Research Councils UK Energy Programme Strategy Fellowship

Summary of “light touch” workshop on

Industrial Energy

Working Document

August 2013

This is a report of a workshop held to support the development of the Research Councils UK Energy Research and Training Prospectus at Imperial College London on 17 July 2013

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Research Councils Energy Programme

The Research Councils UK (RCUK) Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £625 million in research and skills to pioneer a low carbon future. This builds on an investment of £839 million over the period 2004-11.

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

In 2010, the EPSRC organised a Review of Energy on behalf of RCUK in conjunction with the learned societies. The aim of the review, which was carried out by a panel of international experts, was to provide an independent assessment of the quality and impact of the UK programme. The Review Panel concluded that interesting, leading edge and world class research was being conducted in almost all areas while suggesting mechanisms for strengthening impact in terms of economic benefit, industry development and quality of life.

Energy Strategy Fellowship

The RCUK Energy Strategy Fellowship was established by EPSRC on behalf of RCUK in April 2012 in response to the international Review Panel's recommendation that a fully integrated "roadmap" for UK research targets should be completed and maintained. The position is held by Jim Skea, Professor of Sustainable Energy in the Centre for Environmental Policy at Imperial College London. The main initial task is to synthesise an Energy Research Prospectus to explore research, skills and training needs across the energy landscape. Professor Skea leads a small team at Imperial College London tasked with developing the Prospectus.

The Prospectus will contribute to the evidence base upon which the RCUK Energy Programme can plan its forward activities alongside Government, RD&D funding bodies, the private sector and other stakeholders. The tool will highlight links along the innovation chain from basic science through to commercialisation. The tool will be flexible and adaptable and will take explicit account of uncertainties so that it can remain robust against emerging evidence about research achievements and policy priorities.

One of the main inputs to the Prospectus is a series of four high-level strategic workshops and six in-depth expert workshops taking place October 2012- July 2013. Three additional "light touch workshops", one of which is summarised here, are being conducted between July and September 2013. Following peer-review, the first version of the Prospectus will be published in November 2013 and will then be reviewed and updated on an annual cycle during the lifetime of the Fellowship, which ends in 2017.

This document reports views expressed at a "light-touch" workshop held on 17 July 2013. These views do not necessarily represent a consensus of workshop participants nor will they necessarily be endorsed in the final version of the Energy Research and Training Prospectus

Contents

List of Acronyms

B2B	Business-to-business
B2C	Business-to-consumer
CCA	Climate Change Agreement
CCC	Committee on Climate Change
CCS	Carbon capture and storage
CCU	Carbon capture and use
CDT	Centre for Doctoral Training
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
EfW	Energy from waste
EngD	Engineering doctorate
EOL	End-of-life
EPSRC	Engineering and Physical Sciences Research Council
ESCo	Energy service company
ESRC	Economic and Social Sciences Research Council
GDP	Gross domestic product
I-O	Input-output
IP	Intellectual property
KTN	Knowledge Transfer Network
KTP	Knowledge Transfer Partnership
MaSCo	Materials service company
MEMS	Micro-electrical-mechanical systems
MoU	Memorandum of Understanding
NPL	National Physical Laboratory
Ofgem	Office of gas and electricity markets
PV	Photovoltaics
RCUK	Research Councils UK
REF	Research Excellence Framework
OEM	Original equipment manufacturer
R&D	Research and development
TRL	Technology readiness level
TSB	Technology Strategy Board
UKERC	UK Energy Research Centre

1 Overview

This document summarises the outcomes of a workshop held on 17 July 2013 in order to identify research and training needs relating to industrial energy. The workshop was organised with input from Julian Allwood of Cambridge University and Roland Clift of the University of Surrey.

There were 15 participants at the workshop (excluding the Fellowship team), most of whom were academics and researchers falling within the communities supported by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Science Research Council (ESRC).

This record of the meeting constitutes a working document intended to capture the outcomes of the workshop. It represents an intermediate step in the production of a full Energy Strategy Fellowship report, which will set out the prospectus for energy research and training needs relating to industrial energy. It has two purposes; a) to provide a resource which can be 'mined' in order to produce the prospectus document; and b) to provide an account of the workshop for archival purposes.

This document reports views expressed by individuals at the "light touch" workshop held in July 2013. Not all views expressed represent a consensus. Views expressed are noted by the Fellowship team but not all will necessarily be endorsed in the final version of the Energy Research and Training Prospectus.

2 Introductory Session: The Energy Strategy Fellowship and the Workshop

2.1 Introduction

During the opening session, the Strategy Fellowship team described the background to the workshop and introduced the day's activities. The presentation covered three topics: the background to the Energy Strategy Fellowship; emerging conclusions from preceding "strategy" workshops; and the conduct of the industrial energy workshop.

2.2 Background to the Fellowship

Jim Skea (Energy Strategy Fellow) made a presentation outlining the background and rationale for the RCUK Energy Strategy Fellowship and the activities being undertaken. He noted the role of the Prospectus in informing the future design of the RCUK's Energy Programme. The presentation covered the following points:

- The recommendations of the International Panel for the 2010 RCUK Review of Energy;
- The conclusions regarding the high quality of the science tempered by concerns about links to policy and follow-through to commercialisation;
- The vision for the Energy Research and Training Prospectus under development by the Fellowship Team;
- The programme of strategic and expert workshops and light-touch reviews being conducted; and
- The purpose of the expert workshops and the process which through the workshop outputs would be translated and synthesised for the prospectus document.

2.3 Emerging conclusions from strategy workshops

Aidan Rhodes summarised the outcomes of the preceding "strategy" workshops.

The first workshop, *Energy Strategies and Energy Research Needs,* had highlighted a gap between participants' *aspirations* for an ideal energy system in 2050 which met the UK's climate objectives and the system they *expected* to emerge. The deployment of technologies associated with the low-carbon agenda was anticipated to be lower than aspirations and the deployment of incumbent technologies correspondingly greater. The example of electricity generation technologies was presented, with unabated gas expected to play a larger role than would be desirable, while technologies such as offshore wind would play a lower role. Participants had also assessed the range of energy technologies in terms of their relevance to future UK energy, the UK's industrial capabilities relative to competitors and the UK's scientific capability. In areas such as *oil and gas* and *energy systems analysis* the UK scored very highly.

The second workshop, *The Role of Environmental Science, Social Science and Economics,* was less easy to summarise but participants had believed that the UK academic incentive system did not encourage interdisciplinary working. There was also a belief that energy research was currently focused too much on "kit" and did not pay enough attention to human behaviour.

The third strategy workshop, *The Research Councils and the Energy Innovation Landscape,* had used two case studies, *marine renewables* and *molecular PV,* to exemplify respectively "use-inspired" and "science-inspired" research areas. Participants noted the needs for: stronger mechanisms for feeding back findings from later stages in the innovation process to basic research projects; adaptable and flexible testing facilities; ensuring spin-out companies can understand and access their potential markets; and clear policy signals and market regulations.

2.4 Conduct of the workshop

Jim Skea introduced the plan for the day's activities. The purpose was to: listen to the opinions of participants; identify ideas for the research prospectus; and highlight priorities for future research. Broadly, the morning's activities would identify "hotspots" for future research, while in the afternoon the participants would do a "deep dive" to identify more specific research challenges associated with the hotspots.

3 The Research Landscape: where are we now and who is missing

3.1 How well placed are we?

Working individually, people were asked to identify how well placed the UK currently is in terms of industrial energy research capabilities so that we can meet the challenges of the future. They were invited to score these on a scale of 0-10 (0 = no chance, 10 = well set up) and explain their score on a post-it note. Figure 1 shows the distribution of the 24 post-it comments.

The majority of participants rated the UK in the range 2-6 with an average score of 4.3 and a standard deviation of 3.3. This represents the lowest rating in any of the workshops run in this series and chimes with the relatively low number of participants with whom we were able to engage. The single score of 10 can be interpreted as an ironic statement about the decline of the UK's industrial capabilities. If so, the average score falls to 3.9. Some strong themes emerge from the comments: the UK's reliance on imports and inward investment weakens links between research and the supply chain; the community is relatively small and fragmented; and incentives to reduce industrial energy demand are weak.

Table 1: UK's perceived capability levels to address existing energy research challenges

<table>
<tr><th colspan="4">High capability levels</th></tr>
<tr><th colspan="2">8</th><th colspan="2">10</th></tr>
<tr><td colspan="2">System level optimisation: good skill base' could be activated given incentives</td><td colspan="2" rowspan="2">I don't think any other country in the world is ahead of us on demand reduction</td></tr>
<tr><td colspan="2">Some technologies understood and ready(ish) to deploy</td></tr>
<tr><th colspan="4">Medium capability levels</th></tr>
<tr><th colspan="2">5</th><th colspan="2">6</th></tr>
<tr><td colspan="2">Lack of clear long-term energy policy and strategy</td><td colspan="2">High capacity in some research areas; low interest in industry and government</td></tr>
<tr><td colspan="2">Understanding of growth/products/industrial energy demand; some promising models linking materials and energy to economy, but still long way to go especially in relation to forecasting models.</td><td colspan="2" rowspan="2">The UK is better at individual technology optimisation than re-thinking the broader system</td></tr>
<tr><td colspan="2">Lack of drivers and incentives for uptake - policy and regulation</td></tr>
<tr><th colspan="4">Low capability levels</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td rowspan="5">The economics of demand reduction is poorly understood</td><td>Because of growing dependence on imports we have limited contact with key part of the supply chain</td><td>Limited research community in industrial energy</td><td rowspan="2">Playing catch-up, but new focus from government; weak CO_2 price is big issue.</td></tr>
<tr><td>Political reality of taking a long-term view – government should end this</td><td>Use of low-grade heat: self-imposed barriers</td></tr>
<tr><td>Industry structure: fragmented supply chain; isolated company intra-firm interfaces</td><td>Many small fragmented research groups; lack of impact. The positive is world-class R&D</td><td rowspan="3">Government confused c.f. fracking as a solution; can't leave to market</td></tr>
<tr><td rowspan="2">Low level of domestic manufacturing activity and skills</td><td>Different business models to reduce industrial demand – changing delivery of goods and services;</td></tr>
<tr><td>Lack of understanding of current energy demand and 'useful' wastes</td></tr>
</table>

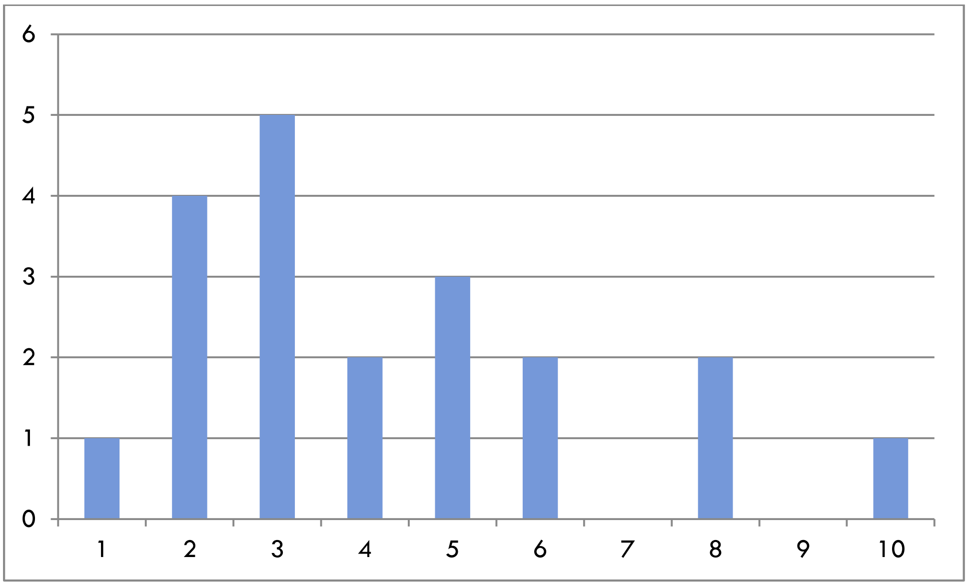

Figure 1: Distribution of perceived UK industrial energy research capabilities

3.2 Who's missing from the meeting?

Given that this was a relatively small workshop, participants were asked which groups of people or skills were missing from the meeting and whose insights might subsequently be engaged. A range of suggestions was made:

- Those with an interest in industrial CCS
- Economists of the type who use industrial data in models (e.g. TIMES; MARKAL; ESME).
- Material scientists
- Process engineers
- Those who know about consumption
- Expertise on possible uses for low-grade heat!
- Recycling industry
- Energy from waste community

A general lack of industry representatives was also noted. They might have provided insights on regulation. It was also noted that it was particularly difficult to capture non-energy intensive industries. Some participants argued that the energy supply side should also have been covered by including representatives from Ofgem and/or National Grid. However, it was noted that the supply side had been involved in other workshops.

4 Research 'Hotspots' and Broader Themes for Future Energy Research

4.1 Introduction to the Exercise

This exercise was designed to identify a range of topics that participants believed should be the subject of future UK research in the field of industrial energy future, and which should therefore be reflected in the RCUK Energy Strategy Fellowship's *Research Prospectus*.

4.2 Methodology

4.2.1 Overview

In order to identify future energy research opportunities for the UK in the field of transport energy, the participants were first invited to identify 'research hotspots' that could provide valuable insights, should (further) research be conducted into them. A 'research hotspot' was defined as follows:

> 'A ***Research Hotspot*** is a potentially valuable area of future research, which has been identified by the Expert Workshop participants. It is an area in which the experts believe research challenges will emerge in the future. It may be a broad and overarching question or problem'

To help guide the participants, a couple of good-practice examples of hot spots were presented from the previous Fossil Fuel and CCS workshop.

4.2.2 How Were the Research Hotspots Generated?

The first part of the process involved the participants working individually to generate some initial ideas about potential hotspots. The second part required the participants to form pairs to discuss and record these hotspots with a partner. These were recorded on post-it-notes

Once the pairs had discussed and recorded the hotspots they were then asked to place these on a wall chart as shown in Figure 2. The purpose of the x-y axes was to act as a guide for participants to place their post-its with a view to clustering related hotspots.

	Industrial Processes	Public Policy	Business process	Products
Final consumption (B2C)				
Intermediate goods and services (B2B)				
Industrial sector				
Industrial system				

Figure 2: Conceptual Framework for Research Challenges

4.2.3 Clustering Hot Spots

The organisers noted that many of the hotspots were located in the bottom left corner of the chart (industrial sector/system; industrial processes) shown in Figure 2. They therefore proposed, and the participants agreed, that two groups should be formed. The first would cluster hot-spots located in the bottom left corner of the chart while the second would cluster the remaining hotspots. The groups were invited to identify clearly and name each of their clusters on a single flip chart sheet and add the relevant hotspots.

Following this exercise, the workshop as a whole reviewed the proposed clusters. Each group shared one of their clusters with the other group, who were encouraged to identify any related clusters. Using a system of green, red and yellow cards, participants could confirm their support for the clusters, veto them or provoke further discussion. This process led to the amalgamation of some clusters, the creation of one new cluster and an exchange of individual hotspots between clusters. The final arrangement had the consent of the entire group.

4.3 Results

The following clusters were identified by the workshop participants:

1. Product design
2. Sector Mapping
3. Process Technology
4. Process Energy
5. Systems level management
6. Policy
7. New business models
8. Energy storage

In practice, the final cluster, *Energy storage*, was not taken on to the next stage as it was agreed that this topic had been adequately covered in the previous *Electrochemical energy technologies and energy storage* workshop where the level of relevant expertise has been higher. The clusters and associated hotspots are listed in Table 2.

Table 2: Research clusters and associated hotspots

Cluster Name(s)	Hotspots
1. Product design	– Through process simulation of products to contain energy – Reducing energy requirements for material products – Cost and potential of materials efficiency; supply chain and production basis – Modularity/lifetime extension/lightweight design – design for re-use and recycling – Development of modelling and simulation of fluid flow (including experimental data)
2. Sector mapping	– Better understanding of baseline energy use, especially outside energy intensive industries – Development of metrics for assessment of energy (including embedded energy) in manufactured products – an operational tool – Adaptability of industry to future energy supply scenarios, e.g. decarbonised electricity, hydrogen, biomass – Renewable heat potential (biomass. heat pumps etc.) by sector – Mapping of energy efficiency potential + update evidence
3. Process technology	– Materials research o expensive materials matching complex machined components; o additive layer manufacture; o post-deposition heat treatment and characterisation – Effective large-scale CCS – Use (not store) CO_2 – Efficiency of data centres – Sensor technology for more efficient engines/turbines – Batter catalysts for industrial processes

Cluster Name(s)	Hotspots
4. Process energy	– More effective/precise heating for large scale processes, e.g. large-scale microwave heating – Cheap low-grade heat upgrading – Effective low grade heat recovery/capture from liquid metal processing – Renewable heat potential – Synergies with other sectors, e.g. sharing CHP-district heating network – Re-use industrial waste heat – Cost effective heat recovery systems with potential to retrofit into existing systems – Use of low-exergy heat – Development of robust heat transfer fluids – holistic approach (cost, environmental impacts)
5. Systems level management	– Technologies/systems/regulations for avoiding scrap/waste-over-use – Through process simulation models to include energy, e.g. generate; mine; raw material; semi-fabrication; components; OEM; consumers; disposal – System level management at device level: how is industrial energy in the UK sues and how efficiently? – System level optimisation of transport – Peak Demand management – Holistic model approach to supply chain and circular economy: energy; materials; waste; re-use/recycle – Driver of industrial energy demand (link economy with industry): growth -> goods and services -> industrial energy - > rebound -> growth
6. Policy	– Quick win technology results for gas and heat: waste heat; solar thermal heat generation – Empirical study of UK pass-through rates (capacity to pass on cost in an economic sense) – Define quick wins; what's left to do in energy efficiency considering timescales, economics, technological potential;, information gaps – National metrics of material well-being other than GDP – How can building regulations and planning drive up-take, e.g. new business park near steel facility- require park developer to ensure it is heat-network ready – How can government increase take-up of industrial energy efficiency technologies outside energy intensive industry – social science research
7. New business models	– Energy efficiency options are limited so new ways to deliver goods and services to reduce energy and material demand – Business models with reduced material demand – B2B purchasing decisions; opportunities for clients to drive down materials demand – Holistic model approach to supply chain and circular economy: energy; materials; waste; re-use/recycle – Management barriers to energy efficiency – Costs and potential of materials efficiency: supply chain and production basis
8. Energy storage	– Battery and fuel cell materials – Energy storage: heat; electrical; macro (distribution); micro (distributed) – Battery and fuel cell lifetime studies – Gas storage materials: CCS (permanent); H_2 (renewable)

5 Identifying research challenges

5.1 Introduction to the Exercise

In this exercise, participants were asked to identify key research questions relating to the research clusters and super-clusters that had been identified in the morning session, as well as any potential challenges that might be encountered in undertaking this research and what might need to be done in order to address these challenges.

5.2 Methodology

Participants formed three similar interest groups and each group selected whichever research clusters/super clusters they wanted to examine in greater detail. These are outlined in Table 3.

Table 3: Community groups and their selected clusters for Deep-Dive session

Group	Selected Clusters/Super-Clusters
	Description
A	1. Product Design
	2. Sector Mapping
B	3. Process Technology
	4. Process Energy
C	5. System-level management and understanding
	6. Policy
	7. New Business Models

To assist the deep-dive process, each team was provided with an activity sheet with a set of questions and suggestions as how each question could be approached. The questions were as follows:

1. What are the main research challenges we need to address?

2. To address these what do we need in place? Consider for example:
   - What capabilities / capacities do we need in place?
   - Do our current ways of working need to change? If so, how and why?
   - Whose job should it be/who is best placed to do/fund this research?
   - What needs to happen in terms of coordination and alignment to maximise success?
   - What do we need to have in place to ensure we are ready to address these research challenges? (e.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)

5.3 Results

Group A

Cluster 1: Product Design

Research Questions

- Research questions fall into two parts: a) **making the products** and b) **using the products**. Important that we tackle them simultaneously. Need to be linked but one is a bigger system
- Multi-scale 'through process' modelling of durable products (e.g. cars, textiles etc.) – to optimise energy (& other resources) use in product, manufacturing, use, economy, end-of-life (EOL) etc.

Do our current ways of working need to change? If so, how and why?

- **Not traditionally an area for academic research** - This is a 'get your hands dirty' area, not encouraged by current academic metrics.. It is also typically located at the higher TRLs, which is not normally the focus of academic researchers. Therefore, whilst the skills exist in this area to undertake this type of research, academics typically decide to do other things

- Generic problem of lack of recognition of non-academic research impact even though this research area is focused at the later TRLs and therefore requires higher TRL level perspectives needed. Need to bring non-academic research into the fold.

What capabilities / capacities do we need in place?

- **New models** - Multi-scale mathematical models of product systems and materials engineering
- **Raising awareness** of the above approach to help legitimise it, which will in turn help to raise willingness to adopt this approach
- Need to create a **vertically integrated research network and strategy** that spans across TRLs 1-9+, which includes the "catapults", research councils, TSB, industry etc.
- **Access to industrial data needed –** Valuable data is typically inaccessible (e.g. buried in industry) or unavailable (e.g. commercially sensitive). Ideally data should be supply chain specific

Whose job should it be/who is best placed to do/fund this research?
What needs to happen in terms of coordination and alignment to maximise success?

- Need to explore the scope for **collaboration between RCUK and TSB** in terms of industrial energy research, possibly via catapult centres.

Cluster 2: Sector Mapping

Research Questions

- Currently sectoral data is too specific or too aggregated. For example, we can't do LCA on steel, need to do LCA on product. Need new data to undertake a **mid-level analysis of 'finished products' industrial energy efficiency** and to truly understand the relative energy efficiency of different industrial sub-sectors. Therefore, a new discrimination of sectors should be undertaken by finished product (not process) to:
  - a) Produce basic figures on energy use
  - b) Give material flows and lifetimes

Do our current ways of working need to change?
If so, how and why?
What capabilities/capacities do we need in place?

- Need to **develop UK's current research capacity in this area**. For instance, provide more mid-career researchers with training so they are capable of supervising Masters/PhD, not just Professors.
- Need an **industrial energy CDT that incorporates a focus on industrial energy sector mapping**
- Promote **collaboration between engineers (engineering school) and economists (management school)** to help map the sector:
  - Needs physical in-out (I-O) analysis not just economic.
- **Need more data collection capacity –** Could utilise MSc students to help collect data to map sector
- Need to **increase flow of data from private sector to academia**. To do so we need to manage confidentiality and non-disclosure issues. Might be easier for individual trusted academics to do this:
  - Must acknowledge the costs associated with collecting and managing industrial data

What needs to happen in terms of coordination and alignment to maximise success?

- Need **trade association/major company/academic interaction**:
  - Work where industries have common interest. E.g. investment casting - EU v US companies.
  - Memorandum of Understanding (MoU) between EPSRC and trade associations? Could be an important role for BIS here
- Develop **long term bi-party relationships or 'open' working** to facilitate sector mapping

Group B

Cluster 3: Process Technology

Research Questions

Materials

- Materials discovery and behaviour characterisation
- Manufacturing processes of materials
- What material properties are required to deliver a low-carbon/secure/sustainable energy system?
- Performance and durability of materials - Consider the life cycle of materials i.e. not just production but also how they degrade etc.
- Disposal of materials end-of-life – 'recyclability'
- Examples for focus e.g. high-temperature materials (e.g. ceramics); light-weight materials; composite materials; thin-film PV

Catalysts

- Challenge – identifying alternative catalysts
- Replacement of homogenous with heterogeneous catalysts
- Exploring how we might minimise the amount of energy required to produce something via the use of catalysts
- Production of cheaper catalysts to improve industrial production efficiency
- Re-use of catalysts e.g. catalytic convertors in cars. What structures need to be in place to ensure these are re-used?
- Engineering of catalyst reactions/reaction engineering – improve catalytic process and efficiency of the process

CCS/CCU (carbon capture and storage/use)

- CCS – Need to get the scale for steel and cement CCS and will need pre-combustion oxygen for these processes.
- CCU – Need to collect it and use it e.g. as a feedstock
  - Using carbonates for aggregates for building
  - Use carbon to produce a new fuel – using CO_2 as a fuel stock to produce a hydro-carbon fuel via synthesis processes. Lab scale is possible but we need to scale it up. Development at this stage prior to development. Could help to balance supply & demand on the grid.
  - Use a super-critical CO_2 as a working gas for a bottoming cycle
  - Use CO_2 as an energy vector
  - Send combustion gases into the turbine - Allum cycle. Get very pure CO_2 + water out of the engine – cleaner waste

Data centres

- Need a whole-systems approach to improve data centre efficiency and will require an integrated approach to design these, particularly in relation to control technologies.
- Improved liquid cooling technologies

Sensor technologies

- Sensor systems for plant monitoring and control - Little idea of how much energy is currently used in factories/industrial plants.
- Sensors difficult to design for hostile environment e.g. corrosive
- Data management of sensory data so this can be utilised to improve management
- Sensors to be used to control engines and turbines – feedback between what the engine is doing and how it needs to be managed. Run engines closer to their capacity limit. Having more precise knowledge of your operating conditions to run it more efficiently

Do our current ways of working need to change?
If so, how and why?
What capabilities/capacities do we need in place?

- **Vibrant research community in materials and chemicals**
- Need the **instruments to undertake materials discovery and manufacturing research** that is capable of analysing materials from the atom to the device/macro scale. Taking batteries for instance, you can look at battery materials in isolation and how they might fit together and/or build the battery and analyse it as a whole device
    - Examples cited included the NPL (National Physical Laboratory) and Rutherford Laboratory for mechanical and durability testing of materials
- **Computer modelling** to predict how things will behave without actually testing them in practice
- **Real-world and real-time testing of high temp materials** e.g. a sensor in the middle of a gas turbine or on a wind turbine blade. Need the sensing technology and the facilities to collect the empirical data to really understand how these things perform over a long-time period
    - Process industries don't really have these things at the moment and need the capacity to undertake pilots/test/demonstration schemes
    - How do private sector organisations currently do it? E.g. Rolls Royce – turbines
- **Applied R&D capacity & capability** - UK has capabilities towards the more theoretical end (e.g. chemistry) but there is a breakdown at the more applied R&D and demonstration end of scale, such as a lack of research facilities (e.g. Fraunhofer-style institutes). In particular we need the institutional structure in order to test technologies in an easier and quicker way
- **Keeping things up to date**, e.g. skills; facilities; knowledge etc.
- **Increase utilisation of facilities** - Make sure facilities are 100% used e.g. Rutherford Appleton site
- Make sure that there is a **greater exchange of knowledge internationally** to understand better what is happening abroad in terms of process technology research - What can be learnt?
- **More interdisciplinary research** e.g. mechanical engineers; chemical engineers; chemists; demand for process technologies

What needs to happen in terms of coordination and alignment to maximise success?

- **Process industry energy policy** - Introduce this to encourage R&D in industrial process technology. Feed into funding from RCUK, as well as people thinking about industrial energy efficiency
- **Resolve friction between TSB & RCUK -** TSB is practical & applied but RCUK is more blue sky. How do these two things fit together and importantly, where is the handover?

Whose job should it be/who is best placed to do/fund this research?

- **RCUK**
- Need **more money at the higher TRL levels** to ensure that good ideas at early TRLs are acted upon and made the most of
- **More catapults would be helpful –** Need to consider the energy related questions of process technologies
- **Encourage sharing of data from industry** - If you have a company that has in-house data on industrial processes, would they make this available? Probably not unless these was an incentive. Is there an argument to see if industry could work more closely together to provide academics with the data to examine their processes
    - May need a cross-industry body, where the industries put money in, which is responsible for making the data available to do research

What do we need to have in place to ensure we are ready to address these research challenges? (e.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)

- **Understand the bigger picture** - Need students to know the big picture around their research subject so that they can come out of that to ensure that their research fits into the whole
    - PhD –An additional year's training would be very useful for physics/chemistry degrees to improve their general awareness of the subject, i.e. the wider context
- **EngDs –** Project is defined by industry and they better understand their industry better because they spend ¾ of their time there. This helps to bring industry and academia closer together

Cluster 4: Process Energy

Research Questions

<u>Retrofitting</u>

- Retrofitting systems - Industrial plants are integrated systems and the ability to recover waste streams (e.g. waste heat) will very much depend on the nature of the system already in place e.g. heat exchangers; efficiency of turbines; exhausts etc. It is possible that you may need to re-engineer a lot of the system just to integrate one new technology. Need to figure out if retrofit is better/worse in terms of effort; energy efficiency; and financial cost basis than compared to designing a new system 'from scratch'
    - A whole-systems understanding of industrial systems would help

<u>Waste Heat</u>

- Heat recovery - Development of working fluids from a life cycle perspective, capable of recovering waste energy from industrial processes. Need to understand the environmental and economic impact of using these fluids, particularly considering that they are challenging to model
- Waste heat – Need to understand where the waste industrial heat is and whether this can be used. Map industrial heat and its potential consumers/consumption options.

    - How hot is it? What applications could it be applied to? Where are these potential consumers of it? What kit would be required to take advantage of these uses? What are the relative costs of this kit
- Machinery and unit process design – Heat exchanges; heating fluids; fouling; breakdown of fluid

Alternative heat sources for industry

- Biomass, microwaves, EfW (e.g. anaerobic digestors)
- Renewable opportunities - PV – uses the roof space
    - Wind turbine to power the factory e.g. GSK Barnard Castle
- Power stations on site – integration of industrial process. Making the most of the industrial power plant to ensure its v efficiency. E.g. Boots use waste heat to heat water to grow algae. It is used as a fuel source or a natural resource e.g. pharmaceuticals

Waste Water

- Recovery of water after minimising use, given that water use has an energy and environmental footprint. How is this water recovered if it's contaminated - you can't just pump it out

What capabilities / capacities do we need in place?

- **Modelling & simulation of heat transfer fluids is missing.** There is not much experimental data on things like heat transfer and fluid mechanics. Lack of testing/data and models to make use of this, such as computational models capable of simulating the fluid dynamics of these heat fluids to understand how they behave and perform particularly in complex, multiphase and multi-component systems
- **Develop experimental capabilities in the UK to verify computational models for fluid flow and heat transfer**
- **Facilities to characterise fluids** e.g. UCL chemical engineering department.
- **Release of data** - Difficult to model and simulate these heat transfer fluids, particularly because there is very little data. This is because they are often very new – therefore transfer properties are often not well known and not incorporated into existing models:
    - E.g. Designers of heat pumps; exchangers don't really have the necessary performance data to influence their designs

Group C

Cluster 5: System-level management and understanding

Research Questions

- Understanding likely changes through the energy system as a whole, such as the volume of carbon released via both production and consumption.
- Modelling material efficiency for carbon reductions purposes
- Mapping question – physical flows of (e.g. materials, resources, carbon, energy etc.) through the industrial system/economy. There is a big difference between the current snapshots we have and a proper process model that is capable of tracking physical flows through the industrial sector.
    - Need to model physical stocks as well as physical flows. Why? Need to use stocks to deliver services. Are we managing stock levels properly, e.g. buildings often only occupied 1/3 of the time? Doing so could provide efficiency gains
- We seem to have a lack of information about the complexities of the economy and how to spot industrial inefficiencies.

- Recycling – only currently applies to a small range of materials but end-of-life and upstream impacts are fundamentally important.

What capabilities / capacities do we need in place?
Do our current ways of working need to change?
If so, how and why?

- **Economists** - Shortage of applied economists who understand the language used by the wider research world. Improvement needed in environmental economics – can't model material inefficiencies at the moment well.
- **Lack of resources** - Need to look at system-level analysis of the energy sector in this area. Not enough resource at the high levels. Not much resource – everyone in academia is here!

What needs to happen in terms of coordination and alignment to maximise success?

- **Academia-Government relationship** - Government and CCC fund short-term, urgent pieces of work, which are more suited to consultants than academics. Government will also only listen to some evidence, i.e. stuff that meets their needs. Is government moving from 'evidence-based policymaking' to 'principle-based policymaking?'
    - UK research community still doesn't really know how we connect to the policy world, e.g. no process to find specific people in departments. Instead evidence just disappears into a central 'evidence pool'. How can academics make sure they're heard? Review routes for academic outputs to influence TSB and government. Tapping into the key findings of research projects and bringing them to attention – do we need sector champions. Materials and resources span many government departments. DECC/DEFRA split. Need to talk to mid-level civil servants (grade 5/6/7/) to influence things.
- **Collaborative working between research centres** - While Research Councils want centres to work together they do not provide the funds to do this.
- **Appointment of research champions** to promote industrial energy research
- Need some degree of **ownership of 'materials' by government departments**
- **Secondments between industry and academia** – this is particularly valuable due to the strong focus on industry here but not happening much at the moment. Knowledge exchange can for example be undertaken via cross-council or TSB secondment programmes. Conversely, this will also help academia understand the perspective of industrial energy managers working within companies

What do we need to have in place to ensure we are ready to address these research challenges? (E.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)

<u>PhD Training</u>

- **Need far more PhDs**
- We also need to remove 'silly rules' about not providing project-based PhDs. Need a **balance between project and CDT PhDs**
- Currently having **trouble getting postdocs but piles of good quality PhD applicants**. How can this be addressed?
- Need to **ensure CDTs operate as truly interdisciplinary centres**. Disciplines tend to restrict PhD project topics in this area – need to be more open-minded.
- Something at CDT level jointly between ESRC and EPSRC to **bring people together with economists,** before people get too entrenched.
- Must ensure that **PhDs are problem focused rather than methodology focused** (e.g. modelling)

Data Infrastructure

- Need a **better evidence base for industrial energy,** e.g. data sets, aggregated at sector or corporate level but especially site level. It is hard to imagine that companies would release this data as it is very sensitive. Carbon Trust did some work here to produce energy audits for companies. Could be big opportunity under UK's Energy Efficiency Directive to deliver further energy audits

Cluster 6: Policy

Research Questions

- Research into the design of policy processes for industrial energy/materials:
    - Socio-technical research into practices/influence?
    - Engagement of the 'nudge' team

What needs to happen in terms of coordination and alignment to maximise success?

- **Educate government policymakers -** Educating politicians that there is no single one-size-fits-all industrial energy policy fix. Need to explore how academia can influence government more effectively to change their methods of policymaking?
    - **More academic secondments in government** - DECC seems to be full of people on secondment from energy companies. How can academia put more secondments in?
- **Promote inter-departmental communication -** Do DECC talk to the people who set the building regulations, for example?
- **Encourage the right people/groups to respond to industrial energy consultations**

Cluster 7: New Business Models

Research Questions

- What are the incentives and opportunities to develop innovative industrial energy business models, such as service based industrial business models. For example:
    - Selling industrial services rather than materials via Materials Service Companies (MASCos)
    - Selling energy service rather than energy units via Energy Service Companies (ESCos)
- Proof of concept – Economic business case needed, i.e. can new business models actually deliver efficiency/sustainability gains in a financially viable manner?
    - Some people yet to be convinced. Concerns that services often lead to inefficient use of materials.
- Transition from niche to dominant design – how do new business models flourish and spread?
- Selling new models as an idea – consultancies tailoring to companies. Economic barrier isn't on the household/consumer side but more on the company side.
- Exploring policy drivers/barriers of industrial energy business model innovation
    - Potential driver e.g. Landfill tax
    - Potential barrier e.g. Inequity of VAT – paying VAT on repairs to houses, but not on new houses etc.

What do we need to have in place to ensure we are ready to address these research challenges? (e.g. PhD training, data collection/curation, research Infrastructure, funding philosophy etc.)

- Key partners to undertake this research:
    - Business/management schools.
    - Modellers

    - Investment community

6 Reflective writing

6.1 Process

The purpose of this exercise was to ensure that the finer detail generated during the workshop was not lost. It provided participants with the opportunity to build upon ideas they had formulated during the clustering and deep-dive exercises and allowed them to flag any broader issues they wanted to raise. Participants were provided with two options for the reflective review session:

Option One: *Independent Reflection*

Participants were invited to work on their own to record their thoughts and ideas in writing

Option Two: *Reflect and Chat*

Participants were invited to firstly reflect on their thoughts and ideas, before sharing them informally with other people in the room. This enabled participants to develop their ideas by 'bouncing' them off other members in their group. Again participants were asked to record the outputs of this session in writing

Participants were encouraged to post any written output from this session into a reflections post box or email their thoughts to the organisers.

6.2 Outputs

- **Some areas had been under-represented** at the workshop including:
    - Industrial energy rebound effects and other unintended consequences of energy interventions
    - The link between energy associated with product use and the production of the product
    - Imports and the bigger picture worldwide from a consumption based perspective
    - Detailed process & wider systems analysis - Typically use very different techniques but it may be valuable to identify where the cross-over is between the two and where techniques from one can be successfully applied to the other
    - Technological obsolescence of products, light-weighting etc.
    - The different research approaches that might be required to study both the energy intensive and non-energy intensive industrial sectors
    - Resource criticality is driving increased energy-use and this is already happening in aluminium production
- It was thought that some areas had been **over-represented** such as the utilisation of industrial waste heat
- **Importance of whole-systems analysis -** Consensus that the problem of industrial energy is complex and demands a whole systems approach that transcends any one discipline. It was thought that such an approach should be sensitive to a range of research areas including policy processes; new business models; supply chain, sustainable manufacturing; and circular economies.
- **Energy efficiency potential -** We need to better understand the potential for energy efficiency gains in industry
- **Affordability of industrial energy -** As long as energy is considered to be cheap, industrial energy efficiency is unlikely to be a priority. Also, what happens to any incentives to reduce industrial energy demand if a cheap form of energy suddenly becomes available (e.g. shale gas?)

- **Implications for industry -** We need to better understand the trade-offs between industrial outputs and environmental protection. What are the negative impacts of an emphasis on only one of these and should we worry about this?
- **Damaging effect of short-term thinking -** Concern about how we are going to achieve the 'joined up thinking' required when the current government is so driven by market forces and short-termism. Industry and energy commitments are weak, often linked to poor public understanding and perception, e.g. Fukushima and public being anti-nuclear but the alternative is coal
- **Industrial energy transcends current funding structure -** Thought that industrial energy does not fit comfortably within one research council, as it requires a 'whole-systems', inter-disciplinary research approach. This may prove problematic within the current research funding system that is still very disciplinary. May require a shift in funding for specific technologies or disciplines, towards more inter-disciplinary research
- **Co-ordination across Research Council investments.** There is a need to establish a communication protocol across projects and Centres and align investments with international efforts. The research portfolio across Councils needs to be managed more coherently.
- **New knowledge** arising from Research Council investments needs to be incorporated into engineering education.
- **Explore outputs from previous workshops -** Suggestion that it would be worthwhile trawling the notes on the workshop on 'Energy in the Home & Workplace' for insights into industrial (i.e. work) energy demand reduction opportunities

7 Key pointers for the Research Councils – start/stop/continue

Participants worked in groups of three to generate recommendations, falling into three categories, as to how the Research Councils could assist:

- Start doing/do more of
- Continue to do
- Stop doing/do less

The responses were recorded on flipcharts and each group reported back verbally on one issue they had identified.

Table 4 presents the outputs of this exercise.

Table 4: Suggested Actions for the Research Councils

Start doing/do more of	Continue to do	Stop doing/do less
Research Funding Structure & Management		
Greater interaction with industry to help develop: • Skills profile • People profile • Funding bid structure • Proactive policy on IP	Continue and expand centres like UKERC	
More managed funding calls	2-stage bidding	
Bringing together outputs from different research projects	Support engagement and communication activities	
Help us with channels to communicate with policy processes		
Promote trans-disciplinary research with close collaboration with industrial organisations		
Focus of Research Funding		
Higher TRL applied research – recognise its importance and value	World class, high quality research standards	Stop funding 'pie in the sky' technologies that are always 30 years away from roll-out
Inter-disciplinary research	Funding for demand-side approaches to industrial energy	If no more money is available for research then we should focus less on TRLs 1-3 and more on applied R&D
Traditional focus on new technologies in old industry	Support for whole systems and inter-disciplinary research	Single-discipline incremental research
Transdisciplinary whole systems research in industrial energy, focusing on products, economy etc.	Support for experimental work to aid development of computational models	Less nuclear fusion research
	Support for fundamental science as well as that with immediate impact	More cautious about science 'fads' (e.g. micro-electrical-mechanical systems (MEMS), nano, bio, graphene etc.)
	Promote pre-competitive research, that has industry application	
	Support inter-disciplinary work focused on the problem, as opposed to methodologies and disciplines	
PhD & Post-Doc Training		
Fund project linked PhDs		
Funding non-EU students		
Support for early career researchers		
Other		
Restructure REF so that it encourages rather than blocks inter-disciplinary research		
Fund champions who act as a bridge between government and research communities		

8 Wrap-up and next steps

During the final session, participants were invited to write up any additional thoughts on "what we had missed" and "post" them in a box to be included in the workshop report. These are reproduced in Annex A.

Finally, Jim Skea noted that a key theme running through all the workshops had been the need for the academic world to be better connected to industry and commerce. This theme had come through particularly strongly at this workshop, perhaps inevitably given the subject matter.

There was a general view that REF incentives discouraged this connection, though one individual cited a different experience at their institution. It was noted that senior academics might be less guided by REF incentives than junior researchers would be.

The role of Knowledge Transfer Networks (KTNs) was noted, though there were divergent views about their success in connecting academia with industry. The learned societies, such as the Institution of Chemical Engineers, also have relevant interest groups which help link academia and industry.

Annex A: Output from the "what have we missed" session

New Business Models

- ESCos and MaSCOs (materials service companies)
- Economics not properly understood
- What are the incentives and opportunities: range of disciplines to make the business case; VAT on refurbishment as well as new build
- Proof of concept for material efficiency gains – more for less.
- Ayres and Roo data: impossibility of green growth; rebalancing the economy
- Energy supply curve - zero, short-run marginal cost renewables
- CDT on management, modelling and investors

Policy

- Research into the design of policy processes for energy/materials: socio-technical research into practice/influence; engagement of the 'nudge' team
- Long-term buildings with low mass
- Getting the 'right' responses to consultations (from appropriate individuals/groups)

System-level understanding and management

- Understanding likely changes in the energy system
- Modelling materials efficiency for carbon reduction purposes
- Physical flows (materials, energy and carbon) through the economy
- Issue of stocks (of existing goods) and service delivery; buildings occupied only 1/3 of the time
- End-of-life and upstream impacts
- Lack of information

Ways of working

- Interdisciplinary
- Shortage of applied economists
- EPSRC/ESRC CDTs

Capabilities/capacity

- Energy use at the site level; commercial constraints and access to data; lack of knowledge by companies
- Carbon trust audits?
- Energy Efficiency Directive audit?
- Select group studying industrial energy: energy consumption in the UK'
- Energy Managers perspectives
- Diversity of models/competition in the market
- Cross-Council activities, including KTPs
- Policymakers and researchers not working well together; timescales for joint working
- Evidence-based or principle-based policymaking

Co-ordination and alignment

- Collaborative working between centres

- Review routes for academic outputs to TSB and government (Grades 5-7)
- Appointment of research champion
- No ownership of "materials" by government departments

Data needs and facilities

- Better evidence base for industrial energy, e.g. more information from 52 sector CCAs
- Data repositories
- PhD training: PhDs on projects not CDTs; transdisciplinary CDTs; PhDs focused on the problem not so closely on the methodologies

Annex B: Agenda

10.00	Arrival, Registration and Coffee
10:30	**Introductions**
10.35	**Session One:** ***Introduction*** Introduction to the purpose and process of the Workshop and the overall development plan for creating an Energy Research and Training Prospectus
10:50	**Session Two:** ***The Current Industrial Energy Research Landscape*** Who is currently active (research/funding)? What are they up to? Who's missing from the meeting?
11:10	**Session Three:** ***Identification of Key Industrial Energy Research Challenges*** Use a "conceptual framework" chart to provoke the identification of key research challenges; cluster these into higher level research themes
12.45	Lunch
13.30	**Session Four:** ***Analysis of Emerging Research Themes*** What are the associated research questions? Whose job is it to take these forward? What research infrastructure do we need (research/testing facilities, data collection/curation etc.)? What are the training needs?
15:15	Tea break
15:30	**Session Five:** ***Drawing it all together and Next Steps*** What have we missed? What should the Research Councils continue to do, do more/less of?
16.30	Close

Annex C: Attendance List

Forename	Surname	Organisation
Julian	**Allwood**	University of Cambridge
John	**Barrett**	University of Leeds
Kevin	**Bygate**	Swansea University
Roland	**Clift**	University of Surrey
Alana	**Collis**	IChemEng
Liz	**Flint**	Technology Strategy Board
Geoff	**Hammond**	University of Bath
Matthew	**Hannon**	Fellowship Team
Jenny	**Hill**	CCC
Dave	**Holtum**	EPSRC
Mark	**Jolly**	Cranfield University
Jonathan	**Norman**	University of Bath
Shahin	**Rahimifard**	Loughborough University
Aidan	**Rhodes**	Fellowship Team
Jim	**Skea**	Fellowship Team
Kevin	**Smith**	STFC
Peter	**Stephenson**	ESRC
Andrew	**Wheeler**	University of Southampton