowledge has contributed to the steady move by food packagers and food retailers towards the adoption of such packaging which is helping to reduce the amount of long term non-biodegradable waste produced.

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=20954

4.8 Transforming Foundation Industries ‡

Challenge:

This challenge will transform the UK's foundation industries (**glass, metals, cement, ceramics, chemicals**) to make them internationally competitive, securing more jobs and greater sector growth by 2025.

The challenge will create a network world-class pilot facility to demonstrate new and radical technologies. Subject to business case and match funding from industry, government is prepared to invest up to £66 million in this challenge.

Response:

- PDEs for solving heat and mass transport problems for optimising industrial processes.
- Modelling cleaning and decontamination of production vessels.
- Free-boundary problems for multi-phase materials modelling.
- Inverse problem for in-situ, real-time monitoring and determining in furnace parameters.
- Homogenisation in materials modelling multiscale materials.
- Control theory for the design of industrial process control.
- Design optimisation for minimising waste and maximising output.

Case Study:

The glass industry uses theoretical modelling to control, improve, and reduce the cost of designing and manufacturing novel glass products. In a glass furnace, many tiny gas bubbles are produced as the raw material melts and reacts. It is essential that all of these bubbles are eliminated before the glass leaves the furnace for further processing, to avoid defects in the finished product. To this end, the drainage of a bubble at the surface of a viscous fluid was modelled mathematically. These analyses allow the required furnace residence time required to remove all bubbles, to be determined.

The gravitational sagging of heated glass sheets to form windscreens also provides an inverse problem, namely, to predict the temperature profile required to produce a final desired windscreen shape. In research carried out at the University of Oxford, this problem was analysed mathematically and found to reduce to an ill-posed partial differential equation which inevitably changes type from elliptic to hyperbolic across some interior line in the glass sheet.

https://impact.ref.ac.uk/casestudies/CaseStudy.aspx?Id=20200

5. Day One and Two Summary

The previous two section outlines the response to the challenges by a number of UK mathematical scientists. Whilst some are well formed; the offer from the mathematical sciences is clear, others are not so well formed and require more work and engagement to firm up what the interesting mathematical topics behind them are.

Well-formed responses	Less well-formed responses
Faraday Battery Challenge	Transforming Construction
Early Diagnosis & Precision Medicine	Industrial Decarbonisation
Healthy Ageing	Manufacturing Made Smarter
Prospering from the Energy Revolution	Transforming Foundation Industries
Transforming Food Production	Driving the Electric Revolution
Future Flight	Commercialising Quantum Technologies
	Digital Security by Design
	Smart Sustainable Plastic Packaging

6. Co-created Challenges (Day Three)

The following section contains the output of the day three discussions. These discussions were stimulated by short talks by leading industry experts. These short, opinion pieces were designed to overview the challenges various UK sectors have at a high level. The following exercise was to then translate and co-create into mathematically-inspired challenge-led proposals. These proposals were framed around the ISCF Wave 3 expressions of interest form. Small groups worked on each discussion topics and in particular tried to draw out a challenge which addressed the following topics:

- Grand Challenge alignment
- Overview, to include:
  - Imperative
  - Goals
  - Enabling steps
  - Benefits
- Productivity growth
- Market opportunity
- UK strengths and competitive advantage
- Demand from industry
- Why ISCF and how much?

Market challenges were presented by Rolls-Royce, National Grid, Dstl, PepsiCo, and GlaxoSmithKline, these market challenges were then assessed by the mathematical scientists. What is shown below are draft titles and draft challenge statements. The complete proposals will continue to be worked on, and made ready for any possible future opportunities.

6.1 Aerospace – The Future of Power

This challenge is to enable the aerospace power industry to drive productivity through better early stage decision making about the risks and the benefits when launching new programmes.

6.2 Energy - Energy Markets 4.0

To deliver the next generation in energy networks in the UK. By modelling the 'whole' energy system across appropriate scales, this will provide real time monitoring and decision making to create a network fit for future energy needs.

6.3 Defence & Security - Security in Changing Climates

This challenge is to make UK businesses more resilient against 'threats' be it physical or cyber by creating an underpinning industry of risk capability, making the UK the world's biggest exporter of risk and resilience capability.

6.4 Food & Drink - Food Design for the Future Society

To transform the UK Food & Drink sector to a product by predictive design sector, where companies can design the properties (texture, taste, nutrition, appearance, smell) robustly in the virtual world, well before manufacture.

6.5 Pharmaceutical - Better Drug Development for a Healthy Society

Increasing productivity in drug development cycles by harnessing the mathematical sciences to reduce the 90 % failure rate. Through disruptive thinking, we will reduce costs, increase success rates , bring drugs to market quicker, establishing the UK as a global hub mathematically-enabled drug discovery.

7. Concluding Remarks

This document details the efforts of the mathematical sciences community in exploring the mathematical aspects of the ISCF. Some of the challenges and the mathematics which underpins it is well understood and the proposition is well-defined. For these challenges what is necessary now is for the community to engage with the ISCF process:

- Engage with funded programmes / demonstrators / pilots and learn what further challenges they might have, use https://gtr.ukri.org as a resource for funded ISCF projects.
- Speak with decision makers, as it is industry who lead the ISCF. Who are the industries underpinning each challenge? What are the sector groups / influencers?
- Engage with UKRI, challenge teams and the process – there are briefings / meetings, etc for the challenges are as they are delivered. Stay up to date with https://ktn-uk.org.
- The relevant section of the report will be delivered to the challenge director (where available), innovation leads across Innovate UK, UKRI and KTN, and plans for closer working between these individuals and the mathematical science community will be developed.

Other challenges have not been as well defined, these require further attention. This could be achieved through:

- Strategic Study Groups. Groups which target the C-level people at large organisations who help to define the challenges. These could be clustered by similar methodologies (mathematical modelling / statistical methods etc) or by similar application areas (circular economy / electrification etc).
- Specific meetings and workshops (using the UK mathematical science infrastructure of the INI and the ICMS) with UKRI leads to draw out the challenge areas.

The session on co-creating challenges introduced the mathematical science community to the process and requirements of an ISCF challenge fund proposal. Using the ISCF questions to begin a discussion on what underpins industry R&D processes allows the mathematical sciences to see where the research in universities can make the biggest impact on business.

- KTN will complete these draft mathematically inspired ISCF topics and have them ready for consideration if and when future opportunities emerge. These could form projects through other funding sources also.

Annex 1: Workshop Agenda and Delegates

Agenda - Day One - Wednesday 20th February

10:00 Welcome & Introduction

David Abrahams, INI. Matt Butchers, KTN

10:15 Keynote: ISCF Plenary Presentation

Mike Biddle, Deputy Executive Chair, Innovate UK

10:45 A Mathematician's Experience with the ISCF

Colin Please, University of Oxford

11:10 Previous ISCF Challenge Status Presentations

- Transforming Food Production
- Prospering from the Energy Revolution
- Faraday Battery Challenge
- Data to Early Diagnosis & Precision Medicine
- Healthy Ageing

11:45 Break

12:00 Transforming Construction

Liam Winder, Innovation Lead, Transforming Construction, Innovate UK

12:25 Break-out Session:

'How the mathematical sciences can make a difference to existing / well established ISCF Challenges'

13:15 Lunch

14:15 Break-out Session (cont.):

How the mathematical sciences can make a difference to existing / well established ISCF Challenges'

15:15 Plenary Feedback

15:45 Day One Summary

Martine Barons, University of Warwick

Agenda - Day Two - Thursday 21st February

09:45 Day One Recap & Day Two Agenda

Jo Jordan, Independent

10:00 Keynote: UKRI Landscape Presentation

Professor Sir Ian Diamond, UKRI Board

10:30 Wave 3 Challenge Presentations

- Commercialising Quantum Technologies (Roger McKinlay, UKRI)
- Driving the Electric Revolution (Martyn Cherrington, Innovate UK)
- Future of Flight (Andrew Lawrence, EPSRC)

11:30 Break

12:00 Wave 3 Challenge Presentations (cont.)

- Digital Security by Design (Andrew Lawrence, EPSRC)
- Manufacturing Made Smarter (Lynne McGregor, Innovate UK)
- Industrial Decarbonisation (Sheena Hindocha, KTN)
- Transforming Foundation Industries (Robert Quarshie, KTN)

13:00 Lunch

- Smart Sustainable Plastics Packaging (Matt Lodge, EPSRC)

14:00 Break-out Session:

'How can the mathematical sciences get involved in the upcoming Wave 3 opportunities'

15:15 Plenary

16:15 Keynote: 'Making Industrial Mathematics Mutually Beneficial'

Professor John Ockendon FRS, University of Oxford

16:45 Day Two Summary

Jo Jordan, Independent

Agenda - Day Three - Friday 22nd February

09:45 Day Two Recap & Day Three Agenda

Matt Butchers, KTN

10:00 Keynote: Where do ISCF Challenges Come From?

Sue Dunkerton OBE, Knowledge Transfer Network

10:30 Panel Session:

'The mathematical sciences and challenge-led research? (Chaired by Martine Barons)

- Ruth Kaufman OBE, Independent
- Ronni Bowman, Dstl
- Collin Bleak, St Andrews University
- Adele Marshall, Queens University Belfast

11:15 Break

11:45 Session Introduction

David Abrahams, INI

11:50 Industry Primers

- Ronni Bowman, Dstl
- Stacie Tibos, PepsiCo
- Gordon May, Rolls-Royce
- Andrew Richards, National Grid
- Nicola Richmond, GlaxoSmithKline

13:00 Lunch

14:00 Break-out Session:

'Developing mathematical science inspired, industry-led ideas'

15:15 Plenary

15:45 Workshop Summary & Close

David Abrahams, INI

Attendees

Surname	First Name	Institution
Abrahams	David	University of Cambridge
Akylzhanov	Rauan	Queen Mary University of London
Ampountolas	Konstantinos	University of Glasgow
Anjos	Miguel	University of Edinburgh
Aston	Philip	University of Surrey
Barons	Martine	University of Warwick
Biddle	Mike	Innovate UK
Bleak	Collin	St Andrews University
Bowman	Veronica	Dstl
Burgess	Helen	St Andrews University
Butchers	Matt	Knowledge Transfer Network
Calder	Brenda	Scottish Government
Carvalho	Rui	University of Durham
Challenor	Peter	University of Exeter
Champneys	Alan	University of Bristol
Chen	Baixin	Heriot-Watt University
Cherrington	Martyn	Innovate UK
Connaughton	Colm	University of Warwick
Cruise	James	Heriot-Watt University
Diamond	Ian	UKRI
Duncan	Andrew	Imperial College London

Dunkerton	Sue	Knowledge Transfer Network
Dyson	Rosemary	University of Birmingham
Eftimie	Raluca	University of Dundee
Enright	Jess	University of Edinburgh
Fitch	Davey	University of Edinburgh
Giansiracusa	Jeffrey	University of Swansea
Gibson	Gavin	Heriot-Watt University
Glendinning	Paul	University of Manchester
Grabowski	Łukasz	University of Lancaster
Hattam	Laura	University of Bath
Hindocha	Sheena	Knowledge Transfer Network
Jordan	Jo	Independent
Kaufman	Ruth	Independent
Kędra	Jarek	University of Aberdeen
Lawrence	Andrew	EPSRC
Leimkuhler	Ben	University of Edinburgh
Linsley	Matthew	Newcastle University
Lionheart	William	University of Manchester
Lodge	Matt	EPSRC
Lyons	Terry	Oxford University
Macrina	Andrea	University College London
Madzamuse	Anotida	University of Sussex
Marshall	Adeel	Queen's University Belfast

May	Gordon	Rolls-Royce
McGinty	Sean	University of Glasgow
McGregor	Lynne	Innovate UK
McKinlay	Roger	Innovate UK
Mishuris	Gennady	University of Aberystwyth
Monk	Andy	Scottish Government
Mottram	Nigel	Strathclyde University
Murray	Philip	University of Dundee
Ockendon	John	University of Oxford
Please	Colin	University of Oxford
Polydorides	Nick	University of Edinburgh
Purvis	Richard	University of East Anglia
Quarshie	Robert	Knowledge Transfer Network
Ray	Surajit	University of Glasgow
Richards	Andrew	National Grid
Richmond	Nicola	GlaxoSmithKline
Sabanis	Sotrios	University of Edinburgh
Samuel	Stephen	Oxford-Brookes University
Savostianov	Anton	University of Durham
Singer	Michael	University College London
Swailes	David	University of Newcastle
Tanner	Gregor	University of Nottingham
Telford	David	Knowledge Transfer Network

Tibos	Stacie	PepsiCo
Volkov	Konstantin	Kingston University
Wallace	David	ICMS
Walsh	Emily	University of the West of England
Wasley	Dawn	ICMS
Wilson	Stephen	Strathclyde University
Winder	Liam	Innovate UK
Woodside	Caroline	University of Edinburgh

Annex 2: ISCF Contact Points

Innovate UK address format:	firstname.surname@innovateuk.ukri.org
ESPRC address format:	firstname.surname@epsrc.ukri.org
NERC address format:	firstname.surname@nerc.ukri.org
KTN address format:	firstname.surname@ktn-uk.org

** indicates Challenge Directors*

Faraday Battery Challenge

Tony Harper*	Innovate UK
Jacqui Murray	Innovate UK
Nazanin Rashidi	Knowledge Transfer Network

Data to Early Diagnosis and Precision Medicine

Penny Wilson	Innovate UK
Giulia Boselli	Knowledge Transfer Network
Terry O'Neill	Knowledge Transfer Network

Healthy Ageing

George MacGinnis*	Innovate UK
Hazel Harper	Innovate UK
David Calder	Knowledge Transfer Network

Prospering from the Energy Revolution

Rob Saunders	Innovate UK
Jenni McDonnell	Knowledge Transfer Network

Transforming Construction

Sam Stacey*	Innovate UK

Mike Pitts	Innovate UK
Mark Wray	Knowledge Transfer Network

Transforming Food Production

Dean Cook	Innovate UK
Calum Murray	Innovate UK
David Telford	Knowledge Transfer Network

Commercialising Quantum Technologies

Roger McKinlay*	Innovate UK
Chris Jones	Innovate UK
Bob Cockshott	Knowledge Transfer Network

Digital Security by Design

Agata Samoljowicz	Innovate UK
Jon Kingsbury	Knowledge Transfer Network
John Baird	EPSRC

Driving the Electric Revolution

Martyn Cherrington	Innovate UK
Paul Huggett	Knowledge Transfer Network
Kathryn Magnay	EPSRC

Future Flight

John Morlidge	Innovate UK
Michelle Carter	Knowledge Transfer Network
Andrew Lawrence	EPSRC

Industrial Decarbonisation

David Hytch	Innovate UK
Peter Clark	Knowledge Transfer Network
James Fleming	EPSRC

Manufacturing Made Smarter

Simon Masters	Innovate UK
Malcolm Harold	Knowledge Transfer Network
Katie Daniel	EPSRC

Smart Sustainable Plastic Packaging

Nick Cliff	Innovate UK
Sally Beken	Knowledge Transfer Network
Rob Gillies	NERC

Transforming Foundation Industries

Ben Walsh	Innovate UK
Robert Quarshie	Knowledge Transfer Network
Nicola Goldberg	EPSRC

Annex 3: Acronyms

CDT	Centre for Doctoral Training
DARPA	Defence Advanced Research Projects Agency
ESPRC	Engineering and Physical Sciences Research Council
GCRF	Global Challenges Research Fund
ICMS	International Centre for Mathematical Sciences
INI	Isaac Newton Institute
ISCF	Industrial Strategy Challenge Fund
KTN	Knowledge Transfer Network
NERC	Natural Environment Research Council
R&D	Research & Development
REF	Research Excellence Framework
UKRI	UK Research & Innovation

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