Research Councils UK Energy Programme Strategy Fellowship

ENERGY RESEARCH AND TRAINING PROSPECTUS: REPORT NO 2

Industrial Energy Demand

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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 and Training 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 contributes to the evidence base upon which the RCUK Energy Programme can plan forward activities alongside Government, Research, Development and Demonstration (RD&D) funding bodies, the private sector and other stakeholders. The tool highlights links along the innovation chain from basic science through to commercialisation. The tool is intended to be flexible and adaptable and 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 has been a series of four high-level strategic workshops and six in-depth expert workshops which took place between October 2012 and July 2013. The main report, *Investing in a brighter energy future: energy research and training prospectus*, was published in November 2013. This is one of nine topic-specific documents supporting the main report. All reports can be downloaded from: www3.imperial.ac.uk/rcukenergystrategy/prospectus/documents/reports. This first version of the Prospectus will be reviewed and updated on an annual cycle during the lifetime of the Fellowship, which ends in 2017.

This report is the product of work conducted independently under EPSRC Grant EP/K00154X/1, Research Councils UK Energy Programme: Energy Strategy Fellowship. The draft report was reviewed by Lizzie Chatterjee of DECC and Mike Tennant of Imperial College London. While the report draws on extensive consultations, the views expressed are those of the Fellowship team alone.

Contents

Executive Summary

This report covers research in the field of industrial energy demand. Initial consultations with professional bodies and others revealed that the community of academic researchers active in this field is small and fragmented. Much of the evidence upon which this report is based was gathered at a one-day workshop involving 15 individuals, mainly from the communities supported by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC).

While global energy demand in the industrial sector is projected to increase, demand in the UK has fallen over a period of decades and the most recent Government projections foresee future energy demand remaining flat. Demand is now dominated by a small number of sectors, principally chemicals, food and drink, mineral products (including cement), paper and vehicle manufacture. Much of the carbon embedded in goods consumed in the UK derives from imported goods.

Overseas ownership is prevalent in energy-intensive sectors. Such companies tend not to locate their main Research and Development (R&D) facilities in the UK. Given that industrial energy use is intrinsically an applied area of energy research the opportunity for collaboration between academic researchers and industry is thus weakened. The current academic reward system also discourages more applied research.

- Research needs in this area fall into two broad classes. There is a continuing need for more traditional engineering-based industrial energy research focusing on incremental and radical process improvements. The UK has both less need and less capability in this area compared to countries retaining a larger manufacturing base. The second broad area covers 'whole systems' perspectives including materials flows, product design and the nature of economic interactions between sectors. The UK has competences in these areas which received a substantial amount of attention in the expert workshop which we convened.
- There is a robust case for the Research Councils continuing to support 'whole systems' type research in the industrial energy field, for example through the new End Use Energy Demand Centre (EUED) **InDemand**. Related investments, notably the **Innovative Manufacturing Initiative**, may also contribute to this type of research. Continuing dialogue between ESPRC and ESRC is needed to support research in this area.
- The case for directed support for more traditional industrial energy research is less clear. If support for this type of research were to be increased, it would require managed mode funding and perhaps the appointment of a 'research champion' to reinforce links with industry and the policy world. Collaboration with innovation bodies supporting more applied R&D would be important if this approach were taken.
- The alternative approach for the Research Councils, especially EPSRC, would be to continue to improve scientific capabilities in underpinning areas of research that have potential application both inside and outside the energy domain. These include catalysis, materials science and the modelling and simulation of fluid flows. The scientific community could then collaborate with industry on a more *ad hoc* basis, supporting bids into initiatives led by bodies such as the Technology Strategy Board (TSB) as and when necessary. Regardless of whether a directed or more hands-off approach is adopted, better mechanisms for supporting links between the academic and industrial communities would increase the impact of research activity.
- Industrial energy research has a number of underlying infrastructure needs. As in other areas of energy research, this community would welcome more access, in terms of operational days per year, to large experimental facilities such as those operated by the Science and Technology Facilities Council (STFC) at the Harwell campus. The quality of data characterising industrial energy demand is also lacking, especially at the meso-level (e.g. industrial sites). As noted by the

International Energy Agency (IEA), this problem is not unique to the UK and is manifested in the regulatory as well as the research domain. To improve the situation, efforts are needed to overcome barriers associated with intellectual property (IP) and confidentiality.

- As in other areas, a mixed model for supporting PhD training would be appropriate. This would blend Centre for Doctoral Training (CDT) arrangements with project-based studentships. CDT investments would be best focused on developing cross-cutting research capabilities in fields such as catalysis or materials science.

Acronyms

AHRC	Arts and Humanities Research Council
BBSRC	Biotechnology and Biological Sciences Research Council
BIS	Department of Business, Innovation and Skills
CCC	Committee on Climate Change
CCS	Carbon capture and storage
CDT	Centre for Doctoral Training
EJ	exajoules
Eng.D	Engineering Doctorate
EPSRC	Engineering and Physical Sciences Research Council
ESCos	Energy Service Companies
ESRC	Economic and Social Research Council
ETP	European Technology Platform
EUED	End Use Energy Demand Centre
GHG	Greenhouse Gas
IEA	International Energy Agency
IP	Intellectual property
LCICG	Low Carbon Innovation Carbon Group
LCTP	Low Carbon Transition Plan
MASCos	Materials Service Company
MoU	Memorandum of Understanding
mt	million tonnes
mtCO$_2$e	million tonnes of carbon dioxide equivalent
mtoe	million tonnes of oil equivalent
NERC	Natural Environment Research Council
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
RCUK	Research Councils UK
RD&D	Research, development and demonstration
STFC	Science and Technology Facilities Council
TINA	Technology and Innovation Needs Assessment
TRL	Technology Readiness Level
TSB	Technology Strategy Board

1. Introduction

This document is one of a series of reports that sets out conclusions about UK research and training needs in the energy area. The focus of this report is industrial energy demand. The primary audience is Research Councils UK (RCUK) which supports energy research in UK higher education institutions through the RCUK Energy Programme.[1] However, other bodies involved in funding energy research and innovation, notably those involved in the UK's Low Carbon Innovation Carbon Group (LCICG)[2] may also find the content useful. The report is also being disseminated widely throughout the UK energy research and innovation community to encourage debate and raise awareness of the work conducted under the Fellowship.

The most important input to this report has been an expert workshop held at Imperial College London on 17 July 2013. There were 15 attendees at the workshop (excluding the Fellowship and facilitation team), most of whom were academics and researchers falling within the community supported by the Engineering and Physical Sciences Research Council (EPSRC) with some representation from the Economic and Social Research Council (ESRC) community. A number of attendees were from government organisations and funding agencies and one participant came from a commercial background.

This subject of Industrial Energy Demand is one of three[3] where a light-touch approach has been taken. This is because, in this case, the community of researchers in the UK is small and fragmented, as documented in this report. A one-day workshop was organised using a cut-down version of the facilitation methods used in six previous residential expert workshops.

A full report of the workshop has previously been published as a working paper.[4] The working paper was the document of record and has acted as an intermediate step in the production of this report which focuses on key messages and recommendations. The workshop also drew on the outcomes of a series of 'strategy' workshops which addressed: **energy strategies and energy research needs; the role of the environmental and social sciences**; and **the Research Councils and the energy innovation landscape**. Reports of these workshops are also available on the Fellowship website.[5]

The conclusions respond to a recommendation of the 2010 International Panel for the RCUK Review of Energy[6] that the research supported by the Research Councils should be more aligned with the UK's long-term energy policy goals. The key criteria used in developing this report have been the three pillars of energy policy – environment, affordability and security – coupled with potential contributions to UK growth and competitiveness.

The Fellowship team is using the EU/International Energy Agency (IEA) energy R&D nomenclature[7] to map out the energy research landscape. This report covers **Area I.1, Energy Efficiencyin Industry**. Some aspects of industrial energy demand, notably generic technologies commonly used in light industry (e.g. lighting, electric motors) and decision-making processes, are also covered in Prospectus Report No 5, Energy in the Home and Workplace. The IEA Energy efficiency/industry sector essentially

1 http://www.rcuk.ac.uk/research/xrcprogrammes/energy/Pages/home.aspx
2 http://www.lowcarboninnovation.co.uk/
3 The others are **Wind, Wave and Tide** and **Nuclear Fission**
4 https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Light%20Touch%20workshop/Industrial%20Energy%20Report%20Working%20Document%20Final.pdf
5 http://www3.imperial.ac.uk/rcukenergystrategy/prospectus/documents/reports
6 http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/ReviewOfEnergy2010PanelReportFinal.pdf
7 http://ec.europa.eu/research/energy/pdf/statistics_en.pdf

covers industrial processes and is generically defined to cover: a) reduction of energy consumption in industrial processes including combustion; and b) development of new techniques, new processes and new equipment for industrial application; and c) other. This contrasts with the tone of the workshop discussion which also emphasised cross-cutting and systemic issues. Carbon capture and storage (CCS), which could potentially play an important role in industry, is referred to tangentially in the report and is covered more thoroughly in Report No 5, **Fossil Fuels and Carbon Capture and Storage**.

This report is structured as follows. **Sections 2-4** provide the wider context within which research and training challenges are identified. Section 2 focuses on the possible role of industrial energy demand in future energy systems both globally and in the UK. Section 3 describes the current UK research landscape and capability levels. Section 4 reviews existing roadmaps and assessments of research and innovation needs. **Sections 5-8** draw heavily on the Imperial College London workshop. Section 5 sets out high-level research challenges in the two areas upon which the workshop focused: industrial processes/sector mapping; and systems thinking, product design and decision-making. Annex A delves more deeply into these research challenges and identifies specific research questions that need to be addressed. Section 6 focuses on the ways in which the Research Councils operate, how the research they support is conducted and underlying needs for research infrastructure and data collection/curation. Many of the conclusions are generic in the sense that they may be applicable across the energy domain or even more widely. Section 7 addresses training provision. Section 8 addresses generic issues about the role of the Research Councils within the wider UK energy innovation system and EU/international engagement. **Section 9** outlines the key conclusions and recommendations from the report.

2. Current and future role of industry in the energy system

2.1 Global industrial energy demand

Globally, industrial energy demand has been growing, albeit more slowly than primary energy demand (Figures 1 and 2). However, industrial demand in developed countries has been on a plateau, or even slightly declining, for decades. Demand increases have arisen in developing countries, especially emerging economies such as China where growth has been particularly strong since the year 2000. Figure 2 shows that recent demand increases have largely been fuelled by the additional use of coal. Electricity has steadily increased market share from about 15% in 1971 to 26% in 2010. The use of oil in industrial markets has been eroded, with a corresponding swing to natural gas.

The IEA projects that global industrial energy demand will continue to grow by 30% by 2020 and 45% by 2050, even in a scenario where the world constrains greenhouse gas (GHG) emissions so that global temperature rises are kept to 2°C above pre-industrial levels (Figure 3, 2DS scenario). Under a scenario where global temperatures rise by 4°C, demand would grow 40% by 2030 and 65% by 2050. This latter scenario is more or less consistent with Shell's recent **Oceans** scenario. Electricity is projected to continue to increase market share, as will natural gas. Coal use is higher in IEA's 2DS scenario than it is in the 4DS scenario. This is because the assumed availability of CCS in the 2DS scenario allows much more coal use in a carbon-constrained world. Under the 4DS scenario, without CCS, coal use falls from now until 2030 but then starts to grow again.

Figure 3 demonstrates the scope for innovation in the area of industrial energy use at the global level. CCS, for example, could have an important role to pay in industry as well as in the power sector.

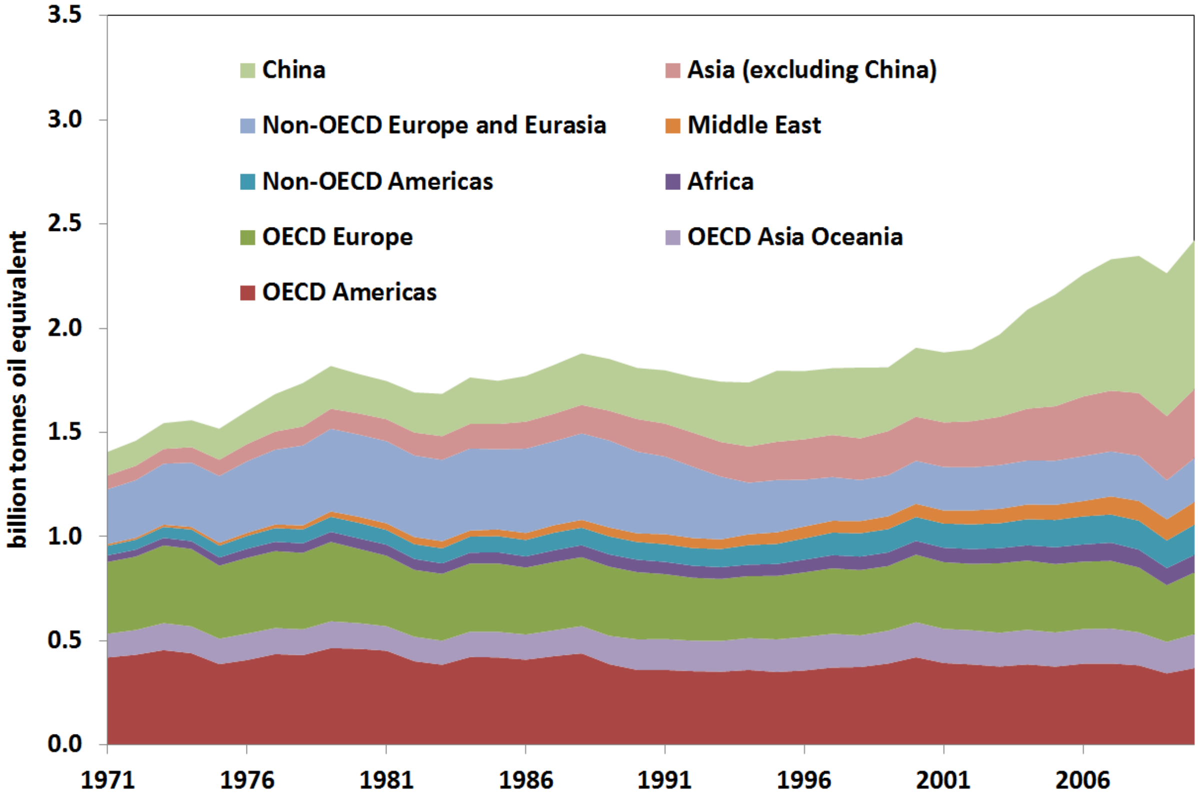

Figure 1: Global Industrial Energy Demand by Region

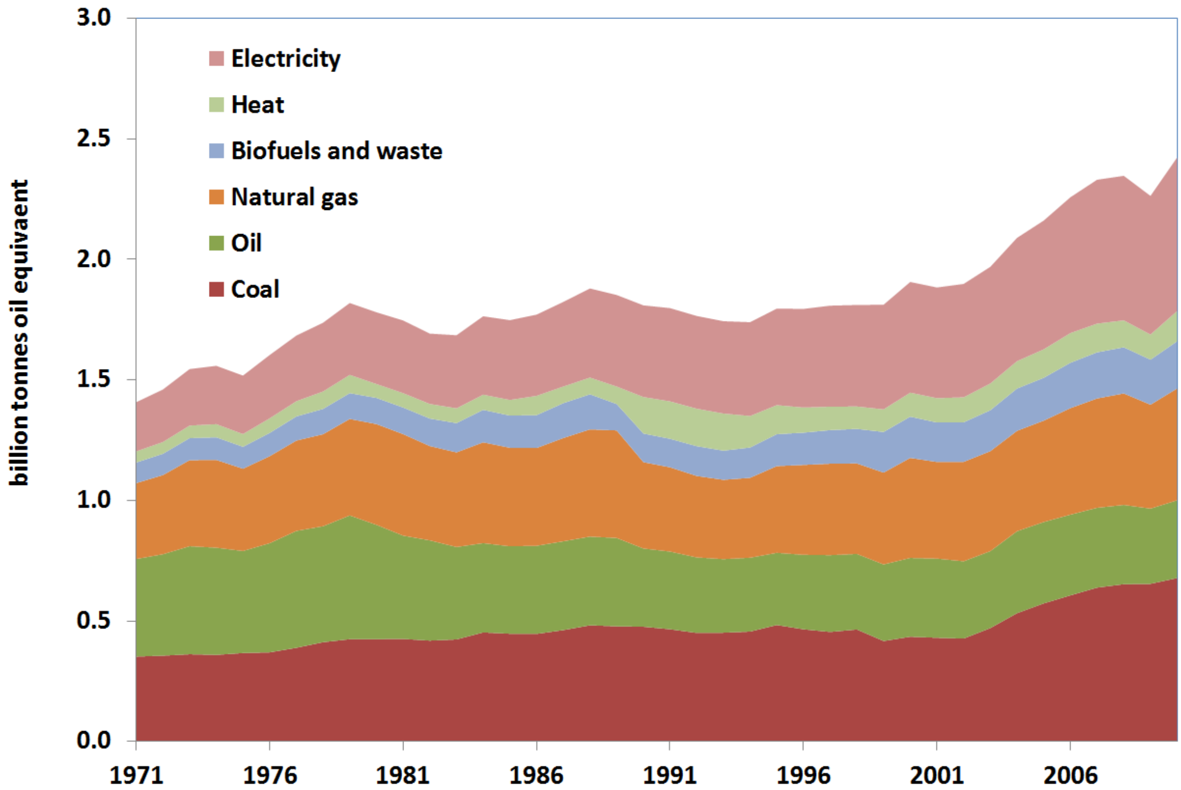

Figure 2: Global Industrial Energy Demand by Fuel

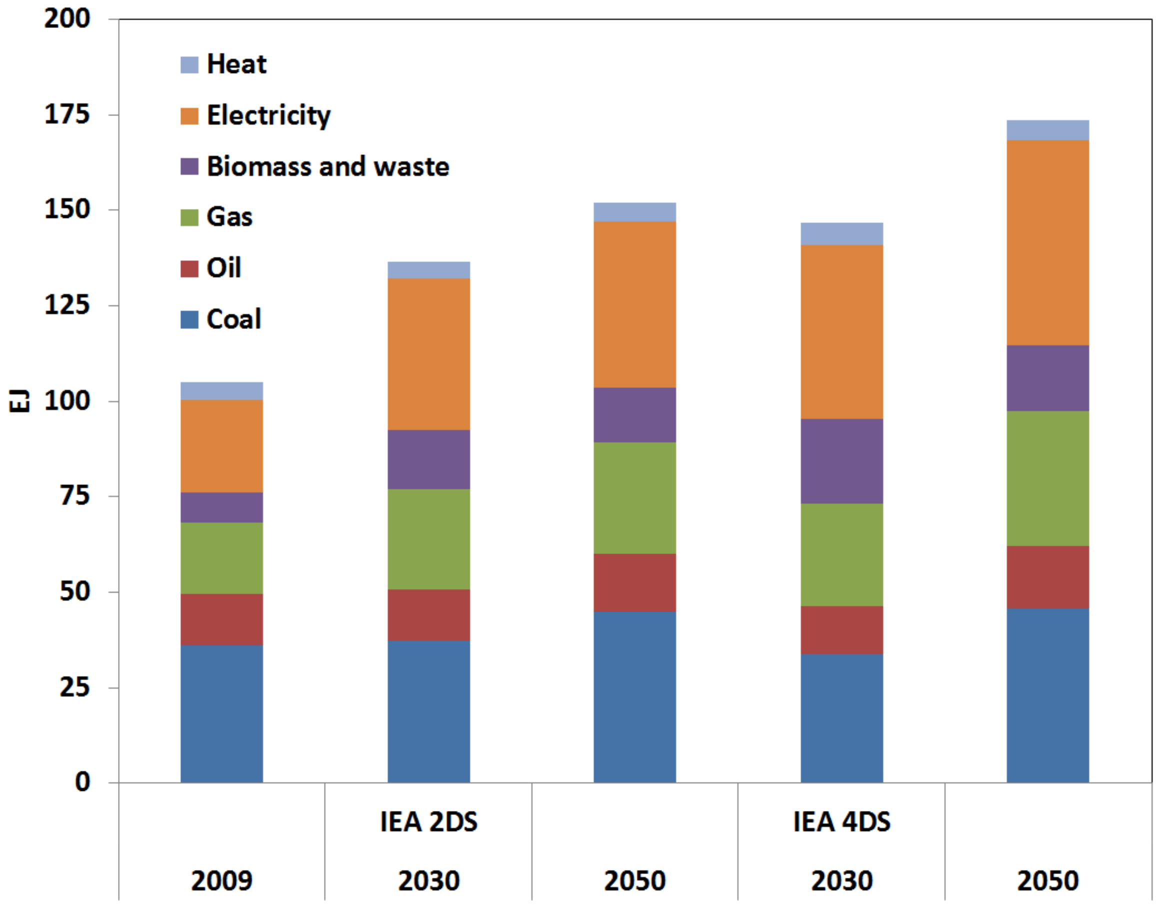

Figure 3: Global Industrial Energy Demand Scenarios

2.2 UK industrial energy demand

The position in the UK stands in contrast to the global picture. Figure 4 shows that industrial energy demand has fallen over the last decades and the fall appears to be continuing. Demand is now 60% below the level in 1970, with a particularly large fall taking place in the early 1980s recession as energy-intensive industries contracted sharply. Coal use in industry has essentially been eliminated, except in the iron and steel sector, and natural gas has largely replaced oil. Reflecting global trends, electricity is taking an increasing share, now one third, of industrial energy demand.

There are several industrial sectors where industrial energy demand has **not** declined substantially and their relative importance is increasing (Figure 5). Five sectors - chemicals, food and drink, mineral products (which includes cement and bricks), paper and printing, and vehicle manufacture – now account for half of all industrial energy demand. Iron and steel has had the sharpest decline with only three integrated steelworks remaining in the UK.[8] Figure 5 illustrates an increasing problem with data regarding industrial energy use. A quarter of industrial energy use is now either allocated to 'other industries' or is unclassified. IEA has noted that this is a global challenge,[9] not a problem exclusive to the UK. The theme of data quality and availability is returned to in later sections.

[8] Tata Steel, http://www.tata.com/company/profile.aspx?sectid=3HYiu6ljpWk=

[9] IEA, **Tracking Clean Energy Progress 2013: IEA Input to the Clean Energy Ministerial,** http://www.iea.org/publications/TCEP_web.pdf

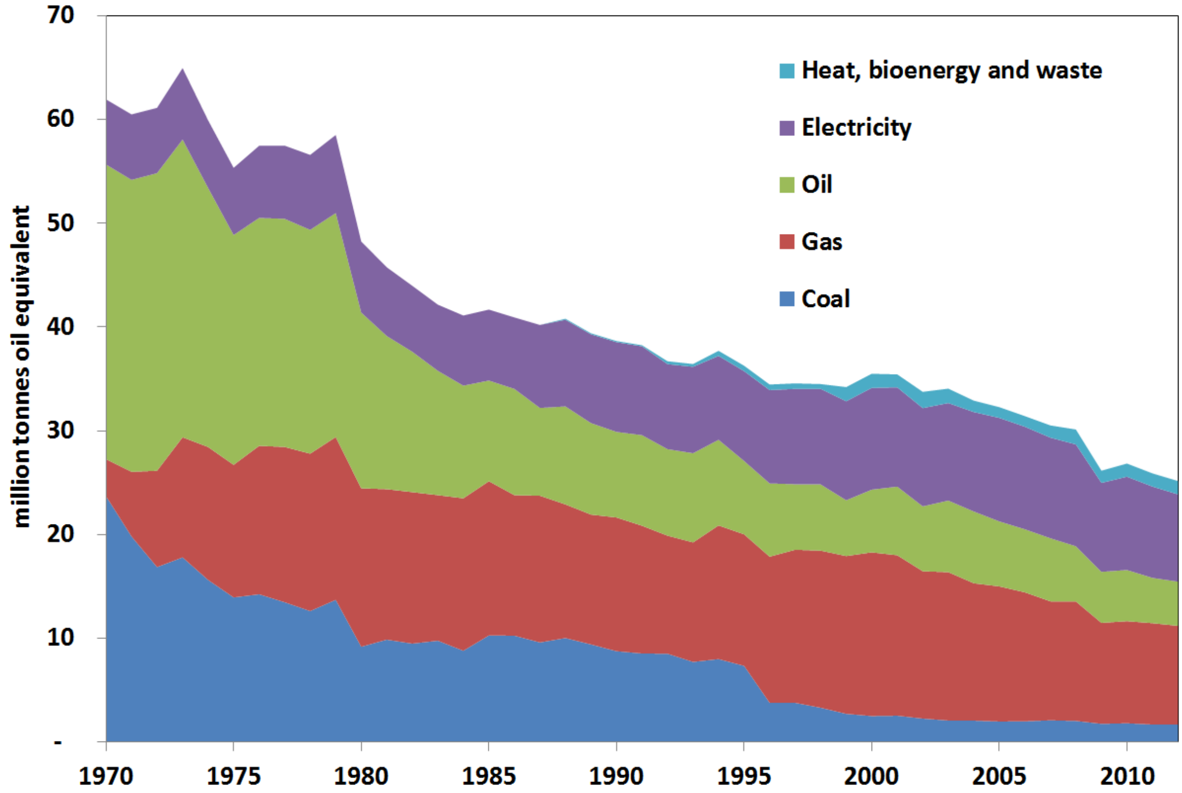

Figure 4: UK Industrial Energy Demand by Fuel

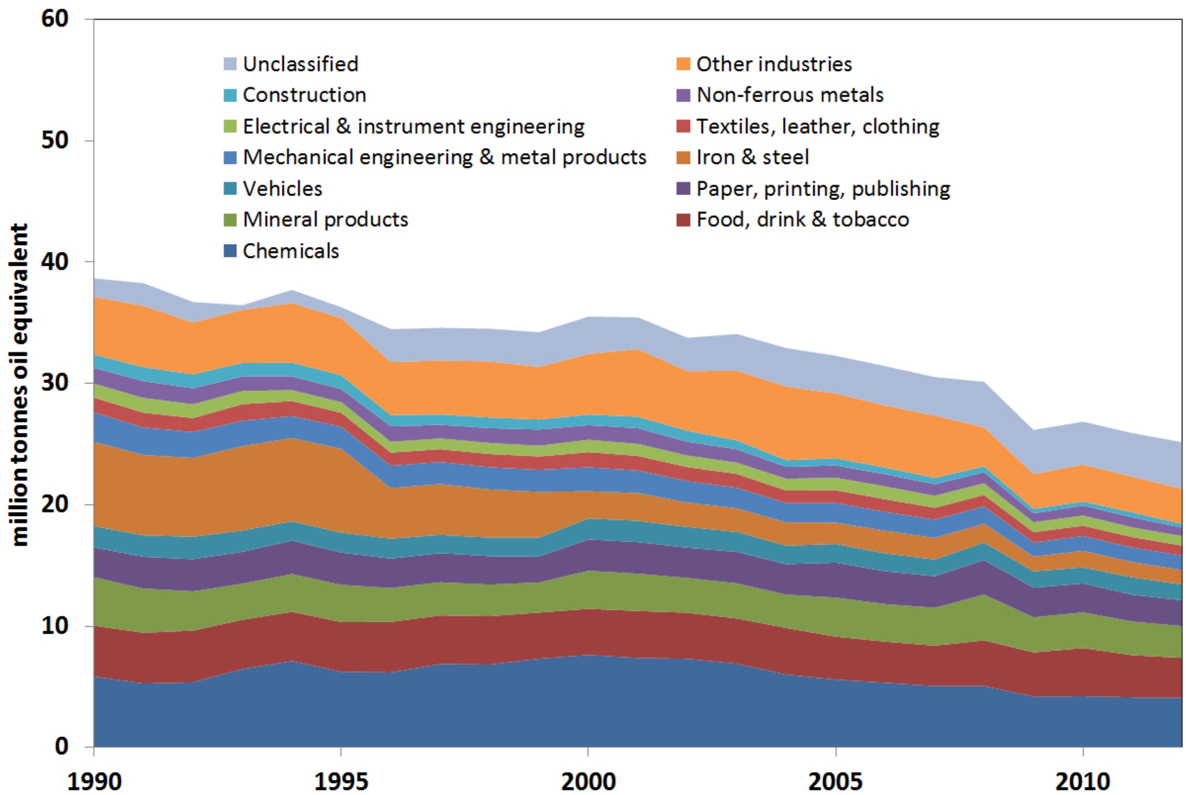

Figure 5: UK Industrial Energy Demand by Sector

The decline in industrial energy demand is linked to an 'offshoring' of heavy industry with energy and CO_2 emissions then being embedded in imported goods. Nevertheless, the UK retains a competitive advantage in advanced manufacturing and specialist products that are less energy intensive. The UK acknowledges the significance of 'consumption-based' GHG emissions in policy design.[10] The analysis in Figure 6 shows that emissions in production sectors in the UK are now matched by emissions embedded in imported intermediate and consumer goods. Figure 6 does not imply that the UK imports electricity with 50 million tonnes (mt) of embedded CO_2, but rather that the electricity used to produce goods imported into the UK, including for example textiles, resulted in 50 mt CO_2 emissions. The issue of flows of materials and energy within industry at the UK and global levels was raised at the industrial energy demand workshop.

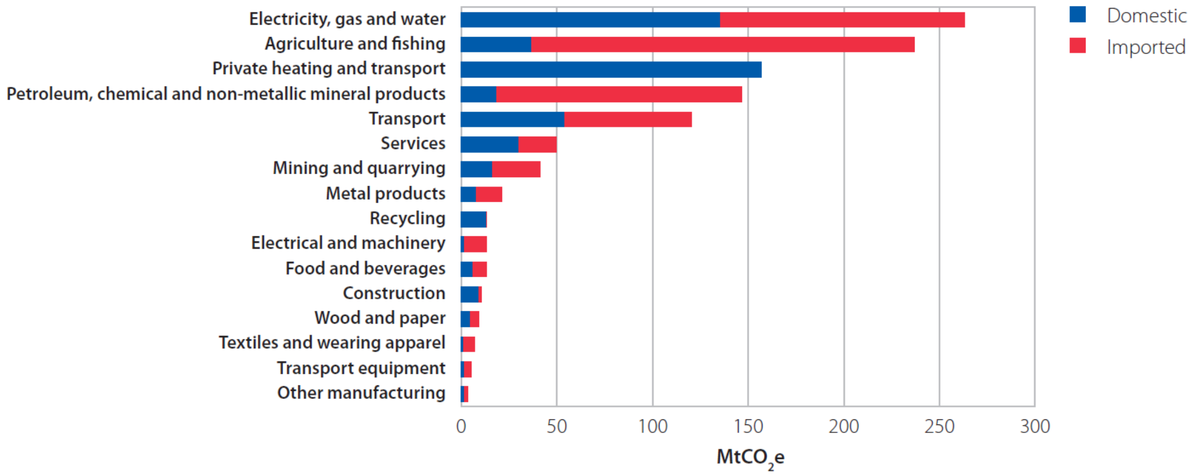

Figure 6: UK greenhouse gas consumption emissions by sector of origin and region (2010). Source: Committee of Climate Change (CCC)

2.3 Energy goals and expectations

The decline in industrial energy demand mirrors the downward trend in UK manufacturing output. Although UK industrial energy demand would fall further if current trends were to continue, past government projections have suggested the reverse (Figure 7). Projections made in 2006 for example foresaw demand of 37.4 million tonnes of oil equivalent (mtoe) in 2010, 40% higher than the outturn figure of 26.9 mtoe. Expectations have since moderated and projections made in 2011 and 2012 envisage demand staying flat.

The Government's 2011 **Plan for Growth**[11] sets out its plans for re-balanced growth that includes a role for manufacturing as well as sectors such as financial services. The current flat projections of industrial energy demand reasonably reflect the aspirations of The Plan for Growth. However, if the aims of The Plan for Growth are not fulfilled then industrial energy demand could continue its downward trend.

Even if the Plan for Growth is successful it is unlikely that significant investment in new energy-intensive manufacturing facilities in primary sectors such as steel, cement and bulk chemicals will take place as the UK has no identifiable competitive advantage. Most facilities in these sectors are under overseas ownership which means that the locus of industrial R&D is generally not in the UK. As energy forms a

[10] House of Commons Energy and Climate Change Committee, Consumption–Based Emissions Reporting: Government Response to the Committee's Twelfth Report of Session 2010–12, HC 488, July 2012, http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenergy/488/488.pdf

[11] HM Treasury/BIS, **The Plan for Growth**, ISBN 978-1-84532-842-9, London, March 2011

significant part of the cost of manufacturing primary materials, energy-saving opportunities have already been pursued quite aggressively and there is only limited scope for further reductions.

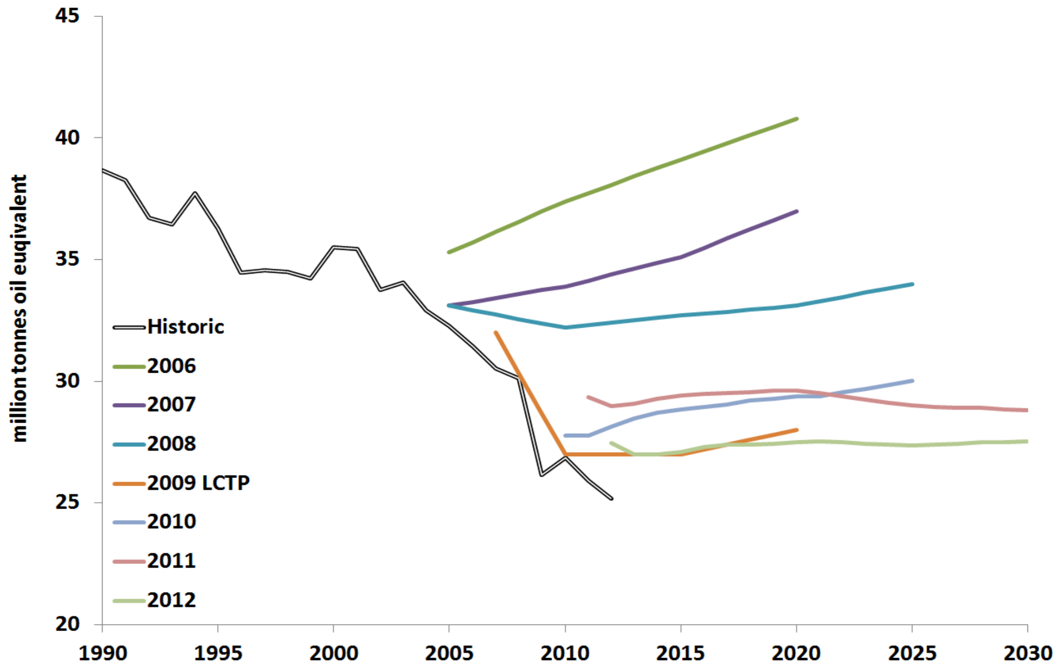

Figure 7: Historic and Projected Industrial Energy Demand
Source: based on DECC

3. UK research capabilities

3.1 Overview

Evidence on UK research capabilities in relation to industrial energy demand comes from three main sources: the Strategic Workshop on **Energy Strategies and Energy Research Needs** held by the Fellowship team in November 2012;[12] a one-day 'light-touch' Expert Workshop on **Industrial Energy** held in July 2013;[13] and the UK Energy Research Centre (UKERC) Energy Research Landscape on **Industry.**[14] Other evidence comes from the LCICG's Technology and Innovation Needs Assessment (TINA) covering the **Industrial Sector;**[15] and interviews held by the Fellowship team in summer 2012.[16] There is a high degree of convergence between the different sources in terms of assessing the UK's modest capabilities in this field.

[12] http://www3.imperial.ac.uk/rcukenergystrategy/prospectus/workshops/workshop0
[13] http://www3.imperial.ac.uk/rcukenergystrategy/prospectus/workshops/workshop10
[14] http://ukerc.rl.ac.uk/Landscapes/Industry.pdf
[15] http://www.lowcarboninnovation.co.uk/document.php?o=13
[16] https://workspace.imperial.ac.uk/rcukenergystrategy/Public/reports/Strategic%20Workshop%20Reports/Energy%20Strategy%20Fellowship%20Report%201%20-%20Summary%20Of%20Stakeholder%20Views%20-%20Fellowship%20%20final.pdf

3.2 Strategic Workshop

There was little discussion of UK capabilities in industrial energy demand at the strategy-level workshop on **Energy Strategies and Energy Research Needs** held in November 2012. In comparison with other area of energy research, industrial energy was considered to be of middling relevance to UK energy futures but low in terms of both scientific and industrial capabilities.

3.3 Expert Workshop

At the expert workshop on industrial energy demand held in July 2013, participants were invited to assess, on a scale of 0-10, how well placed the UK currently is in terms of industrial energy research capabilities so that we can meet the challenges of the future. A score of 0 signified 'no chance' while 10 signified 'well set up'. Most participants rated the UK in the range 2-6 with an average score of 3.9, the lowest rating in any of the expert workshops. Participants believed that the UK community was relatively small and fragmented, that the UK's reliance on imports and inward investment weakened links between research and the supply chain, and that incentives to reduce industrial energy demand were weak.

3.4 UKERC Research Landscape

The UK Energy Research Landscape document on industrial energy dates back to 2009 and consequently the detail is out-of-date. However, the high-level conclusions resonate with other evidence. The document focuses very specifically on industrial process energy efficiency in line with the IEA R&D nomenclature rather than wider issues relating to industrial structure and materials flows. The key conclusions are:

- The diversity of manufacturing processes leads to fragmentation of the research landscape.
- Mechanical engineering in the UK could help to achieve greater thermodynamic efficiency in in energy systems but the UK has fallen behind North American and other European competitors.
- The smaller UK chemical engineering community has been internationally active and has strengths in terms of process integration and process intensification.
- The UK is strong in the fundamental sciences relevant to industrial energy use including fluid dynamics and materials science.
- Work in this area stands to benefit from cross-cutting developments in information and communication technologies.

Other than the strengths in process integration and relevant fundamental science, the Landscape document describes the UK has having medium-level capabilities.

Two major research council investments since 2009 are relevant. The EPSRC Centre for Industrial Sustainability[17] led by the University of Cambridge is working on two fronts: rapidly reducing the resource and energy-intensity in the production of existing goods; and investigating options for a radical redesign of the industrial system. The UK **Indemand Centre**,[18] also led by the University of Cambridge, is one of five **End Use Energy Demand** (EUED) Centres established by ESPRC and ESRC in 2013. It is focusing on reducing the use of both energy, and energy-intensive materials, in the industries that supply the UK's physical needs, and developing a better understanding of the operation and performance of the whole materials and energy system of UK industry.

[17] http://www.industrialsustainability.org/
[18] http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K011774/1

3.5 Other sources

The LCICG TINA does not specifically address research capabilities but notes some areas in which the UK has competitive advantage. These include: low carbon cement; high value chemicals, innovative food products and low carbon cement where strengths are attributed to a strong research base and regulatory framework. The TINA notes mid-level competitive advantage in bio-processing in the chemicals sector; and biomass heat generation in the food and drink industry.

Somewhat contradicting the conclusion reached in the UKERC Research Landscape on **Industry**, some individuals interviewed by the Fellowship team in summer 2012 believed that the UK chemical engineering profession had been 'hollowed out' in research terms, partly because relatively high salaries drew qualified chemical engineers into industry. Others took a different view, noting that the Sustainability Interest group of the Institution of Chemical Engineers was very active.

4. Existing roadmaps and innovation needs assessments

UK

Roadmaps focusing specifically on industrial energy are rare. Industry roadmaps, e.g. on aluminium, which address energy efficiency alongside other considerations are more common. An exception is the LCICG TINA on **The Industrial Sector**.[19] Reflecting the UK's relative weakness in a number of industrial sectors, the TINA focuses on only four sectors: chemicals; food and drink; iron and steel; and cement. Within each sector, the TINA identifies three cross-cutting areas meriting possible public sector innovation support: efficiency improvements; alternative process technologies; and low carbon substitute feedstocks/intermediate products. This latter area was seen to have the greatest potential in terms of benefit for the UK.

Chemicals. Bio-processing including the development of bio-catalysts and the demonstration of bio-processing technology at commercial scale.

Food and drink. Alternative heat generation through a programme to reduce the upfront investment cost of equipment and to improve availability of biomass.

Cement. Low carbon cement and clinker substitution, including: the specifications and standards combined with wider appreciation of where clinker replacement cements can be used; demonstration of long term stability and economic viability of low carbon cement; and the development of plant and equipment to manufacture low carbon cement.

Other areas seen as providing mid-level benefits included: improved separation technologies in the chemicals sector; smelt reduction, electric arc furnace improvement and electrochemical steel production; and CCS in the iron and steel sector.

EU

A number of European Technology Platforms (ETPs) have been established to define medium to long-term research and technological objectives and develop roadmaps to achieve them. These are bottom-up, industry-led initiatives in which the European Commission participates rather than leads. A number of energy-focused ETPs are referred to in other Energy Strategy Fellowship reports. There are also a

[19] http://www.lowcarboninnovation.co.uk/document.php?o=13

set of ‘production and process’ ETPs whose work is relevant to, but does not focus exclusively on, industrial energy consumption. The following industries are covered:[20]

- European Construction Technology Platform (ECTP);
- European Steel Technology Platform (ESTEP);
- Advanced Engineering Materials and Technologies (EuMaT);
- Future Textiles and Clothing (FTC);
- Sustainable Chemistry (SusChem);
- European Technology Platform on Sustainable Mineral Resources (ETP SMR); and
- Future Manufacturing Technologies – Manufacture.

Each ETP has developed a Vision Document a Strategic Research Agenda and, in some cases, a full roadmap. Many of these documents date back to 2004-06. In view of the light-touch’ nature of our work on industrial energy these documents have not been explored in depth, nor were they considered in detail at the ‘light-touch’ workshop.

5. Research challenges

Research challenges in the industrial energy area fall into two broad classes: those of a technical, process-oriented nature that broadly correspond to the scope of IEA Area I.1 **Energy Efficiency in Industry**; and those of a wider systemic nature covering materials flows, the role of industry in economic systems, energy modelling and social science/economics work on decision-making, policy and regulation. A substantial part of the discussion at the July 2013 workshop fell into the latter class. The research challenges identified are therefore wider in scope than those covered by either the IEA classification or the **Industrial Sector** TINA.

Table1 sets out the main technical challenges. On industrial processes, the identified challenges are broader than those identified in the industrial TINA and more suited to underpinning research on topic such as materials, catalysts and heat transfer. This is in part due to the TINA focus on specific sectors whereas Table 1 is generic. For example, the TINA refers specifically refers to novel cell design and cathodes materials in the chloralkali process which is implied by but not specified in Table 1. Much of the industrial process section of Table 1 refers to heat management which is not specific to any one sector. Table 1 covers issues that will contribute indirectly to energy efficiency, such as improved use of materials and waste water recovery. These will become more important as the opportunities for the direct improvement of energy efficiency become exhausted in a number of processes.

Table 1 also addresses the critical issue of data for industrial energy research which has been identified as a problem by the IEA[21] and others. There are currently large gaps in terms of mapping baseline energy use, energy efficiency potential and the potential for renewable heat.

Table 2 focuses on the system-level aspects of industrial energy research, product design and social science/economics-oriented work focusing on decision-making, policy and regulation. The system level challenges appear suitable for research council support, while the need for work on decision-making could also be dealt with through short-term applied research and might be suitable for consultants as well as academic researchers.

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20 http://cordis.europa.eu/technology-platforms/home_en.html

21 IEA, **Tracking Clean Energy Progress 2013: IEA Input to the Clean Energy Ministerial,** http://www.iea.org/publications/TCEP_web.pdf

Table 1: Research challenges: industrial processes and sector mapping

Challenge Area	Challenge	Notes
Industrial processes	Improved materials	
	Improved catalysts	
	Improved sensor technology	Especially for engines and turbines
	Improved heat transfer fluids	Meeting multiple criteria including cost and environmental impact
	Modelling and simulation of fluid flow	Including collection of experimental data
	More effective/precise heating for large scale processes	For example, large-scale microwave heating
	Heat recovery and re-use	Including waste heat recovery, use and upgrading of low-grade/low-exergy heat, retrofitting potential
	Waste water recovery	
	Management of devices within a manufacturing system	How is energy used and how could it be used more efficiently?
	Management of peak demand for power	
	Energy efficiency of data centres	
	Fuel switching	
	Carbon capture and storage for industry	
Sector mapping	Characterisation of baseline energy use	Especially outside energy intensive industry
	Mapping of energy efficiency potential	Evidence base in need of update
	Cost and potential of materials efficiency:	Both production and supply chain perspectives
	Adaptability of industry to future energy supply options	New and improved energy vectors, e.g. decarbonised electricity, hydrogen, biomass
	Renewable heat potential	Sector specific potential for biomass and heat pumps
	Metrics for energy embedded in manufactured products	Operational tools

Table 2: Systems thinking, product design and decision-making

Challenge Area	Challenge	Notes
Systems thinking	Drivers of industrial energy demand	Economic growth, demand for goods and services, rebound effects
	Whole-system modelling of supply chains from materials extraction through to final products.	Covering energy, materials, waste, re-use and recycling
	Systems and technologies for avoiding waste and over-use of materials	Circular economy
	System level optimisation of transport/logistics	
	Synergies across sectors	For example, waste heat use, shared heat networks
Product design	Cost and potential of materials efficiency	Supply chain and production basis
	Cost and potential of energy efficiency	Supply chain and production basis
	Simulation of processes along the supply chain to identify energy embedded in products	
	Product design for re-use and recycling	Addressing issues such as modularity, lifetime extension and lightweight design
Decision-making, policy, and economics	New business models for delivering goods and services	Aimed at reducing demand for both energy and materials
	Shaping business-to-business purchasing decisions	Opportunities for clients to drive down energy and materials demand
	Business decision-making in heavy industry	
	Impact of the business environment on energy efficiency/decarbonisation investment	
	Overcoming management barriers to energy efficiency	
	Identifying quick win opportunities for energy efficiency	Taking account of timescales, economics, technological potential and information gaps
	Policies and regulations to increase the take-up of energy efficient industrial technologies.	Especially outside energy intensive industry.
	The use of planning policies and building regulations to drive energy efficiency	For example, clustering industrial development, co-location with existing facilities, 'heat-network ready' development
	Capacity of industry to pass-through or absorb costs of energy efficiency/low-carbon policies	Especially energy-intensive industry and industry exposed to international competition

6. Research support

6.1 Ways of working

General. The industrial energy research community is small and fragmented. If an effort were to be made to enhance the size and coherence of the community, it would be appropriate to appoint a research champion to promote the area and act as a bridge with industry and policymakers.

Cross-Council working. Industrial energy does not fit comfortably within one research council, as it requires a 'whole-systems', inter-disciplinary approach. It would help if a communication protocol were put in place to link projects, with Centres being better linked and aligned with international efforts. Specific funds could be earmarked for this purpose.

Funding processes. The nature of industrial energy research is such that the Research Councils may need to attach some value to work that looks towards the higher Technology Readiness Levels (TRLs), i.e. more applied research. Nevertheless, more fundamental science and engineering that has potential industrial application, for example experimental work to aid the development of computational models, has an important role to play. This area has relied on responsive mode funding for support. More managed funding would be needed if the status of the area were to be enhanced.

Interdisciplinarity. Two types of interdisciplinarity are needed as part of the industrial energy research portfolio: first, links between the engineering disciplines (e.g. mechanical, chemical) especially in respect of process technologies; and, second, links between engineers on the one hand and applied economists, business/management schools and modellers on the other. A wider range of disciplinary contributions, e.g. from sociology or law should not be ruled out. The latter discipline is within the scope of the Arts and Humanities Research Council (AHRC) which does not participate in the RCUK Energy Programme. Interdisciplinary research would facilitate links with industry. Research council investments such as UKERC have a role to play in promoting this wider interdisciplinarity.

6.2 Long-term perspectives

This community did not show great concern about short-term versus long-term thinking in research planning, but had some concerns that political 'short-termism' had adverse impacts on research in this area.

6.3 Data

The lack of relevant data and its inaccessibility are major concerns for the industrial research energy community. This concern is not restricted to the UK or to the research community. Data issues apply both to the pattern of utilisation of energy in industry and data on the physical properties of, for example, heat transfer fluids. The concern about energy use data echoes a conclusion of the IEA[22] that the poor quality and availability of data on industrial energy is a generic problem that constrains the ability to track and assess energy efficiency progress.

Energy use data may be inaccessible (buried in industry) or unavailable (e.g. of a commercially sensitive nature). A number of steps could be taken to overcome these barriers:

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[22] IEA, **Tracking Clean Energy Progress 2013: IEA Input to the Clean Energy Ministerial,** http://www.iea.org/publications/TCEP_web.pdf

- The flow of data from the private sector to academia could be increased by explicitly managing confidentiality and non-disclosure issues, for example via trusted academics or other intermediaries. Data aggregated at the sector or corporate level, but especially site level, would be invaluable. Progress has already been made on this issue in respect of energy use in the built environment.
- Additional data could be collected by academia, with the cooperation of industry, for example by using MSc students.

Sharing of other types of data, for example data on the physical and chemical properties of fluids and materials would also support better modelling and experimentation.

6.4 Infrastructure and facilities

Testing facilities. The capacity to test high-temperature materials while in use, e.g. through a sensor in the middle of a gas turbine, is needed. This is not currently available to process industries.

Experimental facilities. Facilities and instruments are needed to support materials discovery and the analysis of materials from the atomic to the device/macro scale. Increasing the utilisation of existing facilities, for example the large facilities operated by Science and Technology Facilities Council (STFC), would help. Experimental capabilities are needed to verify computational models for fluid flow and heat transfer.

Computational facilities. Researchers in this field would welcome support for computational modelling facilities and techniques that predict the behaviour of materials and components without testing them in practice.

7. Training

PhD funding models. As in other energy research areas, there is strong support for complementing Centres for Doctoral Training (CDTs) with support for project-based PhDs. Any CDTs in this field need to be interdisciplinary in character incorporating economic and business perspectives. This suggests the need for engagement between EPSRC and ESRC. There are good arguments to be made that PhDs in in the area of industrial process energy ought to be problem- rather than methodology focused. In this respect, the four-year Engineering Doctorate (Eng.D) model operated by EPSRC is particularly recommended, as projects are defined by industry and consequently research engineers/students gain a better understanding through time spent in industry. However, PhD projects with a broader perspective on industrial energy systems might well benefit from a more methodology-focused approach as this field of study is far less developed.

Transferable skills. Given great uncertainties about the future role and make-up of the manufacturing sector within the UK economy, it would be advisable that PhD training fosters the development of transferable skills which could be applied in other parts of the energy domain or more widely.

Understanding of policy/markets. Training in the industrial energy field should give students a sense of the bigger picture into which their research fits. Specifically, PhD students with pure science degrees would benefit from additional training to improve their general awareness of the wider context for industrial energy. New knowledge arising from research council investments could be incorporated into this and wider engineering education. PhD projects looking explicitly at the interaction between energy policy, the business environment and industrial energy demand would find a ready audience in the policy world.

Professional development and career progression. If the UK's research capacity in this area is to be expanded, more mid-career researchers capable of supervising masters and doctoral students will be needed. Currently there are many high quality PhD applicants but fewer qualified postdocs. Researchers need support at the early stages of their careers. Given the applied nature of much of the research in this field, secondments across sectors – academia, industry, policy – would be particularly valuable. The Research Councils and others could play a role in facilitating this.

8. Connections

8.1 Connections across research areas

This area has connections with:

- **Energy in the home and workplace** (Prospectus Report 3) in respect of generic technologies (e.g. lighting, motors) and industrial decision-making;
- **Fossil fuels and CCS (Prospectus Report 5)** in respect of CCS technology and the combustion and utilisation of fossil fuels;
- **Electrochemical energy technologies (Prospectus Report 6)** in respect of materials and catalysts;
- the IEA energy research area **Other Energy Efficiency** (I.4) in respect of: waste heat utilisation; district heating; and the recycling and uses of urban and industrial wastes;
- the IEA energy research area **Applications of bio-energy for heat and electricity (III.4.3)** in respect of: energy modelling; policy and regulation; and technology acceptance;
- the IEA energy research area **Energy Systems Analysis** (VII.1.1/VII.1.2)in respect of: energy modelling; and policy and regulation; and
- the EPSRC Centres for Innovative Manufacturing initiative.[23]

8.2 Linkages outside the Research Council sphere

Wider innovation support. Industrial energy is intrinsically an applied area, not necessarily encouraged by current academic incentives. While the requisite skills may exist in the academic sector, these are currently directed towards more theoretical concerns. The UK suffers from weaknesses at the applied R&D and demonstration end of the scale. A combination of more funding at the higher TRL levels and a re-alignment of academic incentives would be needed to ensure that relevant high-quality university-based work subsequently reaches application. For a more rounded effort, the research councils would need to become part of a vertically integrated research network and strategy spanning the range from fundamental scientific research through to applied work and early demonstration. Collaboration between RCUK and more applied research funders, such as TSB, possibly via catapult centres on the Fraunhofer institute model, would need to be explored.

Policy. There is a large disconnect between the UK research community and those in the policy world. Communication channels are needed. An industrial energy champion could help promote the dissemination of academic outputs that could add to the evidence base for government and TSB.

Industry links and knowledge exchange. Better links between industry and academia would help to develop better profiles in terms of both individuals and improving skill sets across the community. Better links would also improve the handling of intellectual property (IP) issues in funding bids. There is a need for interaction between trade associations, major companies and academics. One possible mechanism

[23] http://www.epsrc.ac.uk/research/centres/innovativemanufacturing/Pages/centres.aspx

is a Memorandum of Understanding (MoU) between EPSRC and relevant trade associations. The Department of Business, Innovation and Skills (BIS) has a potentially useful role in facilitating this.

8.3 International working

Given the UK's relatively weak position vis-a-vis competitors, there would be benefits in greater exchange of knowledge at the international level.

8.4 Other issues

Achieving reductions in industrial energy use would be assisted by better understanding and management of materials and material flows both within industry and between industry and other sectors (e.g. buildings). No-one 'owns' this topic within the government system and a clearer allocation of responsibility, coupled with greater interdepartmental communication, would help.

9. Conclusions and recommendations

Industrial energy use is intrinsically an applied area of energy research where collaboration between academic researchers and industry is essential. Manifest weaknesses in this area of research in the UK, agreed upon by people both within and outside the community, are reinforced by a number of factors. These include: historic declines in many manufacturing sectors; the prevalence of overseas ownership which tends to result in R&D facilities being located outside the UK; and academic reward systems that place less emphasis on applied research achievements.

Research needs in this area fall into two broad classes. There is a continuing need for more traditional engineering-based industrial energy research focusing on incremental and radical process improvements. The UK has both less needs and less capability in this area compared to countries retaining a larger manufacturing base. The second broad area covers 'whole systems' perspectives including materials flows, product design and the nature of economic interactions between sectors. The UK has competencies in these areas which received a substantial amount of attention in the expert workshop which we convened.

There is a robust case for the Research Councils continuing to support 'whole systems' type research in the industrial energy field, for example through the new End Use Energy Demand Centre **InDemand**. Related investments, notably the Innovative Manufacturing Initiative, may also contribute to this type of research. Continuing dialogue between ESPRC and ESRC is needed to support research in this area.

The case for directed support for more traditional industrial energy research is less clear. If support for this type of research were to be increased, it would require managed mode funding and perhaps the appointment of a 'research champion' to reinforce links with industry and the policy world. Collaboration with innovation bodies supporting more applied R&D would be important if this approach were taken.

The alternative approach for the Research Councils, especially EPSRC, would be to continue to improve scientific capabilities in underpinning areas of research that have potential application both inside and outside the energy domain. These include catalysis, materials science and the modelling and simulation of fluid flows. The scientific community could then collaborate with industry on a more **ad hoc** basis, supporting bids into initiatives led by bodies such as TSB as and when necessary. Regardless of whether a directed or more hands-off approach is adopted, better mechanisms for supporting links between the academic and industrial communities would increase the impact of research activity.

Industrial energy research has a number of underlying infrastructure needs. As in other areas of energy research, this community would welcome more access, in terms of operational days per year, to large experimental facilities such as those operated by the STFC at the Harwell campus. The quality of data characterising industrial energy demand is also lacking, especially at the meso-level (e.g. industrial sites). As noted by the IEA, this problem is not unique to the UK and is manifested in the regulatory as well as the research domain. To improve the situation, efforts are needed to overcome barriers associated with IP and confidentiality.

As in other areas, a mixed model for supporting PhD training would be appropriate. This would blend CDT arrangements with project-based studentships. CDT investments would be best focused on developing cross-cutting research capabilities in fields such as catalysis or materials science.

Annex A: Research needs

This section fleshes out in more detail specific research needs within the five challenge areas identified in Tables 1 and 2. These derive from the July 2013 expert workshop.

A.1 Industrial processes

Materials

- identification of material properties needed to deliver a sustainable energy system;
- materials discovery and behaviour characterisation;
- processes for manufacturing materials;
- performance and durability of materials over their life cycle, e.g. degradation over time as well as production;
- recyclability and disposal of materials at end-of-life;
- focus areas: high-temperature materials (e.g. ceramics); light-weight materials; composite materials; and
- modelling materials efficiency for carbon reduction purposes.

Catalysts

- engineering of catalyst reactions to improve catalysis and process efficiency;
- minimising energy requirements through the use of catalysts;
- replacement of homogenous with heterogeneous catalysts;
- cost reduction;
- re-use of catalysts, e.g. from catalytic convertors in vehicles; and
- incentives/arrangements to support catalyst re-use.

Sensor technology

- sensor systems for plant monitoring and control;
- design of sensors for hostile environment, e.g. corrosion resistant;
- processing sensor data for improved process management; and
- sensors to gain more precise knowledge of operating conditions to support the control of engines and turbines for more efficient operation.

Improved heat transfer fluids

- development of working fluids capable of recovering waste energy from industrial processes; and
- understanding and modelling the environmental and economic impacts of new working fluids.

Waste Heat

- heat recovery;
- machinery and unit process design: heat exchanges; heating fluids; fouling; breakdown of fluids; and

- identifying the scope for retrofitting systems by comparing the costs and benefits of retrofit with re-building from scratch[24].

Alternative heat sources for industry

- integration of on-site power stations with industrial process and making best use to maximise efficiency.

Waste Water

- minimisation of water use and recovery of water, particularly contaminated water.

Data centres

- developing integrated approaches to the design of data centres to improve energy efficiency;
- development of control technologies; and
- improved liquid cooling technologies.

A.2 Sector mapping

- develop data to support a mid-level analysis (not too specific or too aggregated) of the energy efficiency associated with finished products and understand the relative energy efficiency of different industrial sub-sectors;
- data is needed on energy use and material flows/lifetimes based on finished products rather than processes;
- understand the availability of waste industrial heat its potential for utilisation;
- map industrial heat and its potential applications in terms of temperature, equipment needs and costs;
- map the potential for use of biomass and energy-form-waste;
- identify other renewable opportunities including the use of roof space for PV and wind turbines; and
- mapping question – physical flows of (e.g. materials, resources, carbon, energy etc.) through the industrial system/economy.

A.3 Systems thinking

- modelling physical flows of materials, energy and carbon throughout the economy;
- modelling material efficiency for carbon reduction;
- modelling physical stocks as well as physical flows of materials so that these can be managed efficiently;
- understanding the implications for the industrial sector of possible changes in the energy system in terms of, for example, the volume of carbon released via both production and consumption;
- recycling a wider range of materials; and
- upstream impacts of end-of-life strategies.

[24] Industrial plants are integrated systems and the ability to recover waste streams (e.g. waste heat) depends on the nature of the system already in place: e.g. heat exchangers; efficiency of turbines; exhausts etc. It is possible that systems may need to be re-engineered to integrate one new technology.

A.4 Product design

- linking questions about the manufacture of products with those concerning their use;
- multi-scale 'through process' modelling of durable products (e.g. cars, textiles) to optimise the use; of energy and other resources in product, manufacturing, use, economy and end-of-life;
- multi-scale mathematical models of product systems and materials engineering; and
- designing long-life buildings with low mass.

A.5 Decision-making, policy and economics

Business models

- understanding the incentives and opportunities to develop innovative industrial energy business models, such as selling energy service through energy service companies (ESCOs) and industrial services rather than materials through materials service companies (MASCOs);
- developing proof of concept to demonstrate that new business models can deliver efficiency and sustainability while being financially viable;
- understanding the diffusion of new business models; and
- proof of concept for material efficiency gains.

Policies and regulations

- explore policy drivers and barriers for industrial energy efficiency; and
- socio-technical research (e.g. 'nudge') into the design of policy for industrial energy/materials.

Annex B: Process for developing the prospectus

This Energy Research and Training Prospectus Report has been developed under the auspices of the RCUK Energy Strategy Fellowship which was established in April 2013. Fellowship activities leading the production of the Prospectus have gone through three phases.

Phase I (Spring –Summer 2012), **the scoping phase**, involved a comprehensive review of relevant energy roadmaps, pathways and scenario exercises in order to provide a framework for possible UK energy futures. Extensive consultation with stakeholders across the energy landscape was carried out in order to encourage buy-in and establish clearly the boundaries and links between the RCUK Prospectus and other products related more to deployment. One conclusion arising from the consultations was that linkage should be sought across the energy research domain and that consequently related topics linked by underlying research skills should be covered in single workshops during Phase II.

Phase II (Autumn 2012 – summer 2013), **the evidence-gathering phase**, relied heavily on workshops bringing the research community and stakeholders together round specific topics. Three 'strategic' workshops on **Energy Strategies and Energy Research Needs, The Role of Social Science, Environmental Science and Economics**, and **The Research Councils and the Energy Innovation Landscape** were held October 2012- February 2013. Six expert residential workshops on **Fossil Fuels and CCS, Energy in the Home and Workplace, Energy Infrastructure, Bioenergy, Transport Energy** and **Electrochemical Energy Technologies** were held January- June 2013. In addition, 'light-touch' activities were conducted in respect of: **Industrial Energy; Wind, Wave and Tide**; and **Nuclear Fission**. A final strategic level 'synthesis' workshop was held in July 2013. During Phase II, reports on each of these workshops were prepared and web-published following comments from participants.

During Phase III, (summer-autumn 2013), **the synthesis stage**, the workshops reports were 'mined' and combined with contextual information to produce the Prospects Reports which were put out for peer review. The Prospectus, including a hard-copy Synthesis Report, was launched in November 2013.

Annex C: List of prospectus reports

No 1	Investing in a brighter energy future: energy research and training prospectus
No 2	Industrial energy demand
No 3	Energy in the home and workplace
No 4	Transport energy
No 5	Fossil fuels and carbon capture and storage
No 6	Electrochemical energy technologies
No 7	Wind, wave and tidal energy
No 8	Bioenergy
No 9	Nuclear fission
No 10	Energy infrastructure