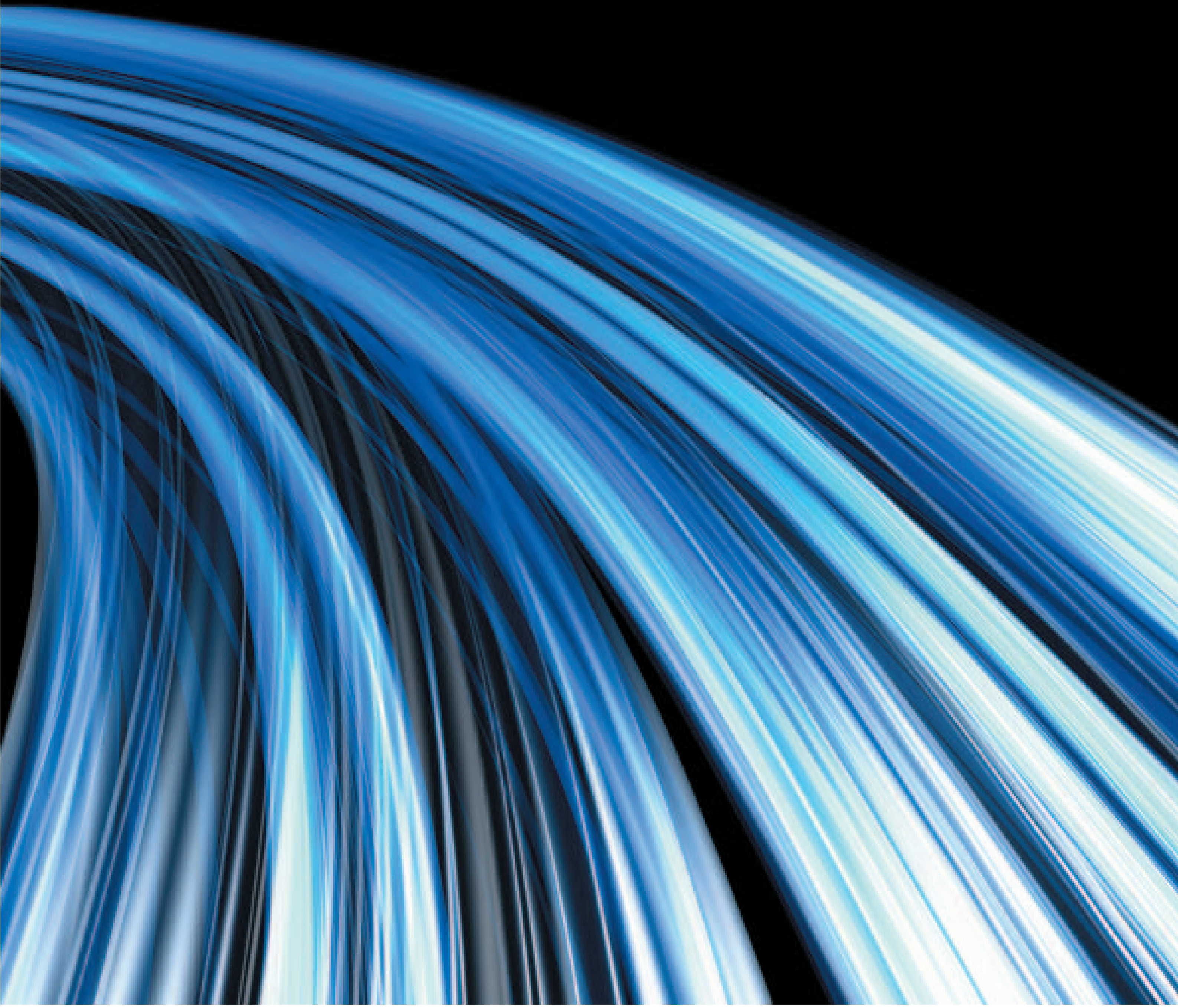
Energy materials
Strategic research agenda



Materials UK Energy Review 2007

Report 1 - Energy Materials – Strategic Research Agenda

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The Strategic Research Agenda

The Strategic Research Agenda (SRA) for Energy Materials is defining the pathway by which Energy Materials R&D in the UK can help deliver:

1. Materials solutions to the Energy Sector that will help meet the Governments targets in the Energy White Paper relating to climate change, security of supply and cost of electricity
2. Wealth creation in the UK through new business, increased investment and employment

As the first step to fulfilling the above objectives, this SRA is delivering a series of technology reports and a set of recommendations that identify the Materials R&D requirements and opportunities for the UK in the areas of;

a. Fossil-fuelled power plant

b. Nuclear power plant

c. Alternative Energy generation

d. Transmission, Distribution and Storage systems

At the same time, it is launching a consultation document on the 'UK Energy Materials supply chain' which is mapping the UK capabilities, identifying gaps and opportunities and how they should be addressed and exploited in the future.

With the support of government departments, Research Councils, MatUK, the Materials KTN and the broad Energy Materials community, it is intended that the SRA, will be a working document which will act to advise the public sector on the areas in which materials R&D funds should be invested and inform the private sector, particularly SMEs, of the potential opportunities materials technology can offer their businesses.

In addition, it will advise and help define the UK priorities for Energy Materials R&D in overseas funded programmes where the UK has direct input and influence, such as the European Framework 7 programme.

It is envisaged that, through MatUK, the SRA will eventually expand to cover other energy related areas where materials technologies can make an impact such as energy usage and conservation*. The transport sector may also be considered after discussion with the sector.

* *Materials for Energy conservation in the built environment is the subject of a review by the Construction Materials Working Group of MatUK and will be published in 2008 and briefly covered in Annex 1 of this report.*

Foreword

Rt Honourable Malcolm Wicks,
Minister of State for Energy

The 2007 Energy White Paper highlights the fact that Energy is essential in almost every aspect of our lives and for the success of our economy and it identifies two long-term energy challenges:

- tackling climate change by reducing carbon dioxide emissions both within the UK and abroad
- ensuring secure, clean and affordable energy as we become increasingly dependent on imported fuel

At the same time, the Materials Innovation and Growth report and subsequently Material UK were identifying 'Energy Materials' as their top priority in providing one of the key underpinning technology solutions that would help tackle Climate Change and support our energy policy.

Materials play a role in all aspects of the Energy supply chain from electricity generation in power plants through to its conservation in our workplaces and homes. The UK has a long and recognized history in the field of materials engineering for the Energy Sector and, whilst markets have changed, we have retained a high added value industry and academic skill-base. This can still provide a foundation on which we can build, develop new markets and tackle the key technical challenges that we face.

The Strategy produced by the Energy Materials Working Group of Materials UK will guide us along the path of helping to achieve these challenging goals. I wish them well as they move into the implementation phase and look forward to them supporting the UK in becoming a global leader in tackling climate change and providing secure, clean and affordable energy.

Chairmen's introduction


Derek Allen


Steve Garwood

Energy Materials Working Group

One of the key recommendations of the Materials Innovation and Growth Team (IGT) report published in 2006 [1] was to establish Materials UK (MatUK) as an authoritative independent organisation owned by the UK materials community. Its vision is to establish the UK as one of the foremost advanced technological societies in which world-class materials expertise underpins sustainable growth. Much of this will be achieved through the implementation of the recommendations of the IGT report and further development of a national Materials strategy. One key technology area identified by the IGT in which materials can make a real global impact is in Energy and the Environment. As its delivery mechanism, MatUK established an Energy Materials Working Group which it has been our privilege to Chair.

Key strategic energy challenges were identified in the 2006 Energy Review[2] and the Energy White Paper [3] as:

- Tackling climate change by reducing carbon dioxide emissions both within the UK and abroad
- Ensuring secure, clean and affordable energy, as we become increasingly dependent on imported fuel.

In addition to identifying future energy challenges the report seeks solutions and, more importantly, looks for exploitation into the marketplace. The UK will need around 30-35GW of new electricity generation capacity over the next two decades. Two thirds of that capacity is required by 2020. This provides massive opportunities for the sector and its materials supply chain. On a global scale, materials opportunities increase by orders of magnitude. UK business must be positioned to take advantage of such opportunities.

The Energy Materials Working Group set itself the remit to:

"Develop a Strategic Research Agenda (SRA) and Deployment Plan for the UK Energy Materials supply chain that would improve profitability and effectiveness in the sector whilst meeting the key energy-related challenges of sustainability, climate change and security of supply"

The review, which is now being reported, began in the Spring of 2006. This Strategic Research Agenda (SRA) summarises our key findings and offers recommendations on how to implement the agenda. It is supported by a series of associated Technical Reports and a consultation document relating to the UK material supply chain.

During the preparation of these reports it has become clear that the UK energy sector and its associated Materials community have emerged from the severe cutbacks in research and manufacturing experienced over the last 30 years, with a renewed commitment to meet future environmental challenges. It has been a pleasure to work with this reinvigorated and enthusiastic community over the last eighteen months.

As Chairmen, we would like to thank our colleagues from MatUK, industry, academia, government bodies and numerous other stakeholders who have provided input into this work. We particularly thank members of the Working Group, Advisory Committee and Task Groups for their efforts and look forward to working with you all again as we implement the SRA.

D H Allen   SJGarwood

Derek Allen   Steve Garwood

Co-Chairmen Energy Materials Working Group

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1.0 Executive summary

Materials for Energy Applications were identified by the Materials Innovation & Growth Team report[1] as a priority for UK R&D as they underpin the entire energy infrastructure and hence play a vital role in meeting targets on emissions, electricity availability and reduced cost.

This Strategic Research Agenda (SRA) has been brought together by the Energy Materials Working Group (EMWG) of MatUK. This body represents a broad cross section of the UK materials supply chain working primarily, but not exclusively, in the field of Energy. It also is a group with expertise in design, processing and manufacture, recognising the importance of the integration of materials early in the design process. The SRA is based on recommendations from a number of reports[4-7] being published simultaneously by Task Groups of the EMWG, covering energy generation, transmission, distribution and storage and a consultation document[8] on the status of the UK energy materials supply chain.

This Strategic Research Agenda (SRA) is being published at an opportune time. Rarely has 'Energy and the Environment' had a higher profile, nor posed more challenges for the UK & global energy sector. The Agenda identifies, at the top level, the materials challenges that the UK should address in order to support the Governments Energy Policy objectives and create new long-term business opportunities for the UK. This is against a background where the global market for electricity generation is projected to almost double in the next 20 years. The SRA aims to stimulate and focus expert Materials resources (people and facilities) within the UK, to tackle the challenges ahead.

The UK Energy landscape is changing rapidly particularly with the plans for the building of up to 35GW of new plant in the UK in the next 20 years, with 20% of the total supply coming from renewable sources by 2020. To meet these requirements it needs to adopt a balanced 'portfolio' approach. There is no single 'quick fix' technology. Several materials research areas therefore need to be addressed simultaneously to support the product portfolios that are being proposed, from large carbon capture plant, to solar panels.

[Courtesy of Alstom Power]

1.0 Executive summary

Incremental product improvement by materials R&D is needed to improve the efficiency, safety and reliability of our existing fleet of conventional fossil and nuclear plant, and, if necessary extend their lives. At the same time, investment needs to be made in higher risk/higher return projects for generating clean power and capturing CO_2 from existing plants. The materials challenges within this dual track approach are summarised in this document and detailed in the supporting technology reports of the task groups.

The SRA categorises, under three key technology related areas, where materials R&D can make a significant impact within the energy sector and where the UK has both strength and balance of industrial and academic expertise to address the issues. We have identified the areas where Energy materials R&D in the UK can make the biggest impact as:

- **Reducing Time to Market and Life cycle costs:**
  Significant shortening of the materials development and validation life cycle time for quicker entry to market (eg new alloy development and deployment for fossil plant). Significant cost reduction, including material substitution, for increased competitiveness to give the UK a market lead (eg. solar pv, fuel cells)

- **Higher Performance in Harsher Environments:**
  Development of high integrity materials systems for operation in the increasingly aggressive conditions (temperature, stress and environment) particularly seen by the emerging energy technologies such as wind, wave, tidal, carbon capture, biomass, energy transmission, distribution & storage and also relevant to conventional fossil and nuclear materials

- **Improved Life Management and Reliability:**
  Improved predictability of materials behaviour will produce significant savings on unforeseen plant outages and maintenance costs. This includes understanding the degradation of materials in service, their inspection and repair. It also includes the development of materials with improved reliability and properties and increased service lifetimes that will ultimately reduce cost of electricity. (eg offshore wind)

In all of the above, the consideration of the integration of materials with design and manufacturability must be considered.

In addition, seven over-riding requirements must be addressed for the successful delivery of this SRA:

1 **Communication**

Wide communication of the findings of the SRA to the academic and industrial materials community, stakeholders and the relevant funding agencies is essential.

2 **Establishment of a coordination and delivery body**

This will comprise key stakeholders from industry, academia and funding agencies from both public and private sector. Operating through MatUK, it will have a clear remit to promote and implement the SRA and ensure initiation of the R&D programmes and advise funding agencies. It will own the SRA and be responsible for its updating to take account of such things as changes in Energy Policy and legislation.

3 **Stable and sustainable long term funding mechanisms:**

There is a need to establish long-term sustainable funding mechanism(s) for cradle-to-grave materials R&D. This mechanism should involve materials development from laboratory-scale through to full-scale demonstration and deployment. The above body[2] will work with both public and private sector funding agencies to develop and secure this.

4 **An Energy Materials Knowledge Management System:**

Establish a coordinated knowledge management system, through an existing Materials Knowledge Transfer Network (KTN) node, that will be given responsibility for Energy Materials. This is to ensure that maximum benefit is obtained from both existing knowledge and from that generated in future R&D.

5 **Innovative Technology Transfer & Coordination:**

The materials challenges being posed by the drive for low emissions, high reliability and low cost are not unique to the energy sector. The Materials community must look for innovative ways to work across both disciplines and sectors to find novel ways of finding solutions and transferring technologies. Recommendations are made to address this.

6 **International Engagement:**

The resources in the UK cannot solve all of the Energy Materials challenges by itself. Where appropriate, it should develop international relationships to improve UK prosperity. An international node of the Materials KTN should be formed, looking across all materials to represent, influence and align the content of international programmes where the UK has a vested interest.

7 **Development of Skills and Resources:**

The buoyant Energy sector needs to attract high-class individuals back into the business to add to the existing skills base. The proposed R&D should be linked to skill-base refreshment to develop and retain expertise and knowledge. The MatUK Education & Skills Group will address this.

The task group reports highlight the large number of Energy technologies being developed in the UK, not all of which will be 'winners'. Some choices will be based on political, regulatory or financial intervention rather than technical criteria. The maturity of the various technologies and their deployment also cover different timescales. Many technologies are already deployed and established, some are at the demonstration stage, and others are at earlier stages of development. Materials R&D priorities can be assigned against their level of impact on;

- Energy policy
- Accelerating deployment
- Wealth creation

1.0 Executive summary

Recommended Materials R&D

Priorities
for incremental development to support/enhance existing knowledge
(life extension)

- Materials for nuclear and conventional fossil applications and electricity networks

Priorities
for applied R&D
(assist rapid large scale deployment)

- Materials for Clean Fossil (including carbon capture), offshore wind, wave/tidal, fuel cells and electricity networks

Priorities
where more basic research is still needed
(remove barriers to market)

- Solar photovoltaics, hydrogen storage, superconductors

In addition to the technical challenges, significant changes in the UK Energy Innovation chain and funding landscape are emerging following the:

- **Formation of the Energy Technologies Institute (ETI)**
- **Restructuring of the Technology Strategy Board**
- **Announcement of initiatives such as the Environmental Transformation Fund**

The time is right to analyse the UK Energy Materials R&D portfolio and supply chain in order to become better coordinated and take advantage of significant national/global business and technology funding opportunities.

The materials community must provide technology solutions that help UK business create wealth through the short-medium term market buoyancy in the Energy Sector. Longer term challenges of Climate Change, security of supply and provision of affordable energy will provide further opportunities.

To take forward the above issues the SRA sets out a series of recommendations and an '**agenda for action**'.

2.0 Agenda for action

Agenda for action: **implementing the SRA**

ACTION	WHAT?	WHY?	WHO?	WHEN/HOW?
1. **Dissemination of the SRA**	Broad dissemination of the launch of findings and recommendations of the SRA to coordinate its implementation and funding arrangements. Get the community to take ownership of the SRA	SRA is a document assembled by the UK expert community in Energy Materials and has endeavoured to represent the whole supply chain. It should be used as an advisory and guidance document by the community for setting R&D priorities.	Energy Materials Working Group (EMWG) & MatUK. Press and journals (e.g. IoM3, Energy Materials journal)	Immediate action required. Promotion of reports, further discussion with stakeholders and workshops (planned Spring 2008)
2. **Create delivery body, advisory group**	A formal body to ensure delivery of the SRA and advise stakeholders	To ensure delivery of SRA and implementation of R&D portfolio.	Subset of EMWG + new members + funding agencies	By spring 2008 through discussion with stakeholders and MatUK
3. **Create long term sustainable funding for Energy \materials**	A proposal regarding the optimum way of funding Energy Materials R&D both within the existing funding landscape and outside it.	Materials R&D is a cradle to grave process, which takes many years. Sustainable funding is needed to take R&D from the laboratories into products	MatUK to work with key stakeholders. Eg Energy Research Partnership, Technology Strategy Board, Energy Technology Institute, Carbon trust, Research Councils, RDA's,	Immediate action in progress - Ensure the identified key Materials R&D requirements of the SRA are fed into fund holders strategies and programmes to develop sustainable long term funding. Agreement reached with TSB and EPSRC regarding Energy Materials R&D call (Nov 2007).
4. **Establish Knowledge Management system**	Form new KTN node to capture existing knowledge and transferring it to our existing skills base . • Transfer of existing technologies to other applications • Ensuring all future knowledge and R&D is captured	•Reduce cost and effort and avoid duplication. •Improve efficiency & competitiveness NB. There is an immediate need for knowledge capture. An example of which is information in the nuclear & fossil materials field.	MatUK with Materials KTN to establish new energy node.	Implementation through KTN node (funding needed) by July 08
5. **Technology Transfer and Coordination**	Stimulating innovation through optimal formation of consortia to get better integration of Materials science community with those of Chemistry, Physics, design, engineering etc and across sectors eg aerospace, oil& gas, chemical	Pooling of knowledge/skills to provide innovative solutions to challenges. • Improve UK competitiveness	MatUK with fund holders	Short to medium term action plan to be developed. MatUK to work with funding agencies to consider novel mechanisms for forming multidisciplinary consortia. (e.g. sandpitting). (July 08)
6. **International engagement**	• A new KTN node • Influencing and aligning EU and other Countries programmes with those of UK priorities	Access to significantly more funding and wider skill base	• MatUK to interact with KYN, BERR, TSB and UKTI • Interaction with EC and other international agencies • KTN to establish international node	Immediate- EMWG through the European Technology Platforms (EuMaT) and the EC. Already influenced content of FP 7 2nd call, which includes 'Energy Materials'
7. **Improving Skills and Knowledge**	Need to expand skills in Energy Materials area	Skills gap needs to be filled to ensure UK innovative future in Energy Materials	People & Skills Working Group of MatUK and Sector skills council	Short to medium term action plan to be developed by People & Skills working group (Sept 08)

> *"Global values of the low carbon economy could be as high as £3trillion pa worldwide by 2050. It could employ more than 25m people with over 1m in the UK over the next 20 years."*

Gordon Brown Nov 2007

3.0 The energy landscape

Both globally and within the UK, the energy landscape is changing dramatically. Climate change is now widely recognised and the drive to reduce CO_2 emissions has never been more fierce or taken more seriously. Materials play a major part both in the problem, by way of the energy needed to extract and process them, and in the solution, by means of their innovative use in products to generate or conserve energy in the most efficient manner.

The UK White Paper 'Meeting the Energy Challenge' published in May 2007, highlighted two long-term energy challenges:

- Tackling climate change by reducing carbon dioxide emissions both within the UK and abroad and:
- Ensuring secure, clean and affordable energy, as we become increasingly dependent on imported fuel.

The White Paper highlights, *"...our increasing reliance on imports of oil and gas in a world where energy demand is rising and energy is becoming more politicised"*. A further issue is *"...our requirement for substantial, and timely, private sector investment over the next two decades in gas infrastructure, power stations and electricity networks"*.

Of further concern is the recent announcement [10] that 7 of the UK's 19 nuclear reactors have been out of action due to reliability/maintenance issues leaving the possibility of winter power cuts.

The OECD 'World Energy Outlook' [9] shows similar concerns that:

"The world is facing twin energy-related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much of it. Soaring energy prices and recent geopolitical events have reminded us of the essential role affordable energy plays in economic growth and human development, and of the vulnerability of the global energy system to supply disruptions."

The global recognition of these issues means the drive for novel, clean energy technologies is real and it is here to stay. Materials technologists, designers and engineers around the world are looking to address these challenges.

3.0 The energy landscape

3.1 Facts and Figures

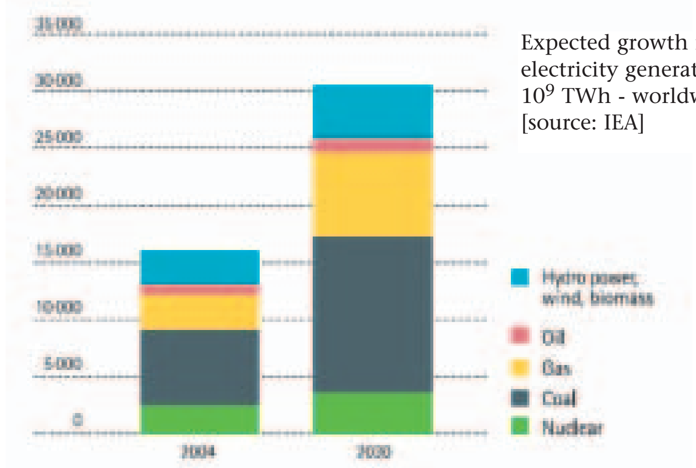
Global demand and Investment

On the basis of present predictions, global energy demand will rise by 55% and electricity demand will almost double over the next 25 years from 15,000 TWh in 2004 to around 30,000 TWh in 2030 (fig 1).

Energy related greenhouse gas emissions will be around 55% higher reaching 40 Gt in 2030 (fig 2).

In addition developing countries will overtake the OECD countries as major emitters of CO_2 around 2012 (**fig 3**) and China is predicted to overtake the United States as the world's biggest emitter of CO_2 before 2010. These trends would accentuate consuming countries' vulnerability to a severe supply disruption and resulting price shock. They would also amplify the magnitude of global climate change and its effect on the earths temperature. (**fig 4**).

Fig 1 **Expected growth in electricity generation to 2030**



Expected growth in electricity generation in 10^9 TWh - worldwide. [source: IEA]

Fig 2 **World energy related CO_2 emissions by fuel**

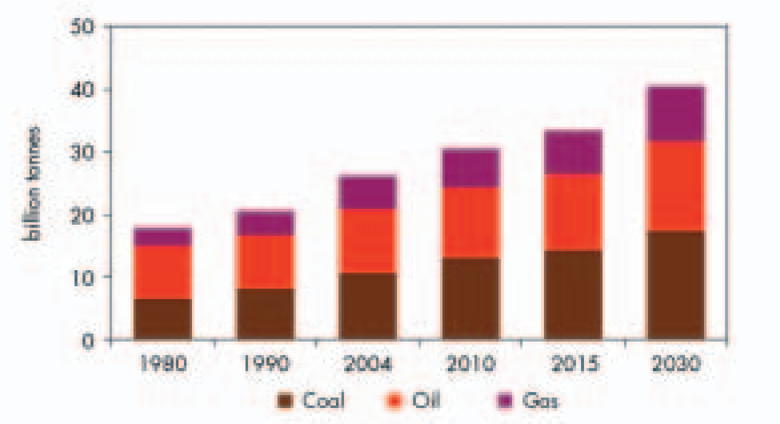
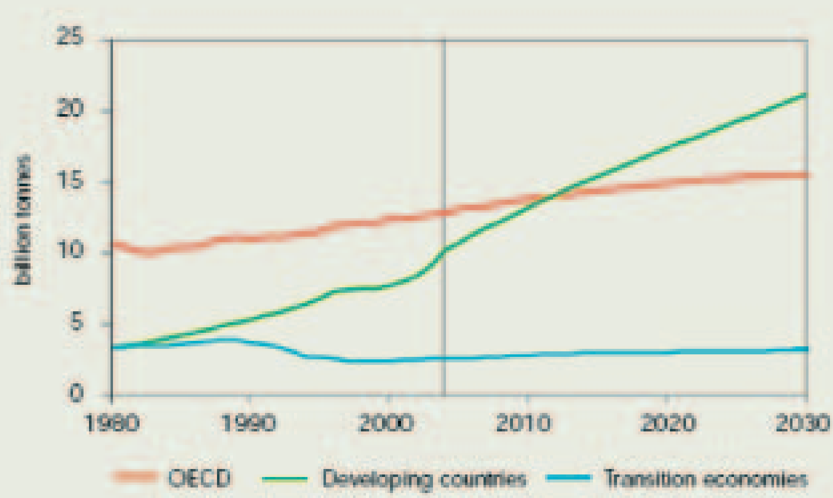


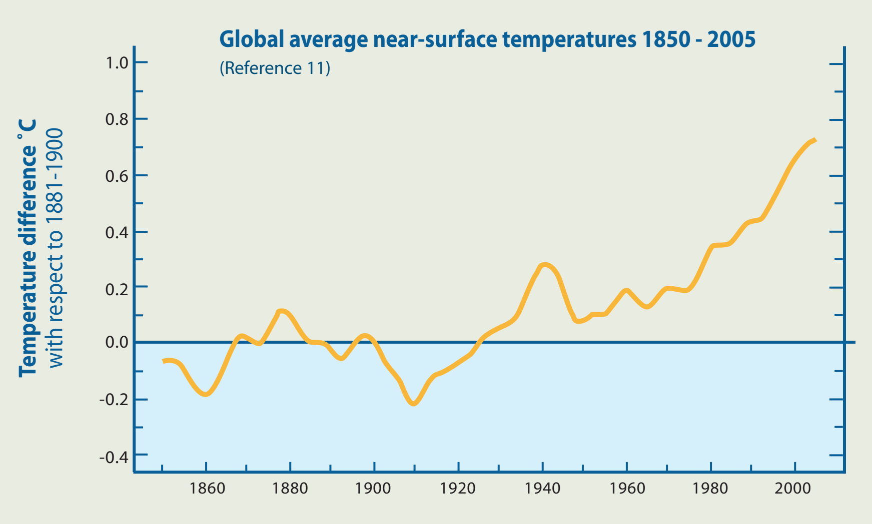
Fig 3 **Energy related CO_2 emissions by region** [source: IEA]



The WEO 2006 identifies under-investment in new energy supply as a real risk. To quench the world's thirst for energy, the projections call for a cumulative investment in energy-supply infrastructure of over $20 trillion in real terms over 2005-2030 (**fig 5**)– substantially more than was previously estimated. Roughly half of all this projected energy investment needed worldwide is in the developing countries.

Using the results from formal economic models, the Stern Review [(11)] estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.

Fig 4 **Global average near surface temperatures 1850 - 2005**

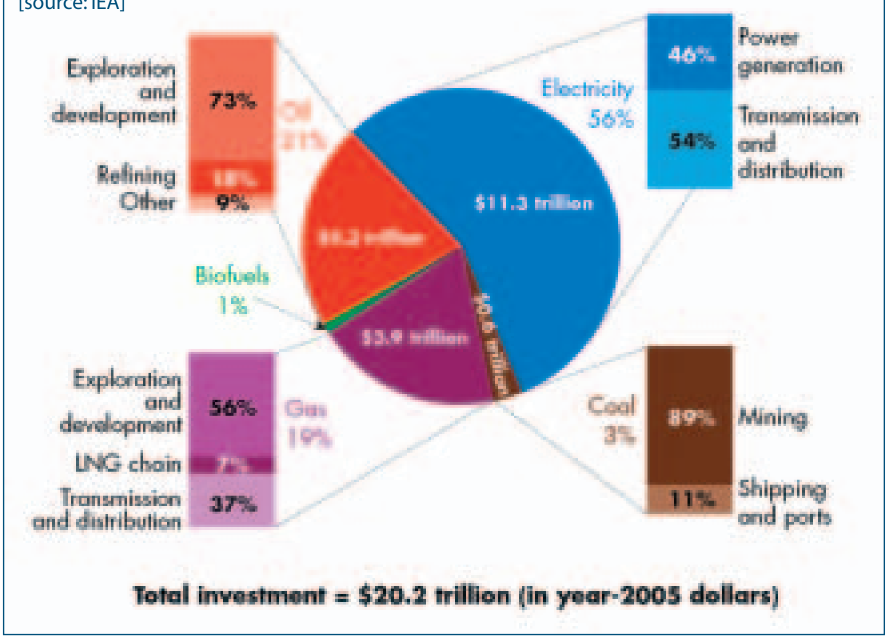


“...with 5-6˚C warming - a real possibility for the next century - models estimate an average 5-10% loss in global GDP.”

Sir Nicholas Stern

Fig 5 **Cumulative projected investment in energy infrastructure 2005 to 2030**

[source: IEA]



3.0 The energy landscape

UK Demand

The global numbers inevitably reflect on the UK and its own investment in energy technology. The consumption of electricity has grown steadily over the last three decades from around 240TWh in 1980 to 350TWh in 2006. (**fig 6**) However much of the UK fossil and nuclear plant is now coming to the end of its design life with one third due for decommissioning or replacement by 2020.

The White Paper states that;

"In electricity markets we will need investment in new generation capacity of around 35 GW over the next two decades to replace power station retirements and meet rising electricity demand as the economy grows." (figs 7,8) [12].

Fig 6 **UK electricity consumption 1980 to 2006**

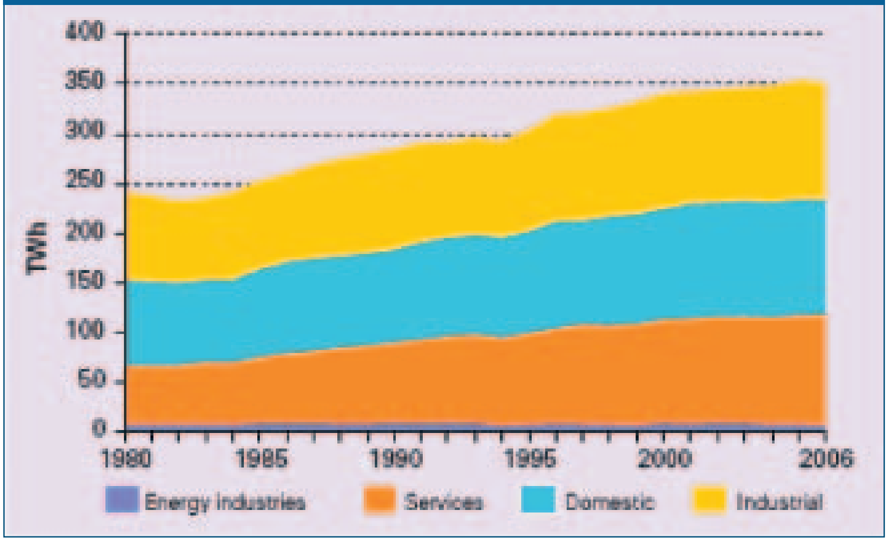


Fig 7 **Projected energy capacity and breakdown by technology with no new build**

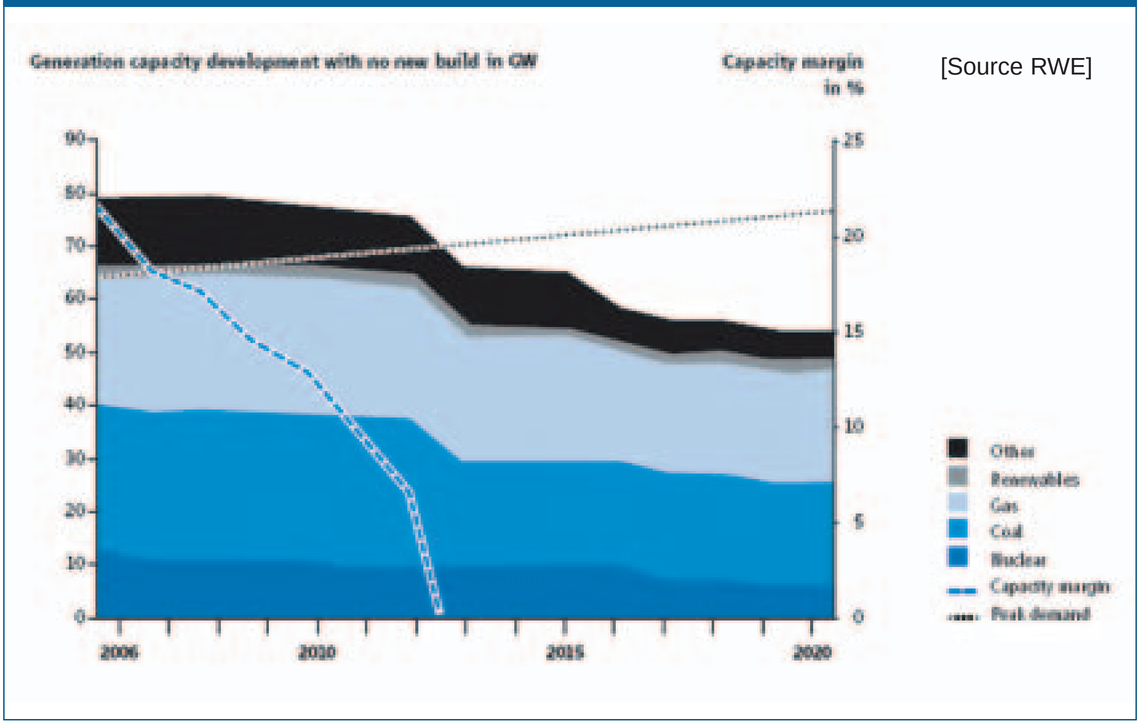


Fig 8 **Projected required new build of power plant in the UK**

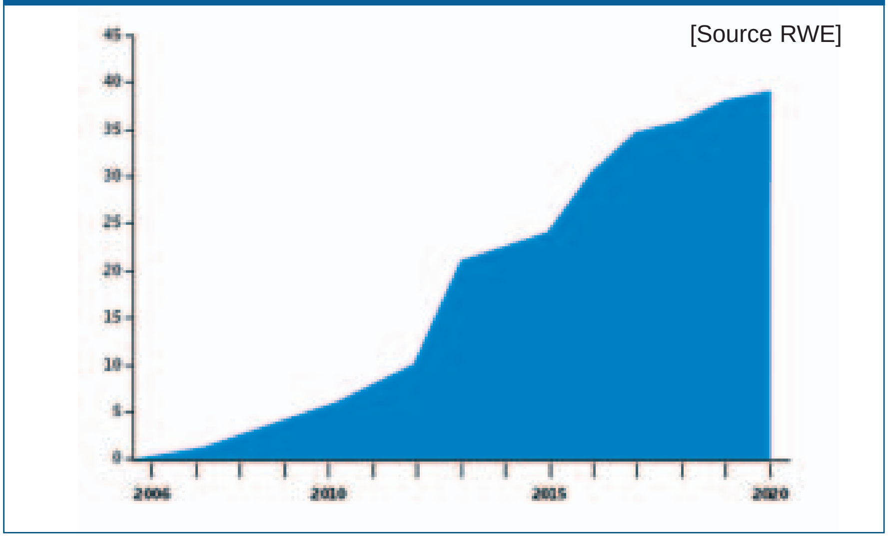
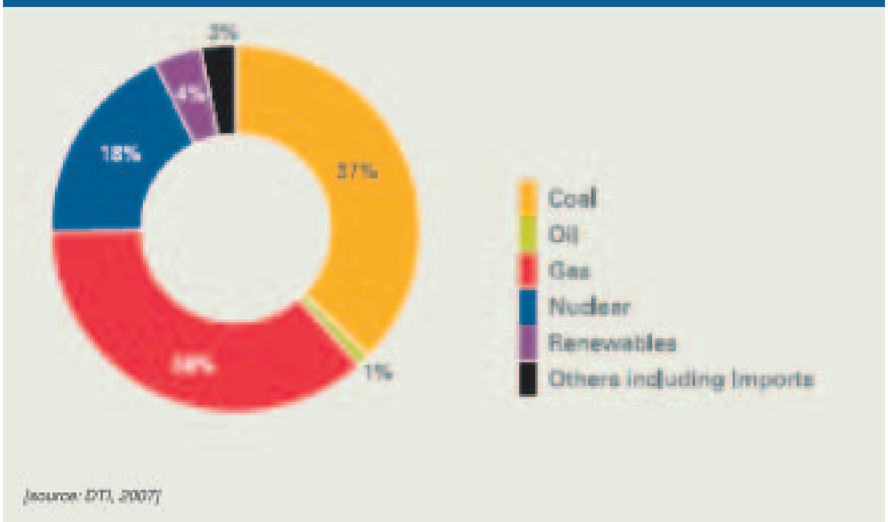


Fig 9 **UK electricity generation mix 2006**



In terms of the CO_2 and the energy balance the UK targets a reduction in CO_2 emissions by 26-32% in 2020 compared to 1990 levels and a 60% reduction by 2050 with at least 20% of its electricity coming from renewable sources by 2020. To put this into perspective, the current UK energy portfolio comprises around 73.5% fossil fuel, 18% nuclear and 4.5% renewables, 4% other (**fig 9**).

3.0 The energy landscape

Whilst generally employment in the Energy Sectors in the UK has decreased dramatically over the last 20 years (**fig 10**). Investment in the Energy industries rose by more than 20% in 2006 (**fig 11**) and the UK Energy Industries still have around 142,000 direct employees and contribute around 5% of GDP. There are numerous references and statistics regarding the World Energy markets and scenarios (9,13,14) which present a detailed overall picture regarding the increase in electricity demand for UK and global markets, energy balance and CO_2 emissions.

Fig 10 **Trends in employment in the energy industries 1980 to 2006**

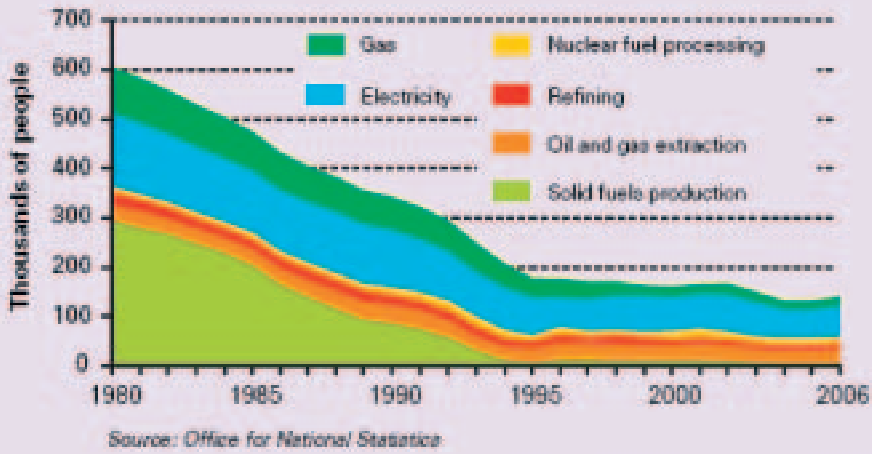
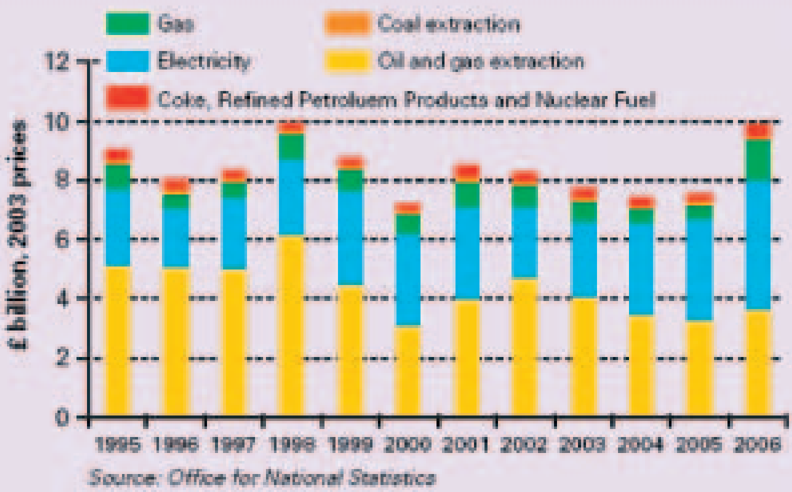


Fig 11 **Investment in the energy industries 1995 to 2006**



Summary

Between 2004 and 2030:

- global primary energy demand will rise by 53%, leading to a 55% increase in global carbon dioxide emissions related to energy;
- fossil fuels will remain the dominant source of energy worldwide, meeting 83% of the increase in energy demand;
- emissions from power generation will account for 44% of global energy-related emissions by 2030, as demand for electricity rises;
- coal will provide the largest incremental source of power generation, with the majority of this increase likely to be in China (55%);
- over 70% of the increase in global primary energy demand will come from developing countries, reflecting rapid economic and population growth; and
- some $20 trillion of investment will be needed throughout the energy supply chain.

Unprecedented market growth...

The question facing the UK energy sector and its Materials community is how can the UK take benefit from this unprecedented market growth in low carbon technologies which is predicted to open up business opportunities worth billions of pounds in the Energy sector?

"Energy companies are also going to be making large investments in the coming years to update and replace ageing power stations and other infrastructure. We need to create the right conditions for this investment, so we get timely and increasingly low carbon electricity supplies."

Alistair Darling EWP

Can the UK take advantage?

[Courtesy of Alstom Power]

4.0 The materials supply chain

Although few major power stations have been built over the last 20 years in the UK, the industry is once again becoming buoyant and offers considerable opportunities for the supporting materials sector. Fortunately, the country has retained a strong capability in design and manufacture of power equipment from main generating plant to transmission, distribution and storage as well as balance of plant for nuclear, fossil fuel and most forms of renewable generation.

A number of major Energy Companies and materials suppliers have either headquarters, manufacturing bases and/or R&D facilities within the UK. They include recognised names such as Alstom, Areva, Corus, BP, Doosan Babcock, EON, Johnson Matthey, Rolls-Royce, RWE, Scottish and Southern, Sharp, Sheffield Forgemasters, Siemens and Vestas. The power equipment sector alone produces an estimated turnover of around £30bn and employ some 300,000 people in the UK. Exports of equipment averaged about £1.9bn per annum in recent years. Inclusion of power related services would double that figure [14]. In addition, there are hundreds of smaller companies active in the sector, particularly in emerging energy technologies such as offshore wind, wave/tidal, fuel cells and solar photovoltaics that are well positioned to take advantage of this growing market.

The need to replace existing plant, and to build new facilities based on low-carbon sources, means that there will be significant pressure on energy plant construction and its associated supply chain. This, combined with the need for new and advanced technologies, will have significant implications for the supply of materials. It will not simply be a case of rapidly rising consumption of existing materials, but demands for more advanced materials and technologies. An inevitable consequence is that the UK will need to place more emphasis and investment in materials R&D in this area if it is to see benefit in this growing market.

In order to better understand the current status of the UK energy materials supply chain, the EMWG has commissioned a review [8] which is to be issued as a consultation document to the sector for feedback.

4.0 The materials supply chain

4.1 The Fossil and Nuclear Materials chain

The UK has retained significant expertise in the 'high-added value' end of the supply chain and remains a centre for technical expertise in fossil and nuclear energy materials, particularly high temperature materials and coatings.

A high proportion of the original equipment manufacturers (OEMs) and their suppliers have maintained key activities located within the UK and most have retained Materials Technology as a skill-base. Whilst the skill base needs to be expanded, the UK has the expertise needed to be at the forefront of future materials driven technical development in large scale conventional power generation.

The lack of investment in new power stations over the last 20 years, has led to the UK losing a large proportion of its supply chain for fossil and nuclear power generation components as suppliers sought alternative markets. Therefore, not surprisingly, the UK does not have a complete materials supply chain. Both fossil-fuelled and nuclear plant are reliant upon a number of raw materials, castings, and forgings from mainland Europe, and some being sourced from Japan, USA and the Far East. Globalisation has resulted in several UK energy materials and component suppliers becoming part of mainland European, Far Eastern and American conglomerates.

Within the UK, Alstom Power, a global leader in the supply and service of power equipment, manufacture and supply retrofit equipment for large steam turbines and Siemens provides spares, repairs in a similar arena. The UK is also home to world leading manufacturers such as Doosan Babcock, a major supplier of boiler plant and related equipment, and Rolls-Royce and Siemens Turbomachinery who manufacture, assemble and service small-medium industrial gas turbines for a world market. Interestingly enough despite the reduced supply chain and a recognised shortage of key technical skills, the UK civil nuclear power industry still has the capability to provide up to 70% of a new nuclear power station with current resources, however most of this would be related to the building of the infrastructure using mainly conventional construction materials. One strength retained by the UK is the ability for complete design, manufacture, construction and operational support capability for fuel cycle facilities, decommissioning and waste management.

In the transmission and distribution arena, the UK hosts a number of major players such as Areva and ABB who provide engineering, procurement and construction services for new transmission and distribution networks (overhead, underground and sub-sea). UK manufacturers can supply a range of equipment from large transformers, HVDC, protection relay equipment to low voltage transformers, power electronics, switchgear and smart meters. The UK is also home to a pioneer in the development and commercial supply of superconducting wire and cable. On the asset management side, the UK is a leading player in plant management, condition monitoring and in service performance monitoring. Whilst many of the materials and components in this sector are sourced from abroad, some high added value component manufacture and R&D is still conducted in the UK.

Whilst the UK is a major importer of raw materials, UK-based companies such as Sheffield Forgemasters, Wyman Gordon, Bodycote, Corus, Howmet, Special Metals, Praxair, Chromalloy and Sermatech, amongst others, continue to make key components and coatings for fossil-fired power generation such as rotors, blades, discs, rings and casings even though for most of them, the Energy Sector is not their major customer. Gaps do exist in the supply chain for key components, for example for very large scale forgings and castings for some nuclear (eg large pressure vessels) and fossil applications (if the next generation of 700C steam power plant requires large nickel forgings and castings, decisions regarding significant investments will need to be made if they are to be manufactured in the UK).

The UK has world-class expertise in repair, refurbishment and retrofit services and life extension and failure analysis for fossil and nuclear plant. It has therefore retained strong technical capabilities to support the after sales market in areas such as inspection, condition monitoring, coatings, welding/repair and life time prediction

Regarding R&D, major utilities, OEMs and materials suppliers increasingly undertake collaborative R&D on a global scale, under schemes such as the European Cooperation on Science and Technology (COST). COST programmes develop new high temperature materials, which are tested/validated as full-scale demonstrators. Rights and costs are shared on material developments whilst their exploitation through design and manufacture of the components is left with the individual organisations This collaboration can reduce the overall cost of R&D and allows developments to be brought to market quicker. Collaboration is less prevalent in gas turbine materials R&D, where the UK retains a world-leading status, primarily driven by the aero engine sector, particularly in high temperature materials and coatings. There are strong synergies with industrial gas turbine development and collaborative materials programmes between aero and industrial gas turbine manufacturers are becoming more frequent.

Regarding R&D, a National Nuclear Laboratory and science centre has been set up with funding from government and industry to provide a centre of excellence for research into nuclear power generation.

Some work is funded by the Research Councils in the area of fossil and nuclear, through programmes such as Supergen looking at extending the life of existing conventional fossil plant and the ‘Keeping the Nuclear Option Open’ KNOO programme, concentrating on maintaining and developing skills in the field of nuclear fission.

In summary, the UK does not have a complete materials supply chain for conventional fossil and nuclear power plants. However, it has adopted a policy of retaining significant R&D capability and academic expertise accompanied by the manufacture of high added-value components, whilst carefully managing its global supply chain. The emphasis should be on the need to expand and refresh the skills base.

4.0 The materials supply chain

4.2 Materials Supply for Sustainable Energy

The market for renewable energy technologies is not yet mature enough to support a sizeable UK-based established supply chain. However, this may change given the global drive towards deployment of renewable energy generation and the UK having one of the worlds best available resources of wind and marine energy to call upon.
The UK already are world-class developers, installers operators and consultants in wind power but lacks a full manufacturing capacity and supply chain. There is a world leading presence through Vestas, the world's biggest supplier of wind turbines who have blade and tower manufacturing facilities in the UK that also utilise UK expertise in composite design and manufacture.

The UK has established itself as an early market leader in tidal stream and wave power generation with about half the world's current technology developers (~30) headquartered in the UK. In addition, the UK has pioneered the establishment of world class facilities for the testing of wave and tidal devices (EMEC). To date, few devices/technologies have reached full-scale testing. The front-runners foresee no immediate materials supply chain issues, as construction largely uses UK's existing offshore technology/know-how. However as the technology evolves, the use of lighter weight composites, coatings, new processing and manufacturing methods and advanced materials systems will become prevalent, where the UK has expertise to support.

There are world-leading manufacturing, materials development and research capacity in PEMFC, DMFC and SOFC fuel cell technologies through companies such as Rolls Royce and Johnson Matthey. In addition, more than a hundred and fifty UK-based companies are active in fuel cell technology - from materials R&D through to systems integration. Full supply chains for such technologies are however relatively immature, although through Johnson Matthey the UK is a world leader in catalysts and catalysed components for fuel cells.

The current level of adoption of pv in the UK is growing but remains small compared with international competition. The UK industry does however have the potential to take advantage of a strong expertise in pv materials R&D. Sharp, the worlds largest manufacturer of pv modules has its European production facility in North Wales and the UK hosts a thin film manufacturer, ICP Solar, in Bridgend. Amongst other key manufacturers are IQE, Romag, PV Crystalox and NaREC. Together they form a strong presence with significant materials expertise that should be exploited.

Power generation from biomass will require R&D to develop materials that can survive hostile environments. The UK has a growing industry in small scale bioenergy systems for heat and power applications. However, Europe is some way ahead in their deployment. The UK strengths in the materials supply chain mirror those of fossil energy materials in materials and components such as heat exchangers and gas turbines.

On the Research side, the UK has a very strong R&D base and is very active in sustainable energy projects, primarily through the Research Councils Sustainable Power Generation (SUPERGEN) programme which is addressing;

- Sustainable Hydrogen Energy
- Marine Energy Research
- Future Network Technologies
- Photovoltaic Materials
- Fuel Cells
- Highly Distributed Power Systems
- Solar Cells
- Energy Storage
- Biological Fuel Cells
- Asset Management and Performance of Energy Systems
- Wind Energy Technologies
- Conventional Power Plant Lifetime Extension

International collaboration is also growing in the renewable energy marketplace, particularly across Europe with initiatives such as the hydrogen and fuel cell Joint Technology Initiative in FP7
There are clear opportunities for investments into the UK for the emerging energy technologies and they will increase as the technologies become commercially viable.

There are explicit strengths of the UK in terms of materials and products and Companies themselves will decide on their future policy of investment. This may revolve around developing and retaining the IPR, high quality R&D, accompanied by the manufacture of high added value components and system assemblies, rather than investing in high volume manufacturing. Their decisions will ultimately be influenced by policy and legislation and any level of government intervention that might accelerate the deployment of these technologies.

Despite the lack of investment over recent years in the Energy Sector, which has led to a reduction and gaps in the materials supply chain, the UK has retained significant expertise in conventional power plant materials technologies and has developed new expertise in the emerging low carbon energy technologies.

What is of general concern to the UK in the short term, is not the lack of supply chain, but the increasing lead times for major power plant components (large forgings, castings, wind turbine components), which in some cases are running into years rather than months. If the UK is to hit its target programme of up to 35GW of new power plant in the next 20 years, this will have to be addressed by innovative supply chain management.

There must be a continued drive to maintain the high profile and public awareness to Energy and Environmental issues, which will in themselves act as a catalyst for producing the next generation of graduates and engineers in this field. It is equally as important to implement best practice and innovation in education and training as it is in materials processing, manufacture and R&D.

[Courtesy of Eon UK]

5.0 Resources - are they adequate?

Sustainable resources, both human and natural, are essential if the UK is going to benefit from the increasing global energy market and contribute to meeting its challenges.

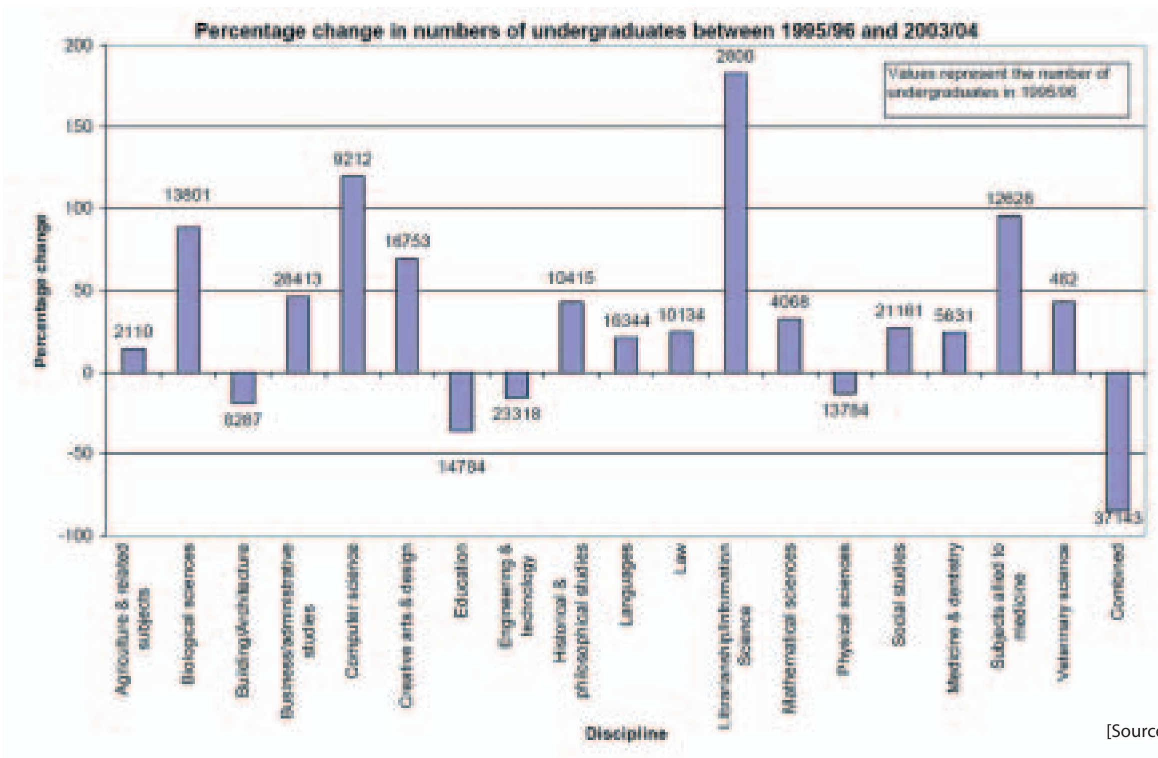
4.1 Human

A consistent theme emerging from the tasks group reports has been the need to improve the supply of skilled workers. This concern runs throughout the spectrum, from advanced research through design and manufacturing. In support of this, in its consultation document 'The Future of Nuclear Power'[19] , the Government warns that:
"As the demand grows globally for new power stations of any technology, there could be shortages in the capacity to supply some of the components and shortages of the human skills needed to develop and build them."

The report points out that the time scale for the planning and construction of new nuclear facilities is such that there is time in which to identify and remedy some shortages. This is does not however apply to energy technologies with shorter timescales for deployment.

The number of undergraduates studying Engineering and applied sciences has reduced significantly over the last decade (**Fig 12**). This means there are fewer skilled personnel coming through into the Energy and materials sector. When combined with the loss of experience after privatisation of the sector and the fact that many of the people remaining in the sector are approaching retirement, gives rise to a concern over a significant experience gap typically in the age range 30-50 .ie the next generation of senior experts and decision makers. There is no easy solution to bridge this gap and it cannot be done by the introduction of new graduates (whilst that is an ongoing need). There is a need to provide innovative knowledge capture from existing experts and transfer to younger staff. In addition, more in house, on the job training and professional courses for those already in employment, to bring our younger engineers to maturity quicker is required. This issue is under consideration by the MatUK Education & Skills Working Group.

Fig 12 **Percentage change in number of undergraduates**



[Source EPSRC]

5.0 Resources - are they adequate?

4.2 Natural resources- the sustainability debate

Population growth and its associated impact on the environment through higher energy demands, continues to be of concern regarding the sustainability of the planets natural resources. Whilst the debate over the long-term availability of natural resources remains as polarised as it was 30 years ago, how materials are used and re-used is now becoming a priority in many sectors and Energy is no exception. It is an area where materials R&D can play a major role in reducing the impact, through novel processing, manufacture and recycling technologies.

Meeting the Requirements of Developing Nations:

The output of China and India rose by 10.5% and 8.5% respectively in 2006 [15]. Such growth can only be sustained by a massive increase in energy production. China aims to bring over 550 coal-fired plants (nearly half the world total number of plants) online in the next eight years, with a current build-rate of two coal-fired power stations per week. India could add more than 200 such plants in the same timescale. Developed nations have both a responsibility and an opportunity to ensure that these fossil-fuelled stations operate to the highest efficiency and use the latest 'clean coal' technologies, whilst promoting the deployment of other low carbon energy sources. The UK should be in a prime position to take advantage of this market.

Not surprisingly, developing nations such as China are having a profound effect on global material usage and costs. For example, nickel usage in China has grown from 50,000 tons pa to 250,000 tons pa in the last decade (**Fig 13**). Nickel is used in a wide range of electrical generating, transmission and storage equipment either as nickel alloys or as an alloying element in stainless steel. As a consequence, nickel prices have increased by an order of magnitude (**Fig 14**) - from around $8,000/tonne throughout the 1980's & 90's to well over $50,000/tonne since the start of the new millennium.

Fig 13 Chinese Stainless Steel Production and Nickel demands

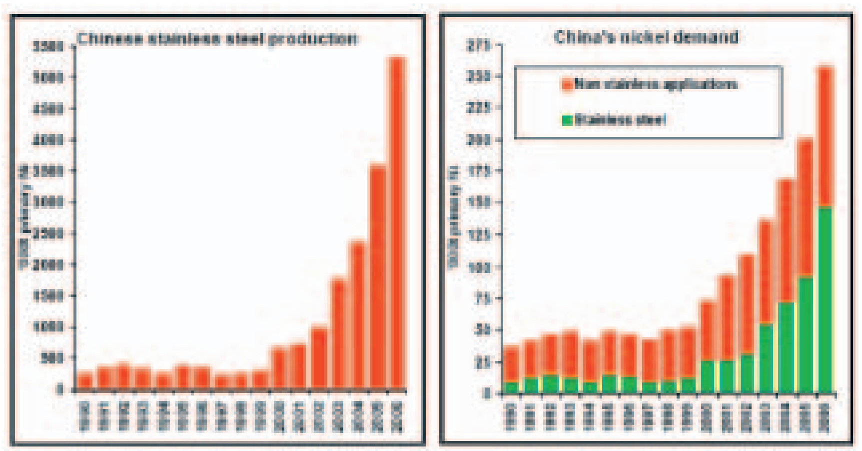


Fig 13 Chinese Stainless Steel Production and Nickel demands
(source ANSG, CRU,CSSC, Macquarie research, May 2007

Fig 14 LME cash nickel price since start of trading

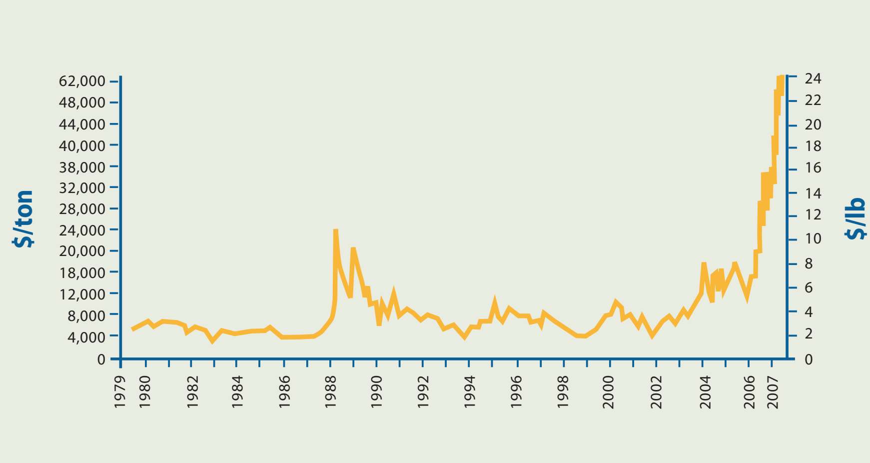


Fig 14 Nickel prices on London Metal exchange since start of trading (Source LME)

Similar trends are seen across other primary metal resources as reflected in the quadrupling of commodity metal prices on the London Metal Exchange (**Fig 14**). These increases in metal prices are not sustainable and significant R&D is ongoing to develop cheaper, high performance substitute materials.

Research into end-of-life management will be critical in the next 20 years. In particular, research is required into cost-effective recovery and recycling of materials and into avoiding subsequent disposal through landfill.

Tables 1 and 2 (17) present the likely life expectancies of major world mineral resources in 2000 based in terms of reserves (known and exploitable amount in subsurface resources) and resources (includes reserves and calculated contents of all mineral commodity in the earths crust-mineable or not) on a number of assumptions related to average annual growth in production.

One reason that the available estimates of natural resources vary greatly and there is no perceived short-term threat is because new resources are being found on a regular basis and new efficient extraction technologies are being developed to optimize yield. Substitute materials are also being deployed to replace the rarer elements. What is clear is that the recycling of materials is now becoming prerequisite and the processes for recycling need to be optimized to maximize recovery rates.

Materials supply depends on 'raw materials' other than those needed for primary manufacture and the growing demand for composites has led to relatively limited supplies of materials such as carbon fibre.

Whilst extreme scenarios could be envisaged, over the next 50 years, mineral depletion is unlikely to cause major problems to the energy sector. However, it is clear that the rate of consumption of natural resources cannot be sustained. With a high dependence on imported raw materials, the UK should monitor the implications for the materials community particularly on sources with finite supplies and focus any R&D in that area on developing 'substitute' materials.

Table 1 Mineral reserves forecast

Commodity	Mineral Reserves Metric tons	1997-2000 average annual production	Life expectancy at 3 growth rates			Average % annual growth in production 1975-2000
			0%	2%	5%	
Aluminium	$25x10^9$	$123x10^7$	202	81	48	2.9
Copper	$340x10^9$	$12x10^6$	28	22	18	3.4
Iron	$74x10^{12}$	560x10	132	65	41	0.5
Lead	$74x10^{12}$	$31x10^5$	21	17	14	-0.5
Nickel	$46x10^6$	$11x10^5$	41	30	22	1.6
Silver	$280x10^3$	$16x10^3$	17	15	13	3.0
Tin	$8x10^6$	$21x10^4$	37	28	21	-0.5
Zinc	$190x10^5$	$78x10^5$	25	20	16	1.9

Table 2 Mineral resources forecast

Commodity	Resource base[b] (metric tons)	1997-1999 average annual production	Life expectancy in years			Average % annual growth in production 1975-2000
			0%	2%	5%	
Aluminium	$2.0x10^{18}$	$22.4x10^6$	$89.3x10^9$	1065	444	2.9
Copper	$1.5x10^{15}$	$12.1x10^6$	$124.3x10^6$	736	313	3.4
Iron	$1.4x10^{18}$	$559.5x10^6$	$2.5x10^9$	886	373	0.5
Lead	$290.0x10^{12}$	$3070x10^3$	$9.4x10^6$	607	261	-0.5
Nickel	$2.1x10^{12}$	$1133.3x10^3$	$1.8x10^6$	526	229	1.6
Silver	$1.8x10^{12}$	$16.1x10^3$	$111.8x10^6$	731	311	3.0
Tin	$40.8x10^{12}$	$207.7x10^3$	$196.5x10^6$	759	322	-0.5
Zinc	$2.2x10^{15}$	$7753.3x10^3$	$283.7x10^6$	778	329	1.9

There must be a commitment to a sustainable materials supply chain from cradle to grave. The full life cycles of materials must be understood and accounted for at the design stage. Innovative R&D in Energy materials can have a double impact by processing and manufacturing materials using less energy and also developing them for components that facilitate high efficiency energy generation, transmission, storage or conservation.

5.0 Resources - are they adequate?

From one extreme...

If the use of Copper by the USA (170kg/capita) [18], were to be mirrored by the emerging nations, a total demand of 1,700Tg of copper would be required, more than the total world copper resource and hence supplies would not be sustainable.

As an extreme example, it has been estimated that if the 500 million vehicles estimated to be in use worldwide in 2000 were converted to fuel cell operation, even with 90% recycling rate that achieved 50% recovery; the platinum resource would only keep such a fleet operating for 15 years before supplies were depleted. This would also exclude its use for other low emission technologies such as stationary power fuel cells that form an essential component of a 'clean power' 'hydrogen economy'.

Uranium 2005: Resources, Production and Demand [19]. estimates that the total amount of conventional uranium stock that can be mined for less than USD 130 per kg is about 4.7 million tonnes. Based on the 2004 nuclear electricity generation rate of demand, this amount of uranium is sufficient for the next 85 years. Fast reactor technology would lengthen this period to over 2500 years.

...to the other?

[Courtesy of Alstom Power]

6.0 Key strengths and opportunities

The UK has a long and recognised history in the Energy Materials sector particularly in large scale power generation, transmission and distribution. It equally has a significant opportunity to take advantage of the growth in emerging energy technologies where the UK has the opportunity to be world leading.

There is an absence of a complete supply chain, however the strategy to specialise in the high added value technologies and innovative R&D expertise seems appropriate.
The big challenge for the UK is to convert its research excellence into commercial opportunities.

Strengths

- Government commitment to Energy policy and tackling Climate Change
- Recognition of Materials as a key technology to underpin energy policy targets
- World class reputation and experience in Energy and Materials Sectors - High T materials & coatings, modelling, composites, nano and functional materials
- Long established academic reputation for excellence in Materials research particularly in areas relevant to the energy sector
- Retained significant degree of ‘high added value’ skills in research, manufacturing and industrial application
- Most energy related businesses in the UK have retained a materials expertise in the UK
- Financial Centre facilitating capital raising to attract inward investment
- High level of expert consultancy available
- Formation of Energy Technologies Institute and National Nuclear Laboratory
- Strong UK partnerships and consortiums developing

Weaknesses

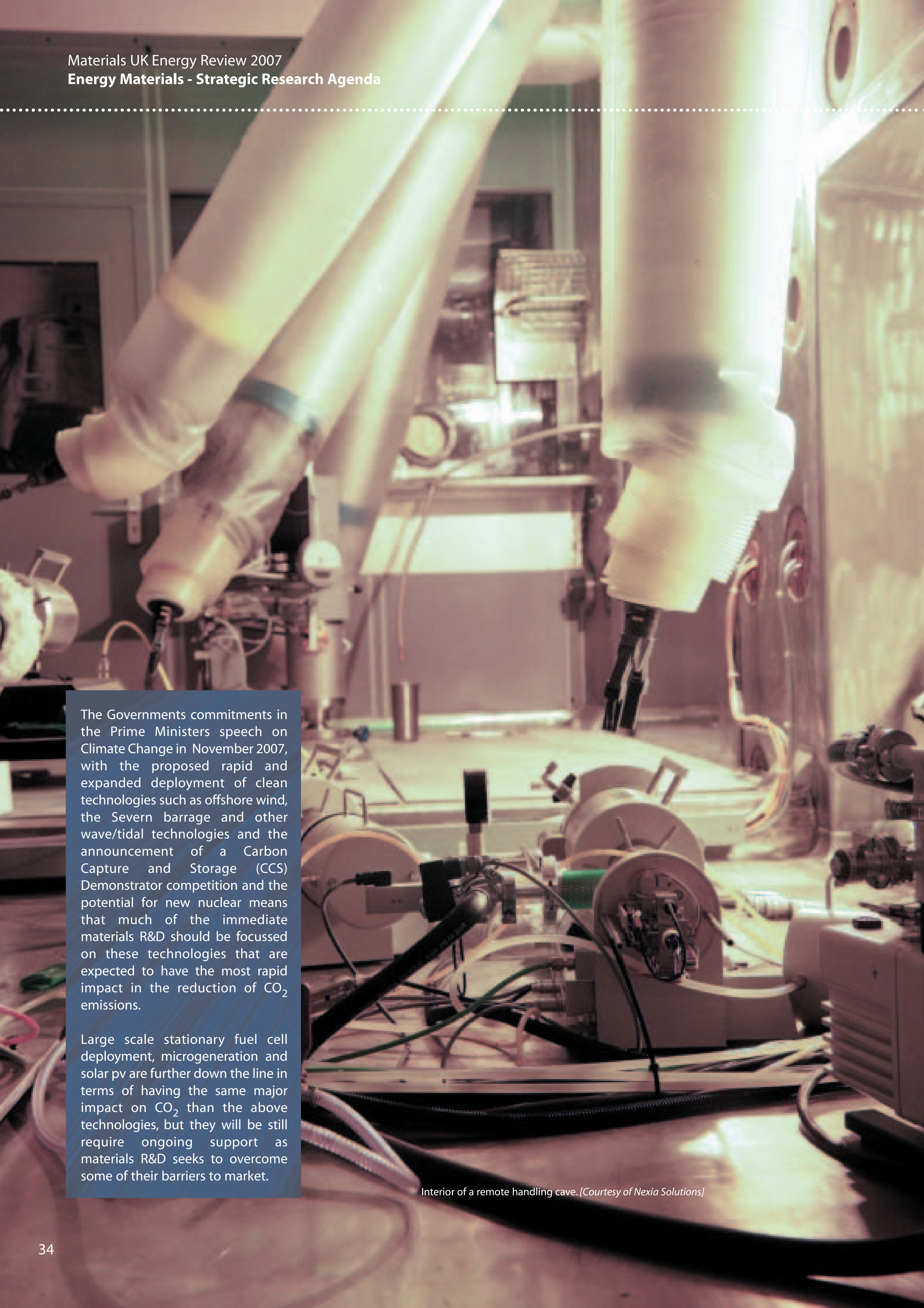
- Lack of national coordination and focus leading to duplication of effort and wasted resources
- Ability to take R&D through the innovation chain to deployment
- Lack of ‘long’ term (+10 years) funding strategy in the sector and historic low investment levels in energy materials research
- Incomplete materials supply chain
- Uncertainty relating to ‘winning technologies’ leading to unfocussed R&D
- Historically a risk averse, conservative industry
- Little engagement with RDA’s in Energy Materials R&D
- In light of ever-shorter product cycles, development times are too long.

Opportunities

- Develop, coordinate and implement a National Energy Materials Strategy
- Restructure processes to bring the best consortia together to optimise output and benefit to UK
- Emerging energy technologies leading to innovative opportunities for materials development
- Diverse energy mix requiring different & innovative material solutions
- New Government initiatives (Energy Technologies Institute, Environmental development fund, National Nuclear Laboratory)
- Large number of SME’s starting up particularly in renewables energy area, with little materials knowledge
- Cross-sectoral collaboration with common materials solutions (automobile industry, chemical industry, aerospace, oil and gas)
- Large and growing UK & Global market
- Commitment to tackling Climate Change
- International collaboration (including influencing International funding) to benefit UK

Threats

- National materials strategies, facilities and proactive lobbyists in other countries
- Danger of missing current opportunities to exploitation
- High dependence on imported materials and components
- Skills shortage & problems recruiting young people for the engineering sciences, plus ageing population
- Technology priorities might be decided by influences outside technologist’s control
- Maintaining competitive strength will require increasing the productivity of industrial processes while reducing energy and material consumption.



The Governments commitments in the Prime Ministers speech on Climate Change in November 2007, with the proposed rapid and expanded deployment of clean technologies such as offshore wind, the Severn barrage and other wave/tidal technologies and the announcement of a Carbon Capture and Storage (CCS) Demonstrator competition and the potential for new nuclear means that much of the immediate materials R&D should be focussed on these technologies that are expected to have the most rapid impact in the reduction of CO_2 emissions.

Large scale stationary fuel cell deployment, microgeneration and solar pv are further down the line in terms of having the same major impact on CO_2 than the above technologies, but they will be still require ongoing support as materials R&D seeks to overcome some of their barriers to market.

Interior of a remote handling cave. *[Courtesy of Nexia Solutions]*

7.0 Materials technology priorities

The key to many of the required technological advances in the energy sector, which will impact on the Governments' energy policy, is the availability and deployment of appropriate materials solutions.

Many of the materials issues restricting energy supply advances are common across a number of other technology areas; hence there is also the opportunity for co-operation and synergy that will allow integration of projects to serve many opportunities.

The issues covered span across a whole range of material types from nano, bio, functional, multifunctional through to structural.

The individual reports of the Energy Materials Working Group (EMWG) Task Groups [4-7] on fossil power plants, nuclear power, renewable energy technologies and transmission, distribution & storage detail the analyses of the differing energy technologies and their implications for materials research and supply in the UK. The SRA identifies common themes for R&D and brings together areas where synergies and added value have been identified. The top level themes are identified in this section. **Annex 1** identifies in more detail, the fundamental and applied R&D requirements for the various technologies that have been addressed. It also highlights areas where international collaboration will be needed.

7.1 The Drivers for R&D

The key drivers for Energy Materials R&D aligning to government policy are how materials technology can contribute to;

- reducing environmental impact
- improving security of supply
- reducing cost of electricity

In addition, there is the opportunity of wealth creation for the UK , not only in terms of the home market, but the potential for exporting our technologies. This is particularly pertinent when we consider that the UK contributes around 2% of global CO_2 emissions. This creates a massive potential export market for UK low carbon energy materials technologies to exploit.

Technology solutions must be cost effective; if they are too expensive, they are unlikely to get to market unless they receive some form of direct or indirect subsidy. However, should the technology be successful and implemented on a large scale, costs reduce accordingly. A number of technologies in use today have experienced cost reductions through economies of scale[11] (**fig16**), which are often brought about by the development of low cost materials, processing and manufacturing.

Deciding where materials make the biggest impact is often dependent on the technology it is addressing. Considering a number of electricity generating technologies,[11] **fig 17** illustrates how they compare in terms of estimated costs of electricity as a percentage of a fossil fuel option as a baseline and how they are projected to decrease as a function of time (deployment). Such costs of electricity can generally be broken down into three categories; cost of capital, fuel and operation/ maintenance. Studying such breakdowns can help define the Materials R&D priorities.

7.0 Materials technology priorities

Fig 18, as an example, presents the cost breakdown for natural gas Combined Cycle (NGCC), Coal-fired, and nuclear plant. For NGCC the biggest cost is fuel, therefore materials technologies to improve efficiency should be a priority. For coal fired plant, fuel and capital are the largest costs, hence efficiency improvements and lower cost manufacturing and materials prevail. For nuclear plant the largest cost is capital and whilst it is important to look at reducing these costs, safety of nuclear plants is paramount and therefore Materials R&D tends to focus on the operation and maintenance aspects of nuclear plants, regarding technologies such as inspection, condition monitoring and lifetime prediction as essential.

For emerging energy technologies the drivers are different. In most cases fuel costs do not come into the equation as the energy is free (solar, wind, wave/tidal) and the major costs depend on whether the technology is land based or offshore. There are huge incentives to reduce the cost of operation and maintenance of offshore wind and wave/tidal technologies and minimise the need for human intervention in hazardous conditions. Therefore the materials technology drivers revolve around increased reliability in hostile environments, ease of installation, inspection and remote condition monitoring.

Land based low carbon technologies such as solar pv, fuel cells and biomass technologies tend to be driven by reduced capital cost, which is acting as a barrier to market, whilst also ensuring efficiency and reliability of the end product. Materials R&D to solve these challenges are therefore a priority.

The following priority themes can be used in conjunction with the specific recommendations of the task groups to develop a coherent portfolio of R&D projects for the UK.

7.2 Deciding the Top Level Priorities for R&D

Following consultation with key stakeholders and accounting for other work (20-23) where the key drivers, barriers and priorities have been studied, combined with the review of the four separate reports in this SRA, three generic themes emerge where UK skills could make most impact. The specific detail of the required R&D is given in the individual reports and summarised in **Annex 1**. These themes can be mapped against the energy policy objectives of; security of supply, reliability and cost. (**Table 3**).

R&D should focus materials solutions which contribute to:

Reducing Time to Market and Life cycle costs

Significant shortening of the materials development and validation life cycle time for quicker entry to market (eg new alloy development and deployment for fossil plant). Significant cost reduction, including material substitution, for increased competitiveness to give the UK a market lead (eg. solar pv, fuel cells).

UK key skills: materials design, modelling, advanced processing and manufacture.

Higher Performance in Harsher Environments

Development of high integrity materials systems for operation in the increasingly aggressive conditions (temperature, stress and environment) particularly seen by the emerging energy technologies such as wind, wave, tidal, carbon capture, biomass, energy transmission, distribution & storage and also relevant to conventional fossil and nuclear materials

UK key skills:- materials development (high temperature through to cryogenic) corrosion, oxidation, coatings, lightweighting, surface engineering, joining

Improved Life Management and Reliability

Improved predictability of materials behaviour will produce significant savings on unforeseen plant outages and maintenance costs. This includes understanding the degradation of materials in service, their inspection (NDE) and repair. It also includes the development of materials with improved reliability and properties and increased service lifetimes that will ultimately reduce cost of electricity.

UK key skills: condition monitoring, NDE, materials development and characterisation, modelling

Fig 16 **Cost reduction of existing technologies** [source IEA 2000]

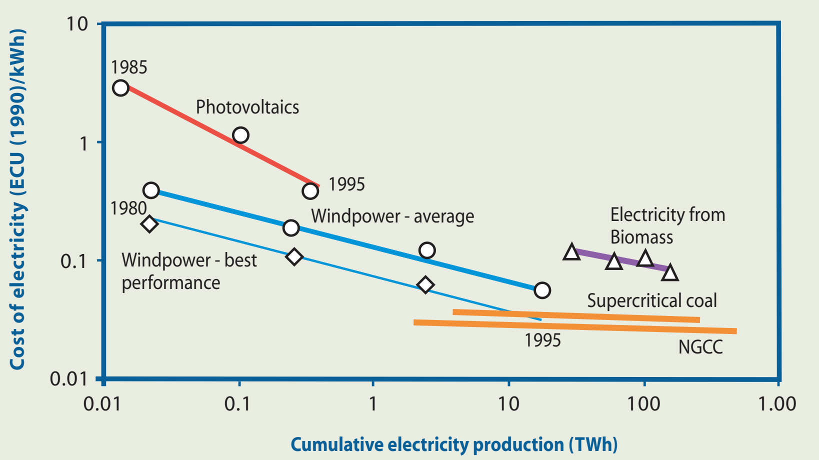


Fig 17 Costs of low carbon as alternative to fossil technologies

Unit costs of energy technologies expressed as a percentage of the fossil fuel alternative (in 2015,2025,2050) [ref11]

Cost as percentage of fossil fuel option

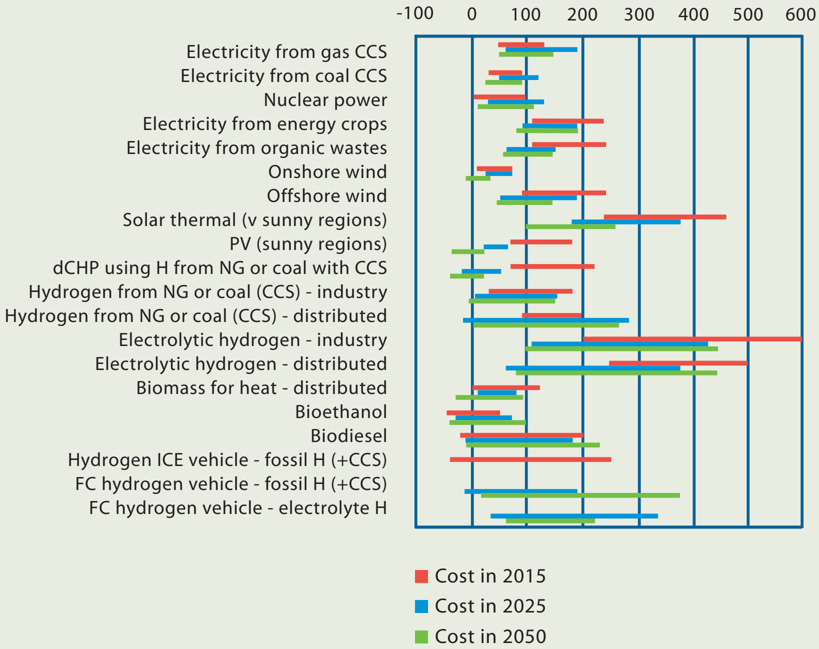
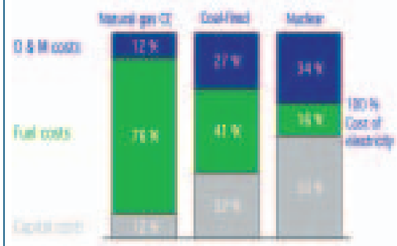


Fig 18 Breakdown of cost of electricity



[source VGB]

Table 3 summarises areas of priority for materials R&D, aligned against both the energy policy objectives and the individual power generation technologies.

Table 3 Priority areas for materials R&D

Energy Policy	Reduced electricity costs	Reduced environmental impact	Security of Supply		
Materials Challenge	Reduced Time to market and Life Cycle Costs	Higher Performance in Harsher Environments	Improved Life Management and Reliability	Comments	Materials Technologies required
Conventional Fossil				Extending life of existing plant	NDE, lifing, modelling
Fossil with Carbon capture				New aggressive environments	high T materials & coatings
Nuclear				Reliability and safety	remote condition monitoring
Offshore wind				Reliability, remote monitoring	remote condition monitoring
Marine				Reliability, remote monitoring	remote condition monitoring
Fuel Cells				Reduce Cost as barrier to market	New materials or processes
Hydrogen				Reduce Cost as barrier to market	New materials or processes
Solar pv				Reduce Cost as barrier to market	New materials or processes
Biomass				Aggressive environments	high T materials & coatings

7.0 Materials technology priorities

Cutting across the sector...

Energy materials cut across the whole spectrum of material types and associated technologies, all of which the UK has significant expertise in.

Functional Materials

Materials are increasingly fulfilling several functions at the same time, something which in the past required a combination of different materials and components. The production and processing of highly-complex, light-weight components with special structural and functional properties are possible for the Energy sector

Materials & Process Modelling

'Fundamental Materials research must look at the visionary goal of designing materials, the technologies used to process them and their individual components, measuring their properties entirely by computer. This method will to speed up development and produce step change reductions in the time to market.

Nanomaterials

There are thermal, mechanical, chemical and electrical limits to what a material can withstand. Extending these limits is crucial to achieving efficiency gains. For this reason, the limits restricting a material's performance must be pushed back.

The promise of nanotechnologies is that more control of the nanoscale structure of materials will lead to the optimisation of their properties This will permit both incremental improvements of existing energy technologies and the introduction of new ones. New nanocomposites could yield stronger and lighter blades for wind turbines, while improved coatings should improve high temperature performance and corrosion resistance in steam and gas turbines. The wider adoption of fuel cells and gas separation will be made possible by improved nanostructured membranes. A new generation of photovoltaics is on the horizon, relying on dye-sensitised nanoparticles or semiconducting polymers, and with the promise of manufacturability on very large scales.

Sensors

There is an increased need to monitor the condition of energy generation plant which is:

- *operating in remote and hazardous environments such as offshore marine and wind*
- *running in harsher operating environments such as biomass, advanced fossil and nuclear*

This creates the need for materials to be developed for sensors, on-line monitoring and non-destructive evaluation. This is an area where the UK has extensive capabilities, particularly through the use of functional and multi-functional materials.

Powders

Powder materials technology will play a vital role the development of Energy Technologies. This could be in isolation such as refractory components for gasifiers, or as part of a fully integrated materials systems such as protective coatings. By their nature they can be blended and designed to have 'engineered' properties such as in the case of SMART coatings for gas turbines combining both tailored corrosion and oxidation resistance. Powder technology may offer superior performance through improved novel material compositions and more cost effective routes to direct manufacture, through near net shaping. They will play a part in the renewable energy scene where large rare earth permanent magnets manufactured from powder are increasingly used in wind turbines and some forms of wave and tidal generation. Further development will enhance their magnetic stability and environmental corrosion resistance. Solid oxide fuel cells present challenges, particularly for ceramic materials in order to achieve cost reduction, reproducibility and system scale-up.

Structural materials

The UK has one on the strongest industrial and academic bases in the development of structural materials from steels through to composites for large-scale applications. It must concentrate on the high added value technologies it has developed over the years to support future developments and look for cross-sector applications and spill-over benefits.

8.0 Funding sources

The energy technologies landscape in the UK is constantly evolving and with it are coming opportunities to coordinate activities and funding of materials R&D.

Materials technologies, like most others, broadly follow the same three stages of development which make up the innovation chain: research and development, demonstration, and deployment. Each stage represents different Technology Readiness Levels(TRL)[24]. Each of these requires public sector support to share the costs and risks of innovation. The landscape under which funding of this chain is available for Energy and its associated technologies is rapidly evolving and is summarised in **fig 19** which also indicates the approximate TRL at each stage of the innovation process.

> *"The direct link between tackling Climate Change and long term wealth creation is now beyond doubt. The business opportunities will be vast."*
>
> John Hutton, Secretary of State for Business, Enterprise and Regulatory Reform. 19th November 2007

[Courtesy of Alstom Power]

Energy materials R&D activities should map onto this landscape as an underpinning technology to ensure a sustainable funding mechanism is available from the early stages of innovation through to full scale deployment.

Different funding bodies and support mechanisms exist at each stage of the innovation process.

- Within the **Research Councils' (RC's)** there are two relevant programmes. One covering Energy and the other covering Materials. Both programmes are led by EPSRC (funded via the Department of Innovation, Universities and Skills(DIUS). The Energy programme supports a full spectrum of energy research working to develop UK research capacity in energy-related areas, including the SUPERGEN initiative. Research Council spend on energy is planned to rise to over £70M pa by 2007 – 2009. The Materials programme valued at around £50M pa covers the whole spectrum of materials research, however , more recently has had targeted calls related to Energy Materials (£2M in 2006 and £2M in Nov 2007 –in a joint call with TSB). The Research Council primarily targets basic R&D typically at TRL 1 possibly moving into level 2.
- the **Technology Strategy Board (TSB)** provides one of the major sources of funding for both materials and energy R&D. The TSB primarily supports innovative industry-led R&D, for UK wealth creation. Both Energy and Materials are Key Technology Areas (KTA) within the TSB. In the energy field it is has historically had a budget of around £20M pa. It is expected that the TSB will continue to fund energy-related innovation as part of its portfolio, including areas such as energy conservation, low carbon technologies, complementary to the Energy Technologies Institute (ETI) and underpinning technologies. In materials the budget has also typically been around £20M pa. The recently announced, November 2007 call, is specifically focussed on Energy Materials. TSB funding primarily targets applied R&D in the TRL2-6 arena.

- the **Energy Technologies Institute (ETI)** is the body announced in 2006 focussing specifically on low carbon energy. Targeting reduced CO_2 security of supply and reduced cost of electricity. It is a public-private partnership with funding of up to £1 bN over 10 years. It will primarily cover the TRL 3-6 regime of the innovation chain targeting rapid demonstration. It is also expected to fund a big increase in international collaboration, to support the UK's global climate change aims. Whilst it is unlikely that the ETI will directly fund materials R&D, it will support programmes containing materials R&D elements as a route to improving component efficiencies, reliability and reduced costs.
- the **Environmental Transformation Fund (ETF)** is a government initiative aimed at bringing together cross-Government activity to develop low carbon economies. Led by the Department of Environment, Food and Rural Affairs (Defra), the Department of Business, Enterprise and Regulatory Reform(BERR) and the Department for International Development(DfID), this will be primarily aimed at getting technologies to market (eg government capital grants for demonstration and pre-commercial deployment) which are the next stages of TRL (6+) after TSB and ETI activities. In addition, Defra want to use ETF to engage with householders, business and the public sector on carbon reduction, and DfID for environmental development internationally. At this stage materials developments would be in full component form ready for deployment

Other organisations operating in the Energy funding landscape include:

- **The Carbon Trust**, an independent organisation funded by Government which supports activities across the full spectrum of the innovation chain including grants for R & D; strategic and business development advice to start up companies; funding to overcome barriers to commercialisation and technical expertise and venture capital investment for low carbon businesses.
- The **Regional Development Agencies (RDA)** prioritise their support for Energy RD, D&D on the basis of regional strengths, capacities and economic priorities. In the recent Comprehensive Spending Review they will allocate a level of their budgets to co-fund TSB programmes as appropriate
- In the **Devolved Administrations (DA)**, for Energy, by far the most proactive is the DA in Scotland. ITI Energy supported, by Scottish Enterprise, identifies technologies required to address future global energy market opportunities and then funds and manages R & D programmes and the subsequent commercial exploitation of new IP.
- the **UK Energy Research Centre (UKERC)** was established in 2004 following the 2002 Energy Review. With funding of £13.8 million over 2004–09, its objective is to provide a focus for energy research in the UK and for international collaboration.

It is important that the Energy materials community through the formation of their implementation group engages with all of the of above bodies to secure a sustainable and long term funding mechanism.

Fig 19 **UK energy innovation chain**

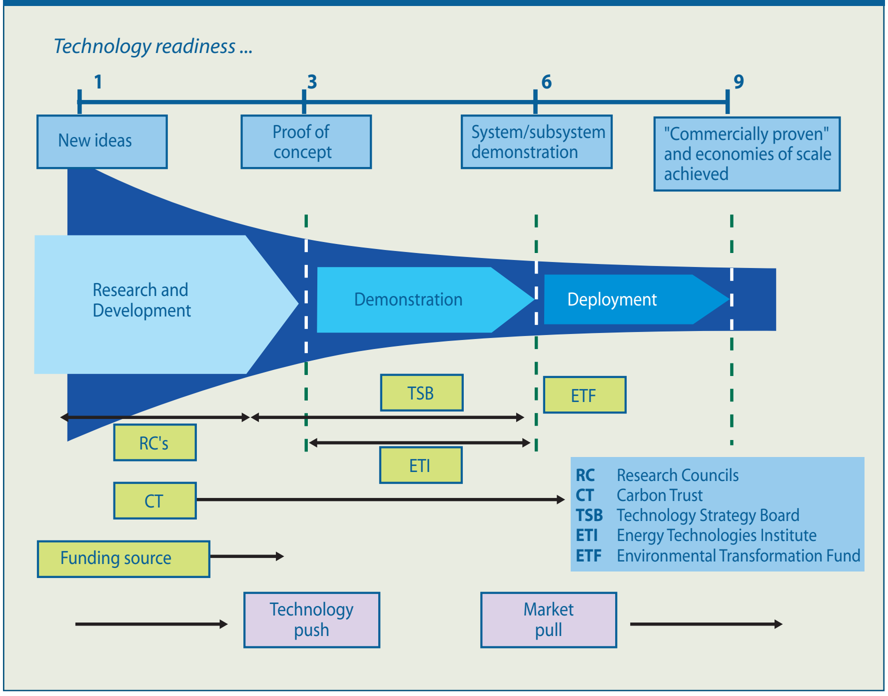


Fig 19 Schematic of UK Energy Innovation Chain and funding agencies

[Courtesy of Alstom Power]

9.0 Underpinning the strategy

To ensure the Technology Priorities of the SRA are recognised and adopted by the stakeholders and that supporting funding mechanisms are available, seven over-riding requirements must be addressed for the successful delivery of this SRA. These were quantified in the 'agenda for action'

1. **Communication;** It is important that the Energy materials community works together and agrees the way forward. Whilst there has been detailed consultation throughout the process of developing this SRA there is a need to widely communicate its findings to the academic and industrial materials community, stakeholders and the relevant funding agencies. The SRA is a working document that will be reviewed at regular intervals.

2. **Establishment of a multi-disciplined coordinating and delivery body** comprising key stakeholders from industry, academia and funding agencies representing the full supply chain. Operating through MatUK, it will have a clear remit to promote and implement the SRA and develop a sustainable and long-term funding mechanism. For this reason, the Body should include business strategists and venture capitalists. It should also act as an advisory body to the Energy Materials Supply Chain and other key agencies.

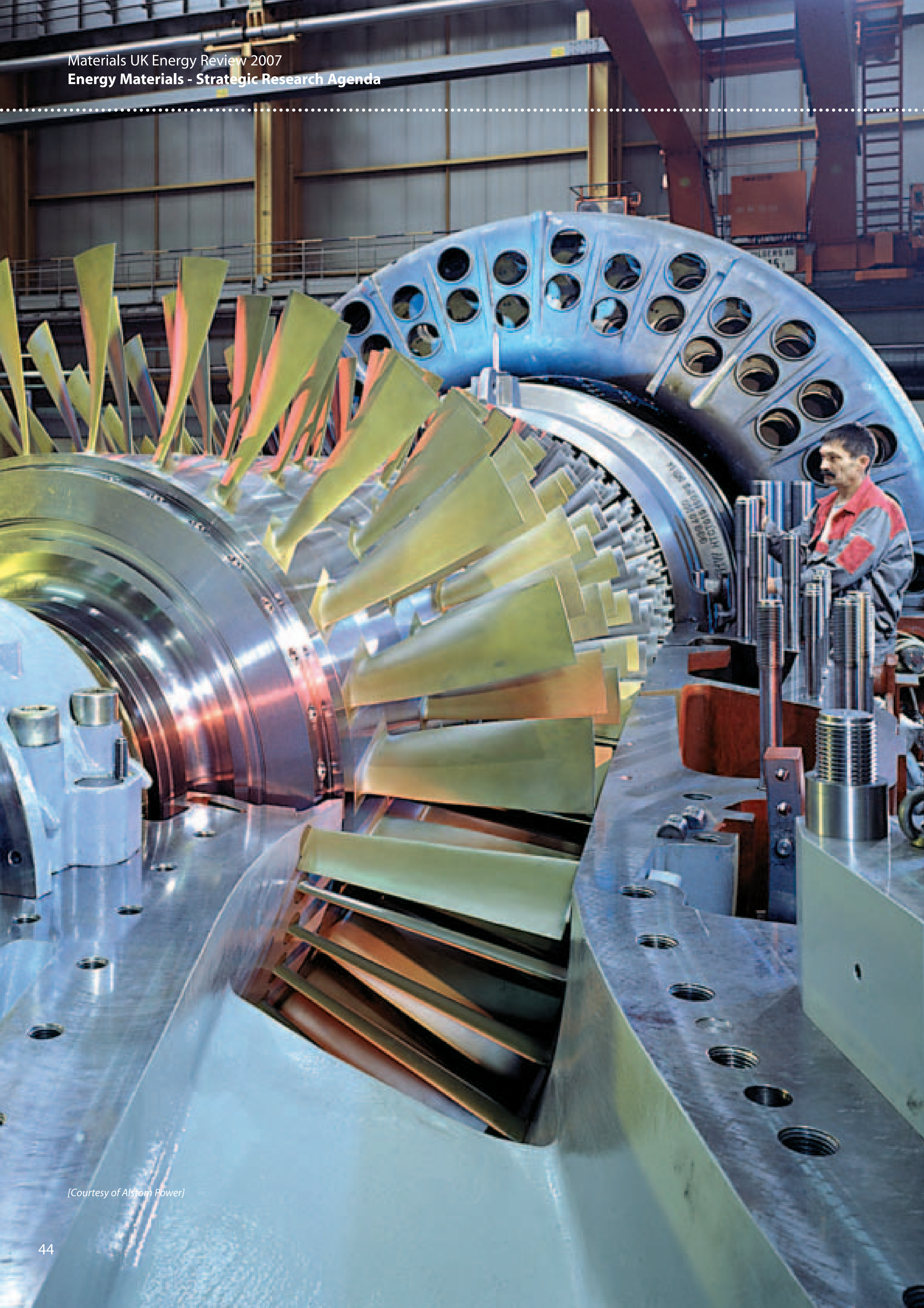
3. **Stable and sustainable long term funding mechanisms:** There is need to establish long-term sustainable funding mechanism(s) for cradle-to-grave materials R&D. This mechanism should involve materials development from laboratory-scale through to full-scale demonstration and deployment. This needs to be integrated with existing funding mechanisms (e.g. EPSRC, TSB, ETI,)and new schemes developed where appropriate.

4. **An Energy Materials Knowledge Management System:** Put in place a coordinated knowledge management system, through an existing Materials Knowledge Transfer Network (KTN) node, that will be given responsibility for Energy Materials. This is to ensure that maximum benefit is obtained from both existing knowledge and from that generated in future R&D thereby saving duplicated effort. Clear terms of reference need to be drawn up and interaction developed with existing bodies, such as UKERC.

5. **Innovative Technology Transfer & Coordination:** The Materials community must work across disciplines and sectors. Energy materials share many common materials issues across transport, aerospace, chemical, offshore and construction. It must find novel ways of transferring technologies. 'Brokering' and funding of 'cross-sector' partnerships in order to optimise consortia as used in the EPSRC SUPERGEN programme and by the TSB Innovation Platforms should be trialled.

6. **International Engagement** The UK cannot solve all the Energy Materials challenges by itself. Where appropriate, it should develop international relationships to improve UK prosperity, whilst supporting national and global environmental policies. We should look to build on existing mechanisms such as the European Framework programmes, COST and ERANETS and work to influence their content to align with our national strategy. An international node in the Materials KTN should be formed, which would look beyond Energy Materials and would have responsibility for representing the UK materials sector.

7. **Development of Skills and Resources** The buoyant Energy sector needs to attract high-class individuals back into the business to add to the existing skills base. The proposed R&D should be linked to skill-base refreshment to develop and retain expertise and knowledge. R&D that uses the UK's inventory of pertinent skills is one of the most effective ways to maintain/refresh its assets. The MatUK Education & Skills Group will address this.



[Courtesy of Alstom Power]

10.0 Key recommendations

1. Widely communicate the findings of the SRA to the academic and industrial materials community, stakeholders and the relevant funding agencies

2. UK R&D for Energy Materials must focus on programmes which:

- Reduce Time to Market and Life cycle costs
- Produce Higher Performance in Harsher Environments
- Improve Life Management and Reliability

In addition, existing programmes should be analysed and a portfolio of projects developed against these criteria based on the specific recommendations of the task group reports.

3. Establish a coordinating multi-disciplined body to implement the SRA and advise the Energy Materials supply chain, funding agencies and stakeholders. The body will:

(a) Establish sustainable funding by implanting materials firmly within the Energy R&D landscape to help initiate the priority R&D programmes.

(b) Work with key stakeholders e.g. Technology Strategy Board, Energy Technology Institute, Carbon Trust, Research Councils, RDA's. etc. in developing well integrated energy programmes

(c) Facilitate the development of a coherent, stable and long-term platform for UK materials development that will support all stages of the material development cycle through to deployment.

4. Establish a KTN node that will provide Knowledge Management systems to capture existing and future knowledge and speedy transfer to the skills base.

5. Initiate more innovative methods for developing optimised partnerships and consortia that can lead to cross-sector and cross discipline interactions and more innovative solutions to problems.

6. Establish a KTN node that will be responsible for forming International alliances with bodies such as FP7 and relevant Technology Platforms in order to provide better alignment of programmes and access to funds and facilities via international collaboration.

7. MatUK Education & Skills Group to consider the state and implications of the skills shortage in the Energy Materials Sector and deal with it in line with their current strategy across the Materials sector.

"We must not stifle innovation, as the UK has recognised world class materials research expertise which can take advantage of the exciting opportunities presented, particularly some of the longer term 'visionary' challenges."

Lord Sainsbury of Turville Oct 2007

11.0 Progress to date

The EMWG has been promoting its activities prior to the publication of this SRA in order to 'hit the ground running' after the formal launch. There are already some successes to report:

1. Engagement of stakeholders

Delivery of the SRA can only be achieved by working with stakeholders, the Energy supply chain and the materials community. Many have already been involved in the EMWG and are aware of the objectives.

The EMWG has engaged with the Technology Strategy Board and EPSRC to provide significant input into the 2007 Technology Programme Autumn call on Energy Materials, valued at £12M.
A significant number of projects should be generated to help meet the SRA goals.

The Carbon Trust announced a Challenge to reduce the cost of photovoltaic (pv) materials in October 2007. This Challenge is aligned with one of the priorities of the SRA.

2. International Engagement

The SRA has recognised the need to build on existing mechanisms such as the European Framework programme. UK has chairmanship of EuMaT (European Advanced Materials Technology Platform) which has adopted the model and priorities of the EMWG in its recommendation that a jointly funded programme between the Energy and Materials Directorates of the Commission should be announced in the FP7 2nd Call in December 2007. This would create excellent funding opportunities for the UK help build strong consortia across Europe.

Opportunities have already been taken to collaborate with industry and research organisations in the United States under the terms a Memorandum Of Understanding between UK BERR and the US Department of Energy on Fossil Energy Materials. In the future, similar collaborations with the high technology Countries, such as Japan and Singapore and developing nations such as China and India, will be sought where they can offer value to UK industry and research groups.

12.0 The way forward

The way forward is clearly laid out in the 'Agenda for Action' of this SRA and its seven key recommendations.

This SRA is seen as the first step in activating and coordinating the Energy Materials Community at a time when Energy and the Environment has rarely had such a high profile, nor have the materials challenges been more exciting.

Whilst it is recognised that the UK does not have a complete supply chain in Energy Materials, it retains an enormous amount of world leading expertise particularly in R&D and in the design and manufacture of high added-value components.

Progress has already been made against the Agenda for Action and this will continue through the delivery and implementation body, which we hope to form by late Spring 2008. With the support of the Materials KTN we intend to deliver a knowledge capture and transfer node within the next 6 months and an International Node within similar timeframes. Discussions will start immediately

We intend to continue to work with the funding agencies and look to develop further programmes particularly with the Technology Strategy Board and EPSRC to maintain the momentum provided in the Autumn 2007 Call on Energy Materials. With future calls looking to focus more on specific priorities as they are identified.

Equally we hope to work with and advise the Energy Technologies Institute in indicating how materials can help meet many of their objectives in bringing low carbon energy technologies to market.

Looking further ahead, it is the intention for MatUK to examine some of the other key materials issues affecting Energy and the Environment, such as energy conservation and useage. This has already been initiated through the Construction Materials working Group, looking specifically at housing materials. This will be reported in 2008. Consideration will be given to the value of evaluating the Materials issues for the transport sector. There has already been considerable work carried out in this area and an analysis of this work and discussion with the sector would be necessary before any work was initiated.

With the support of the community, by working with our key stakeholders and the formation of an implementation and delivery team, we can take the recommendations of this SRA forward to ensure that the UK can take full advantage of the unprecedented growth in the sector and the business opportunity this creates both nationally and globally.

The UK is well positioned to develop many of the materials technologies required for the emerging low carbon technologies, such as renewables and Carbon Capture and Storage, in which the government is investing heavily. However, to optimise this, the community must be better focussed on its strengths and be integrated and coordinated in its approach going forward.

[Courtesy of Alstom Power]

> 'There is an enormous amount of excellent Materials R&D is being carried out within the UK in Energy Materials, however, there is an urgent need for it to be coordinated in order to maximise its benefit.'

[Courtesy of Eon UK]

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Annex 1 Technology priorities

The devil in the detail...

This section summarises the key findings of the Task Groups and highlights the recommended areas for materials R&D. For completeness an additional section (1.5) summarising the priorities for materials R&D in the construction sector is included. This has been provided by the *MatUK Construction Materials Working Group* who are evaluating energy conservation in the built environment. This is the subject of a more detailed review to be published by MatUK in 2008.

1.1 Fossil Fuel Power Plants

Status

By far the most mature technologies, with fossil fuel power plants provide over 70% of the UK's current electricity generating capacity and will remain a major source of energy for the foreseeable future. The ageing fleet will be replaced and plans are already in place for new build together with large-scale carbon capture and storage demonstration plant, bringing with it new materials challenges.

UK Strengths

The UK remains a centre for technical expertise in fossil energy materials, particularly high temperature materials and coatings. A high proportion of the original equipment manufacturers (OEMs) have key activities located within the UK and most have retained Materials Technology as a UK activity. The UK thus has the expertise needed to be at the forefront of future materials driven technical development in fossil-fuelled power generation.

Key Technologies

The key driver for fossil-fuelled power generation is to minimise the impact on the environment through reduction of CO_2 emissions. There is the opportunity to reduce CO_2 emissions from fossil fuel power generation by around 90% using new carbon capture technologies [(4)]. However such technologies can lead to reduced plant efficiencies of >10%, therefore the adoption of a twin track approach of improved efficiency and use of carbon capture technologies is essential. Co-firing with renewable fuels will also be used to reduce emissions. All of these technologies involve operating in severe, aggressive environments with significant implications on the materials.

Challenges for Materials

Improved efficiency and lower CO_2 emissions are achieved through higher operating temperatures. However, the materials used for high-temperature components boilers, steam and gas turbines are already their limits. While there are still opportunities to incrementally improve the performance of existing systems both by design and materials development, to achieve significant future increases, disruptive technologies need to be developed to introduce innovative new materials engineering solutions with tailored and optimised properties.

In the adoption of carbon capture technologies, the materials will operate in novel high temperature, aggressive environments compared to conventional plant. This means many components must withstand conditions and contaminants such as those produced in advanced gasification, oxy-firing and biomass/waste plant. This will impose significant materials challenges leading to the development of high temperature materials systems with excellent corrosion and oxidation properties and will strongly rely on the development of coatings technology as an integral part of the system design. Opportunities will also exist for the development of gas separation membrane technologies where UK currently has little expertise. The key challenges relate to the SRA theme of

higher performance in harsher environments

Another key issue for fossil fuel materials is related to the SRA priority of

reducing time to market and lifecycle cost

Typical materials development programmes for steam turbine or boiler applications can take more than 10 years to achieve a completely reliable, well validated material for commercial deployment.

Annex 1 Technology priorities

Technologies that dramatically reduce time to market will have a major impact. Multidisciplinary developments will be required in alloy design, materials modelling, virtual testing, manufacturing and processing techniques. Currently validation methods rely on long term testing of hundreds of thousands of hours. Such methods developments, if successful, would have major benefits across numerous business sectors both within and outside the Energy sector.
The next generation of steam plant (>700ºC) will rely on Nickel based alloys which are 10x the price of ferritic steels. Therefore innovative design and manufacturing, joining and modelling will all have to be developed to ensure costs do not become prohibitive.

The current ageing fleet is placing a short term requirement on extending the life of existing plant through

improved life management and reliability

Development of more accurate lifing tools, a fuller understanding of degradation mechanisms and improved NDE /condition monitoring will also be a requirement for new plant.

Regarding **international collaboration**, the fossil energy materials community is an exemplar in the way it collaborates with European competitors and suppliers in order to develop new materials.

This has been ongoing since the 1980's in programmes such as COST (Cooperation On Science and Technology) in Europe. Each participating country is funded by their own agencies, but the work and results are shared to the point of demonstration of full-scale component manufacture. The individual organisations then use their own individual expertise and IPR to design with that material in a way to produce the most thermally efficient and cost effective product.

Table A1 Top level SRA R&D priorities: **Fossil Energy**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	Current lead times for new materials typically run to 10years+ and are costly • Reduced time to develop materials at reduced cost and with lower environmental footprint.	• Incremental advances in current technologies • Advanced manufacturing development for cost reduction, through computer aided development and design of materials systems and process modelling	• Novel low cost materials & coatings development • Advanced manufacturing and process simulation • Materials, process and multiscale modelling	• Integrated materials systems development; upscaling and manufacture with full scale component validation and demonstration.
2. Higher performance in harsher environments	Operating environments are becoming more severe leading to potential reduced lifetime • High performance materials for harsh environments for improved efficiency and reduced environmental impact	• Better understanding of degradation and failure mechanisms • Development of new materials classes to meet longer life/increased temperature and more aggressive environmental requirements • Development & validation of models that define the interaction between Materials systems and their operating environment	• Functional materials for advanced cycles (filters, membranes) • Integrated (material, coating, NDE etc) new materials systems development • Identification of disruptive materials technologies (well beyond existing capability) eg high T, low cost, non-degrading	• Integrated materials systems development; upscaling and manufacture with full scale component validation and demonstration.
3. Improved life management and reliability	Improved reliability significantly reduces cost • High reliability materials for extended life in harsh environments	• Development and validation of integrated life assessment procedures including supporting NDE technology	• Advanced Life prediction tools accounting for harsher operating conditions (environmental , temp & stress) • On-line NDE capability development, which can be integrated into lifetime prediction	

Key Applied R&D Priority Areas

The key recommendations are:

- Incremental development of existing materials and coatings to support increased performance in the short-medium term
- Evaluation high temperature behaviour, degradation & life prediction of materials in advanced cycle environments
- Advanced manufacturing development for cost reduction, through computer aided development and design of materials systems, materials & process modelling

Underpinning Research Requirements

- Development of disruptive materials technologies with low cost and high performance. These will need to go beyond conventional materials currently being used.
- Process and multi-scale materials modelling for reduced lead time and cost reduction
- Development of advanced NDE and materials condition monitoring in service to be directly linked into life prediction tools

A summary of the key R&D needs for fossil materials is summarised in Table A1

"Twenty-five years ago it would not have been possible to imagine the UK as a global leader in science and innovation in the world economy, but today it looks like an attainable goal. We can be one of the winners in 'the race to the top' but only if we run fast".

Lord Sainsbury of Turville Oct 2007

Annex 1

Technology priorities

"Pioneering low carbon technologies, including renewables, CCS, and subject to our decision, nuclear, will help secure diverse future energy supplies while tackling climate change. In a global market, the UK's expertise in developing these technologies will also open up business worth billions of pounds"

John Hutton,
Secretary of State for Business,
Enterprise and Regulatory Reform.
November 2007

1.2 Nuclear Power Materials

Status

Nuclear power makes by far the largest 'carbon neutral' contribution to the UK's energy needs, providing around 18% of electricity output in 2006. Much of the existing nuclear plant is ageing and due to be decommissioned within the next 10 – 15 years. Decisions on new build plant are expected by the end of the year. This decision will impact on the level of R&D to be carried out.

UK Strengths

The UK skills base in this area has been severely reduced over the last 30 years and now extensive experience and expertise is invested in a small number of people. The government is endeavouring to retain and expand this expertise through initiatives such as the formation of a national nuclear laboratory.

Until a decision is made on the future of nuclear power in the UK, it is difficult to predict what total resources will be needed. There is an minimum requirement for the UK to be an 'intelligent purchaser' of the technology in order to satisfy regulatory requirements, and to supply advice on installation, safety, operation, maintenance and in the extension of the life of existing plant and its subsequent decommissioning and waste disposal.

Key Technologies

Any new build will involve the use of proven reactor technologies such as those from France or USA. 'Generation IV' designs are also under development which promise cleaner and more economical nuclear power by the middle of the century. The international effort on fusion continues but even if fully successful remains several decades away from commercialisation.

Materials Challenges

In existing plant the primary drivers for materials research are;

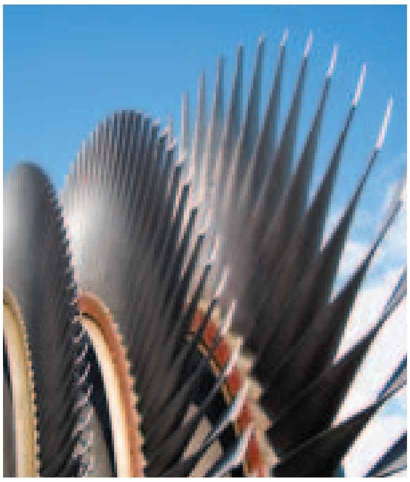
- the need to predict reliably the through–life properties of the core components such as the reactor pressure vessel, fuel cladding and cooling systems,
- the need for plant lifetime extension, and for safe and effective decommissioning and waste storage strategies.

For nuclear fusion, although most of the systems are different, many of the materials issues, and the research methods, are very similar.
The key scientific problems are related to two of the key technical themes of this SRA;

improved life management and reliability

higher performance in harsher environments

Particular issues relate to corrosion and erosion; environmentally assisted cracking; mechanisms of embrittlement, crack initiation and crack propagation; creep-fatigue interactions; irradiation creep and swelling; thermal cycling; joining and interface technologies; effects of helium; very long-term degradation of storage materials; and development of new and improved methods for non-destructive examination and continuous monitoring and inspection of plant performance.



Key Applied R&D Priority Areas

Four immediate opportunities have been identified that play to UK strengths and would yield substantial progress on a number of key cross-cutting issues. These opportunities arise through synergies in experimental and modelling techniques.

Accordingly, the UK would benefit greatly from new or enhanced R&D programmes into:

- in service and in-repository corrosion and degradation of materials
- high temperature behaviour and life prediction of welded structures under complex loading
- irradiation damage in fission and fusion materials
- development of advanced remote repair techniques, NDE and materials monitoring in service

Underpinning Research Requirements

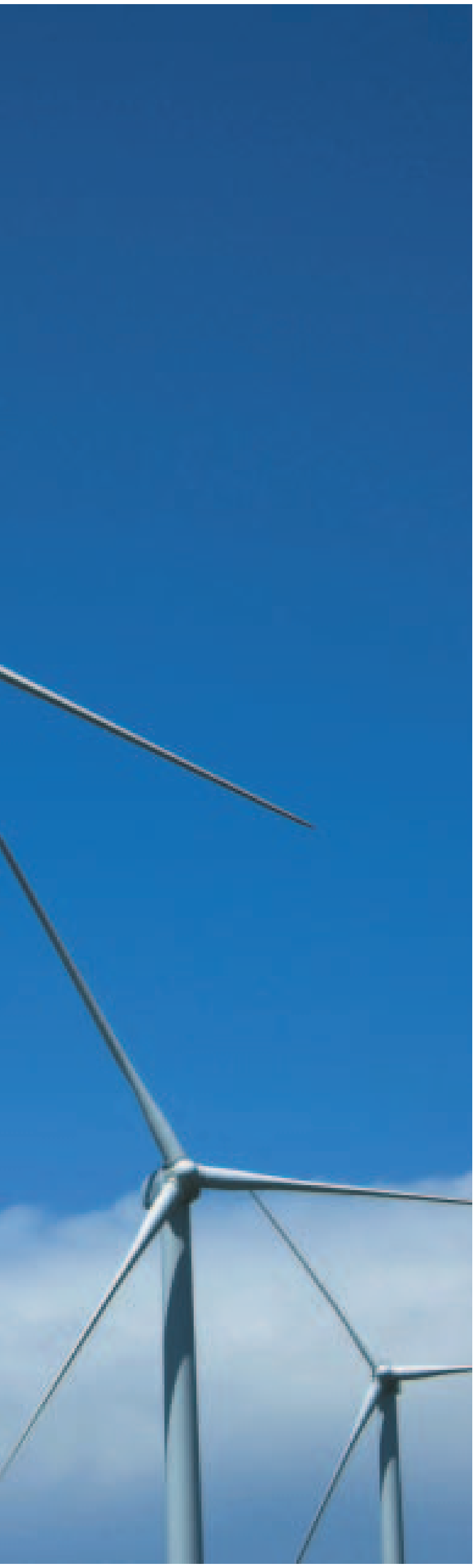
There are exciting new opportunities for productive research in the area of underpinning R&D, building on recent advances in experimental methods for materials characterisation and understanding-based multi-scale modelling of materials behaviour. Materials which need to be studied are austenitic, ferritic and oxide-dispersion strengthened steels; zirconium; graphite; fission fuel materials; refractory metals such as tungsten; and repository materials.

The key challenges are summarised in Table A2.

Table A2 Top level SRA R&D priorities: Nuclear Energy

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Higher performance in harsher environments	• Improve resistance to radiation damage • Improve resistance to environmental degradation • Improve temperature capability of materials, especially for fusion reactor	• Studies of irradiation-assisted creep, and creep-fatigue interactions • Autoclave studies of corrosion behaviour under realistic conditions • Develop improved large-scale processing and coating technologies for ceramics	• Computer modelling and atomic scale experimentation • Fundamental studies of mechanisms of environmentally assisted failure • Fundamental studies of processing and properties of ceramics and ceramic matrix composites.	• Requires access to long-term irradiation and test facilities (Including IFMIF, for fusion materials research) • Requires facilities where corrosion and irradiation occur simultaneously. • International cooperation required to develop advanced ceramic-based materials
2. Improved life management and reliability	• Accurately predict lifetimes of reactor systems and sub-systems • Continuously monitor reactor conditions	• Improve quantitative analysis of behaviour of welded structures subject to high temperatures and complex loading • Develop improved sensors and robust devices that can be installed within critical regions • Development of remoterepair techniques, especially for irradiated material	• Multi-scale modelling of materials behaviour, improved mechanistic understanding of degradation behaviour • Research on physical principles underpinning sensors, plus improved signal processing and image analysis procedures	• Analysis of complex structures, and atomic level modelling, require international effort • Need to further develop internationally agreed standards and protocols for non-destructive evaluation of materials

Annex 1 Technology priorities



1.3 Alternative Energy Technologies Status

The government target of achieving 20% energy generation from renewable sources by 2020 from a current level of around 4%, provides the biggest opportunity to the UK materials community. There is potential for the UK to become world leaders, particularly in offshore generation technologies and the associated R&D.

UK Strengths

The UK's strengths in sustainable energy vary from technology to technology. However, the abundance of natural resources places the UK in a world leading position for development and deployment of offshore renewable technologies. For offshore wind farms, the UK's strengths currently lie in the deployment of technologies and in wave/tidal we lead the world in development of devices, but deployment remains slow. The UK has leading edge manufacturers of intermediate and high-temperature fuel cells. UK solar photovoltaic development and manufacture faces big challenges to reduce costs. Tthe UK has a strong academic base that can support future needs across a broad spectrum of alternative energy materials technologies.

Key Technologies

The UK can play a major role in the future development of wind, wave/tidal, solar pv, hydrogen, fuel cells and biomass. All of these technologies provide 'low carbon' alternatives to fossil fuels and help reduce CO_2 emissions. No single technology can meet the challenge – all have a part to play in meeting increased demand for energy or displacing other options when they reach the end of their commercial life.

Materials challenges

One of the greatest challenges for the emerging technologies is that of

reducing time to market and lifecycle cost

For photovoltaics and fuel cells, cost is a barrier to market and R&D must focus on bringing these costs down. Where the technologies have been deployed and demonstrated the issue is

improved life management and reliability

This is particularly the case of offshore wind where high maintenance costs and reliability are a key issue due to the inaccessibility of the plant.

Reducing costs and proving the reliability of the technologies are clear priority topics for materials research to help to increase the deployment of these technologies. With supported deployment, improved technologies and upscaling, come cost reductions and increased confidence, helping to broaden the market opportunities. The materials challenges facing the alternative energy technologies such as biomass/waste to energy, fuel cells and hydrogen have close synergies with fossil-fuel heat and power technologies requiring

higher performance in harsher environments

In addition there are materials challenges facing those which take advantage of naturally occurring processes from which energy can be derived, including wind, wave/tidal and solar, which provide differing operating environments. These diverse technologies depend on a wide range of structural and functional materials.

Key Applied R&D Priority Areas

- Development of lightweight/high strength composites (epoxy-resin glass reinforced plastics, carbon-carbon composites, etc.) for wind and tidal turbine blades, that can resist high fatigue loads and the harsh offshore environment for larger designs
- Development of surface engineering technologies including;

  -Paints for antifouling of wave/tidal components.

  -Coatings – e.g. drag reducing coatings for wind turbines, corrosion protection for biomass heat exchangers, antireflective coatings for PV cells
- Development of sub-system components in Solid Oxide Fuel Cells (SOFC)
- Improved electrolytes, electrodes and interconnect materials for SOFCs, membranes, materials for H_2 storage, etc.
- Development of test and modelling methods for materials characterisation for harsh environments

Key Fundamental R&D Priority Areas

- Development of innovative and disruptive material designs and processing techniques e.g. sandwich constructions, joints, FRP pre-forming and infusion techniques for wind/wave/tidal turbines.
- Advanced processing of silicon and thin film GaInP/GaAs for photovoltaic cells to reduce costs

Generic areas of R&D

Modelling provides a short cut to improving component design and an invaluable tool for the management of the energy system in service. For many of the alternative energy technologies the issue of life management and reliability have been highlighted as key issues where modelling will give potential high payback. eg

- Wind and tidal turbine blades (reliability and serviceability)
- Heat exchangers in biomass combustion and gasification systems (reliability)
- Reliability improvement of Low and high temperature fuel cell components
- Improved reliability and reduced uncertainty through the development of test and modelling methods for lifecycle analysis/fatigue performance of constituent materials, sub-components and major structures i.e. blades

Development of advanced Non-destructive Examination, Monitoring and Sensors can provide vital information of plant condition and hence avoid unscheduled outages and costs. The needs for remote monitoring (either of the environment experienced or the condition of the material-particularly for plant in remote locations where reliability and regular maintenance are key, e.g. offshore wind farms), there is a need for the collection of data for the development of models and their validation and the assessment of material condition in service. R&D which will lead to;

- Reductions in operating and maintenance (O&M) costs through development of structural health monitoring technologies
- Development and application of NDE techniques for more accurate and rapid defect detection, e.g. for wind turbines
- Development of sensors for in-situ condition assessment
- Development of standards and certification procedures

The key challenges are summarised in Tables A3-A8

*“We also want to mobilise the enthusiasm and potential of individuals and communities to generate their own energy locally, through solar panels and wind turbines for example.
We are therefore bringing forward a range of measures to support more distributed forms of energy.”*

Alistair Darling EWP

Annex 1 Technology priorities

Table A3 Top level SRA R&D priorities, Alternative Energy: **Offshore Wind**

Technology priority areas	**The need**	**Key applied R&D needs (UK can solve)**	**Key fundamental R&D needs (UK can solve)**	**Key R&D for external (need for collaboration outside UK)**
1. **Reducing time to market and life cycle costs**	• Need to produce large composite structures quickly	• Development of rapid fabrication processes including short duration mould times and joining of sub-structures	• Development of advanced composite material systems suitable for high-speed, high volume processing	
2. **Higher performance in harsher environments**	• Requirement for innovative material solutions to overcome 'up-scaling'/ light-weighting challenges. Materials for harsh environments	• Development of material and component/structural designs and processing techniques e.g. sandwich constructions, joints, FRP pre-forming and infusion techniques • Coatings for erosion-corrosion resistance	• Development of test and modelling methods for materials characterisation for harsh environments • 'New' materials-toughened GRP & CFRP or hybrids to enhance fatigue lives • Nanoreinforcements	• State-of-the laboratories for accelerated testing of large components under realistic climatological conditions
3. **Improved life management and reliability**	• Improved operational reliability and reduced uncertainty of turbine performance Reductions in operating and maintenance (O&M) costs	Development and application of: • Structural health monitoring (SHM) technologies • NDI techniques for more accurate and rapid defect detection • crack initiation and fatigue database for life prediction.	• Development of test and modelling methods for lifecycle analysis/fatigue performance of constituent materials, sub-components and major structures	

Table A4 Top level SRA R&D priorities, Alternative Energy: **Wave and Tidal**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	Reduce production cost Improved understanding of material fatigue behaviour.	Develop volume production and manufacture techniques	Development of test and modelling methods for fatigue performance of constituent materials, sub-components and major structures	
2. Higher performance in harsher environments	Requirement for innovative material solutions to overcome 'up-scaling'/ light-weighting challenges. Materials for harsh environments	Development of material and component/structural designs and processing techniques e.g. sandwich constructions, joints, FRP pre-forming and infusion techniques	Development of test and modelling methods for materials characterisation for harsh environments	
3. Improved life management and reliability	Reductions in operating and maintenance (O&M) costs	Development and application of: (i) Structural health monitoring (SHM) technologies (ii) NDI techniques for more accurate and rapid defect detection (iii) Long-term, low cost anti-corrosion coating systems	Characterisation of material degradation and flaw development under environmental conditions	Characterisation of material degradation and flaw development under environmental conditions

Annex 1 Technology priorities

Table A5 Top level SRA R&D priorities, Alternative Energy: **Fuel Cells**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	• Characterisation and control of porous electrode microstructure and processes	• Fabrication processing and characterisation of multi-component porous architectures	• Multiscale modelling of electrodes. • Rational design of electrode materials and structures.	• Fundamentals of Electrode kinetics
	• Improved functional materials	• Improved processing of thin multilayer structures, e.g sintering.	• Accelerated discovery of high performance cell components (modelling and experiment)	• Design and development of high performance cell components
2. Higher performance in harsher environments	• Corrosion resistant materials for interconnects and BoP.	• Oxidation and corrosion testing of materials including characterisation and prediction of lifetime.	• Identify fundamental corrosion mechanisms	• Fabrication of new alloy compositions at R&D and production volumes
3. Improved life management and reliability	• Identification of failure and degradation processes	• Accelerated testing in FC environment	• Modelling and characterisation of in-situ processes	• In-situ characterisation techniques

Table A6 Top level SRA R&D priorities: **Biomass**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	Improved understanding of corrosion mechanisms and development of resistant alloys and protective coatings for boilers, gas turbines and combustion engines.	Improved materials selection and plant design approaches to minimise risk of damage, materials/fabrication costs and facilitate service/repair.	Generation of design-relevant materials data for alloys, coatings and joints. Definition of plant operating limits for different biomass types. Assessment of fuel additives and operational options to reduce fouling/ corrosion.	i) Networking with other biomass plant operators –shared experience to reduce risks. ii) Data generation for different biomass fuels/ operating conditions for model development. iii) Collaboration on novel diagnostic techniques.
2. Higher performance in harsher environments	Excessive corrosion limiting steam temperatures in boilers and hot corrosion in gas turbines and combustion engines.	Development of reliable alloy/ coating materials systems. Improved understanding of the effects of operating conditions on corrosion rates leading to improved designs.	Development of advanced smart coatings to resist variable corrosion mechanisms. Determination of alloy/coating performance limits.	
3. Improved life management and reliability	Excessive corrosion limiting steam temperatures in boilers and hot corrosion in gas turbines and combustion engines.	Development and application of diagnostic techniques. Improved repair procedures.	Characterisation of alloy/ coating degradation mechanisms and development of predictive models relating fuel properties and operating conditions to damage	

Table A7 Top level SRA R&D priorities: **Solar PV**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. **Reducing time to market and life cycle costs**	Cost efficient materials processing for both crystalline silicon and thin film systems.	Development of high yield cutting techniques for very thin wafers. Improved in-line processing tools for thin film systems	Routes to high quality, low cost crystallization. Volume production and processing techniques for think film	
2. **Environmental resilience**	Long-term (>25 years) stability of module materials especially for building integrated systems	Development of suitable coatings and coating techniques.	Characterisation of materials degradation due to sunlight and thermal cycling. Characterisation of effects of concentrated sunlight.	
3. **Improved life management and reliability**	Better understanding of the role and functions of layers and junctions in thin film PV	Enhanced encapsulation methods for rigid and flexible systems	Improved characterisation techniques for the effects observed at layers and junctions	

Table A8 Top level SRA SRA R&D priorities, Alternative Energy: **Hydrogen**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. **Reducing time to market and life cycle costs**	• Production of H2 from renewable and sustainable means.	• Improved next-generation catalysts for high temperature processes. Develop material for improved separation processes	• Development of sensitive, selective sensor materials.	
2. **Higher performance in harsher environments**	• Need to develop efficient storage methods capable of withstanding both the hydrogen environment and the working environment in which the system will be deployed	• Mechanical testing of storage materials. Development of 'hybrid approaches'.	• An atomic- and molecular-level understanding of the physical and chemical processes involved in hydrogen storage and release. • Development of new transition metal hydrides	• Large-scale environmental testing
3. **Improved life management and reliability**	• Need to develop efficient storage methods capable of withstanding both the hydrogen environment and the working environment in which the system will be deployed	• Development of sensitive, selective sensor materials.	• Research on material embrittlement, centred on the atomic-scale mechanisms responsible for materials failure.	

Annex 1 Technology priorities

1.4 Transmission, Distribution and Energy Storage (TDES)

Status

Transmission and distribution networks are ageing and asset replacement programmes currently average some £500M p/a. This regeneration provides an opportunity to introduce innovative materials developments to improve network efficiency and offer energy-saving benefits and increased security of supply to consumers via such new technologies such as SuperGrid & 'smart energy' systems

At present, there are about 8% energy losses from the 25,000km of high voltage overhead cables and over 800,000km of local distribution networks that supply our electricity. This equates to around 3GW of power or 8 million tonnes of CO_2 entering the atmosphere each year. Incremental development of existing materials would significantly reduce this loss, while 'step change'/disruptive materials technologies, such as High Temperature Superconducting (HTS) cables and fault current limiters could lead to 'near zero loss' power delivery.

By 2020 the government is committed to generating 20% of its energy from renewable resources, many of which [e.g. wind, wave and solar power] are from intermittent/fluctuating sources. The size of individual power generation facilities will also vary greatly – from the large fossil- and nuclear-fuelled power-stations that deliver several giga-watts of power, to the microgeneration of small domestic wind turbines, photovoltaic cells etc. that require to deliver a few kilowatts of excess power back into the distribution network. Complex power management, smart metering, and network interconnectivity will require a wide range of sophisticated functional and structural material developments. Such 'changing times' offer an opportunity to introduce new technology in a phased and controlled manner

Large-scale energy storage via supercapacitors or [longer term] Superconducting Magnetic Energy Storage (SMES) will allow large quantities of power to be readily available 'on demand'. At present such power is stored by pumped water systems that take many hours to convert the stored energy back into electricity.

Portable power for environmentally-friendly transportation via fuel cells / hybrid power and battery power for a wide range of business and domestic equipment are further areas in which there are market opportunities for advanced materials technologies to support the strategic needs for a reliable, secure energy supply.

UK's dependence on oil and gas as major fuel sources will continue into the foreseeable future and their secure and reliable transmission and storage via tankers, pipework and pressure vessels must not be overlooked - nor the materials challenges they pose. The 'hydrogen economy' has been proposed as the environmentally friendly fuel of the future. High-pressure hydrogen gas reacts with common pipework steels causing embrittlement, while transfer of liquid hydrogen requires structures capable of withstanding –(minus) 250°C. These are just some of the issues facing well-established structural materials.

Functional materials will be required to switch high voltage power, quickly, safely and reliably using fabrication and microchip electronic technology more commonly associated with laptop computers and small domestic equipment. More robust, high temperature devices, with high-throughput thermal management methods, will be needed. Such devices will move from silicon wafer technology to silicon carbide and possible diamond semiconductor materials

UK Strengths

The electricity transmission and distribution infrastructure is strategically important to the UK economy. In a bid to improve economic efficiency, the UK electricity supply industry was liberalised in 1990, though the transmission and distribution segments remained as regulated monopolies. Centralised electricity research laboratories were disbanded and much of that expertise has been lost. However expertise has been retained among the transmission and distribution networks and within the associated UK supply industries. Energy materials and technological development is strong in both industry and academe for specific high-value niche markets, whereas low cost high volume production has migrated to developing nations. However, niche markets are global and products are exported to rapidly growing areas such as China & India.

UK has key strengths in the transmission of energy supplies such as oil and gas, thanks to the development of North Sea reserves. Whist production from the UK Continental Shelf has reduced over the years, much of the expertise still exists within the offshore industry and pipeline manufacturers to address future materials issues.

The UK also has a strong academic reputation in emerging energy materials, such as fuel cells and superconducting high temperature materials. Some of this expertise is being 'spun off' into new commercial enterprises.

Key Technologies

Transmission, distribution & energy storage technologies are not limited to electricity. They include:

- Electricity transmission and distribution and associated equipment
- Electricity storage (batteries, small scale fuel cells, supercapacitors, superconducting magnetic energy storage)
- Hydrogen storage and transport
- Transportation of oil & gas (pipelines) and fuel storage

Basic and applied research in the energy sector is well served in the UK. Disciplines include materials science, chemistry and mechanical/electrical/civil engineering.

Materials Challenges

One of the key technology priority areas for transmission, distribution and storage is related to:

'reducing time to market and lifecycle costs'

Time between 'concept & component' for innovative designs needs to be drastically reduced in the electrical transmission and distribution sector. New modelling methods - from alloy development through manufacture to component validation – help reduce timescales. Similar reductions are needed in planning approval timescales. This issue was addressed in the 2007 Energy White Paper.

There are a wide range of issues relating to

'higher performance in harsher environments'

These include the development and performance of high voltage/high temperature semi-conductor materials through to high strength structural pipelines for onshore and offshore applications that can operate from nearly 100˚C to –250˚C (for liquid hydrogen transportation).

Reliability is a key issue for security of supply both of electricity and oil and gas. Priorities relating to;

improving life management and reliability

which cover how the lifetimes of transmission, distribution and storage plant can be extended if the condition of the facilities can be more effectively monitored. Such 'condition monitoring' helps avoid unscheduled plant closures thereby maintaining reliable operation. Improvements in remote monitoring, non-destructive evaluation (NDE) and more accurate life prediction methods helps achieve this objective. The ultimate long- term goal is for 'intelligent' plant to monitor itself and introduce remedial action to pre-empt failure. This is the basis of 'self-indicating and self-healing structures'.

Key Applied Energy R&D priorities

- Dealing with aging infrastructures: Defining replacement strategies before failure, based on scientific and engineering judgment and knowledge of materials degradation mechanisms facilitating _risk management of existing transmission and distribution infrastructure
- Development of high performance electrical insulation materials
- Development of fault current limiters using advanced materials technologies, e.g. HTS and semiconductors
- Models and tools for condition monitoring. Application technologies for high-voltage, wide-band semiconductors for SmartGrids
- Advanced polymer composites for high and ultra high voltage equipment.
- Materials developments for supercapacitors and batteries for efficient energy storage
- High strength low cost pipelines (Oil&Gas)

Key Fundamental Energy R&D priorities

- Modelling and the design of transmission and distribution materials/multi-materials for harsh environments
- Development of simulation packages to improve prediction of long-term performance of materials (e.g. + 40 years) to ensure reliability and power quality
- Step-change improvements in electrical, as well as thermal and mechanical performance of energy materials
- Advanced NDE and condition monitoring techniques

The main challenges in this area are summarized in Table A9

Annex 1 Technology priorities

Table A9 Top level SRA SRA R&D priorities: **Transmission, Distribution and Storage**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	• Reducing development time for new and improved materials for transmission & distribution • Development of new and more affordable materials for energy storage • Development of lighter weight and smaller components for energy storage	• Development of electrical insulation , (including nanomaterials) and applications methodology for ultra high voltage and microgrid applications • Development of fault current limiters using advanced materials technologies, e.g. HTS and semiconductor • Development of affordable energy storage solutions (bulk and transportable-scale)	• Improvement in electrical as well as thermal and mechanical performance of energy materials • Modelling and characterisation of superconducting components • Understanding and characterisation of advanced composites and nanomaterials for TD&S • Development of SMART Materials	• Development of advanced conductors • materials technologies for energy switching and transformation (e.g. high voltage silicon and silicon carbide)
2. Higher performance in harsher environments	• Development of transmission and distribution materials for use at extremes (e.g. electrical stress and pressure) and for extended lifetimes • Development of lighter weight and smaller components for energy storage and distribution.	• Application technologies for high-voltage, wide-band semiconductors for SmartGrids • Advanced polymer composites for high and ultra high voltage equipment. • Materials for high strength pipelines.	• Lower-cost cryogenic materials and cooling methods • Modelling and the design of transmission and distribution materials/ multi-materials for harsh environments • Development of simulation packages to improve prediction of long-term performance of materials (e.g. + 40 years)	• Self healing materials (including composites) and self indicating materials • High temperature electrical conductors
3. Improved life management and reliability	• Ability to handle aging infrastructure	• Life prediction methodologies development • NDE and condition monitoring methods development	• Modelling and lifetime prediction of future transmission and distribution materials/ multi-materials • Advanced remote condition monitoring tools	

1.5 Energy Conservation- Construction Materials

The SRA has concentrated mainly on the generation, transmission and distribution of energy. Limited work has been carried out by the EMWG in conjunction with the Construction Materials Working Group (CMWG). A summary is presented here which will be developed further by the CMWG in more detail in 2008.

Status

About 40% of all emissions of greenhouse gases are associated with energy use in buildings, typically about 80% from the use of the building and 20% from its construction and demolition. In UK about 60% of those emissions are from housing, largely from space and water heating but also significant amounts from lighting and appliances.

The industry is extremely disparate, with only a very small number of large companies. In 2005 there were 182,644 private contractors on the BERR's register, of which more than 90% of which had 13 of fewer employees, with no one firm having more than a 10% market share.

UK Strengths

The UK construction industry is vast; its output is worth £100bn a year, it accounts for 8% of GDP and employs 2.1 million people. However, buildings are also responsible for almost half the UK carbon emissions, half the water consumption, about one third of the landfill waste and 13% of all materials used in the UK economy.

Expertise

The construction industry influences the UK's energy usage in three ways:

- The energy embodied in construction materials and products,
- The energy used during the construction process and
- The energy used by the users of the buildings

Significant improvements have been made in recent years; the energy consumed by a house built to today's standards is about one-third that of an equivalent house in 1965, but there is still a long way to go. Materials for the construction products industry is at the heart of the UK economy. The industry provides essential materials for our homes, schools, hospitals, factories, offices, roads and railways. Its products are vital to daily life and it makes an essential contribution to the UK economy.
The diverse nature of the construction industry is reflected in terms of the materials that they manufacture and supply, including steel, concrete, tarmac, composites, timber, glass, ceramics and insulation materials. Despite its disparate nature, the value of constructional materials to the UK is reflected in the fact that the UK is the world leader in the application and use of metals in the construction industry.

Materials Challenges

In late 2006 a Code for Sustainable Homes was launched to drive a step-change in sustainable home building practice. It is intended to become the single national standard for home design and construction. The code will complement the system of Energy Performance Certificates being introduced in 2007 under the Energy Performance in Buildings Directorate (EPBD). This has led to many of the materials challenges for the construction sector to be driven by environmental challenges to improve efficiency through the full life cycle and reduce CO_2 impact. The need for

'reducing time to market and lifecycle costs'

is through, for example sustainable manufacturing methods, novel off-site construction methods and use of more recycled materials. As with other sectors, there is a drive for

'improving life management and reliability'

in both new build and refurbishment and 'retrofit' of old buildings to improve their efficiency. There is a need for the construction industry to work closely with electricity suppliers and the grid, to facilitate the intergration, management and deployment of distributed microgeneration systems such as solar thermal, solar pv , micro wind turbines and CHP.

Development of materials systems for enhanced performance is essential as the construction sector moves forward and operation with

'higher performance in harsher environments'

will become more of a requirement, Hence, coatings, novel joining technologies and materials with increased mechanical and thermal properties are needed. Much of this maybe through the adoption of existing technologies from other sectors.

As with most areas, the ability to achieve the above relies on the availability of a suitably trained workforce to address the main drivers of the sector. This in itself is a major issue for the construction materials sector.

Annex 1 Technology priorities

Applied R&D Priorities

A list of common R&D themes with associated materials challenges has emerged:

- Reducing the embodied energy of common construction materials and the raw materials which input into them:
- Alternative fuels in manufacturing processes; lower cost and carbon alternatives to oil and gas.
- Heat recovery and re-use particularly developing practical ways to use lower temperature heat often wasted in common manufacturing processes.
- Increased use of recycled materials. The issue preventing more direct re-use of recycled materials is often quality, so we require better reclamation processes and/or more robust manufacturing processes which can cope with an increased level of contamination from other materials.
- Lower temperature manufacturing processes. Processes more chemical / biological in nature, rather than high temperature melting. The main issues are likely to be the durability of materials manufactured by lower temperature processes and recycling may be more difficult after permanent reactions.
- Processing of input raw materials may also reduce manufacturing energy further down the chain, for example reduced particle size may speed-up / reduce temperatures.
- An obvious point is that an improvement in the basic properties of a material can result in less of it being required which would have a direct effect on embodied energy. For example, stronger glass may allow thinner glass to be used, with lower embodied energy.

- Coatings or more generally Surface Engineering is an important common theme across material sectors and building elements.

- There is a lack of Low Carbon Alternatives for construction materials and systems. These are needed to investigate the relative benefit of potential improvements and to understand the sensitivity of energy/carbon and other environmental aspects to various factors. They should include end-of-life issues and transport (not just to the factory gate) which is important to assess the benefit of off-site construction methods and be easy to use and allow different scenarios to be compared. This is closely linked to Full Lifetime Costing.

Key Fundamental Energy R&D priorities

- Hybrid systems of various materials will be needed and the interfaces between the different materials will be increasingly important, directly in issues such as air-tightness and thermal bridging, but more generally in joining new elements and materials together. Therefore, joining technologies and the more general subject of interfaces between dissimilar materials is an important theme. Recycling of hybrid systems needs to be considered carefully.

- Thermal mass of materials and systems is a common topic of interest when designing sustainable buildings, including the emergence of phase change materials.

- Reliable and more user-friendly models of building performance will be needed to help designers decide between a multitude of options and to help the materials R&D community prioritise improvement projects. Models will need to be validated which may require new measurement methods.

- Step-change pre-competitive research into novel materials that should be undertaken with central because the scale and technical risk are beyond the resources of individual companies or sectors or who may have little incentive to develop disruptive technologies that may nevertheless be vital to the industry as a whole. If the UK does not develop these novel materials, others will.

The main challenges in this area are summarized in **Table A10**

Table A10 Top level SRA R&D priorities: **Housing Construction**

Technology priority areas	The need	Key applied R&D needs (UK can solve)	Key fundamental R&D needs (UK can solve)	Key R&D for external (need for collaboration outside UK)
1. Reducing time to market and life cycle costs	• Reducing embodied energy of construction materials	• Development and use of recyclable materials without penalty to properties • Lower temperature manufacturing process development	• Development of advanced reclamation processes • Chemical/biological process development	
2. Higher performance in harsher environments	• Development of materials systems for enhanced performance	• Coatings development for improved performance and protection • New joining technologies of materials to allow for lower consumption	• Phase change materials with designed thermal mass • SMART coatings • Hybrid systems and their recycling	
3. Improved life management and reliability	• Ability to handle aging infrastructure and predict performance of new-build	• Condition monitoring of buildings (inbuilt sensors), SMART structures	• Modelling and lifetime prediction of buildings and their performance • Advanced remote condition monitoring tools	

Annex 2 Energy materials

Materials UK (MatUK) Energy materials working group

STRUCTURE AND TERMS OF REFERENCE

1. Objective

Reporting into MatUK, the remit of the Energy Materials Working Group is to develop a Strategic Research Agenda and Deployment Plan for the UK Materials supply chain which will improve profitability in the sector whilst meeting the key energy-related challenges of sustainability, environment and security of supply facing the UK. This should encompass the following scope:

- Power generation (conventional, nuclear and alternative energy sources)
- Transmission & distribution
- Energy Storage
- Efficiency (conservation-initially housing)

This should be achieved by:

a) Accounting for the 2006 Energy Review and 2007 Energy White Paper and looking ahead over a 5, 10 & 20 year horizon, defining the key materials research and development requirements for the Energy Sector.

b) Identifying key strengths, gaps and opportunities for the UK materials supply chain to generate significant new business over the aforementioned timescales

c) Accounting for likely policy, legislative, training and skills impact on the sector to feed into other existing MatUK working Groups

d) Accounting for, consulting with and informing existing National (and European) materials groups involved in the sector; including industrial, governmental, academic, NGO's, research councils and funding agencies.

e) Promoting the formation of a UK Innovation Platform on Materials

2. Scope

Whilst recognising that the transport sector has a major impact on both energy usage and CO_2 emissions, the scope of this Group will initially exclude this sector from its scope as, in particular, the aerospace and automotive sectors are being, or have been covered within other Groups. However, it is intended to recognise the output of these Groups and liaise with them where necessary.

With the above exception, the scope of the Energy Working Group will cover major sectors involved in energy production, transmission, distribution, storage and usage.

3. Structure

The overall structure and responsibilities are shown in figure 1.

a) The Group will comprise an Advisory Committee consisting of industrial representatives of the full materials supply chain from producers to end-users. It will also include RDA's, RTO's academics and research councils and government agencies

Additional organisations will be invited to join as deemed necessary by the Committee to form a balanced sector view.

b) Task Groups will be set up to tackle specific issues or technology areas as required. Task-group membership will be open to any stakeholder or individual experts who can make a useful contribution. The initial proposed Task Groups are shown in Fig 1. These will comprise a chairman or co-chairmen (who ideally will be a member of the Advisory Committee) and typically up to six additional experts in the relevant field. Their remit and scope will be set by the Advisory Committee. (For the remit/scope of the initial Task Groups see Annex 1)

4. Organisation

d) The Energy Materials Working Group Advisory Committee will be co-chaired by Derek Allen (Alstom Power) and Steve Garwood (Rolls-Royce plc).

e) The secretariat will be supplied by BERR

f) The Group will report into the Executive Committee of Materials UK through the co-chairs, but will also have the freedom to act upon its own initiatives where and when appropriate, particularly in the implementation phase.

g) It is anticipated that the Group will have an initial lifespan of 2 years

5. Deliverables

1. A Strategic Research Agenda (SRA) for energy materials which defines the drivers, barriers and roadmap for R&D over the next 20 years

2. A Deployment Plan which indicates how the SRA will be implemented and impact on the UK materials industry.

This will be formally presented through MatUK to key stakeholders of Government officials, Research Councils, RDA's and the Technology Strategy Board to develop an agreed, long term, sustainable Energy Materials Research Programme for the UK.

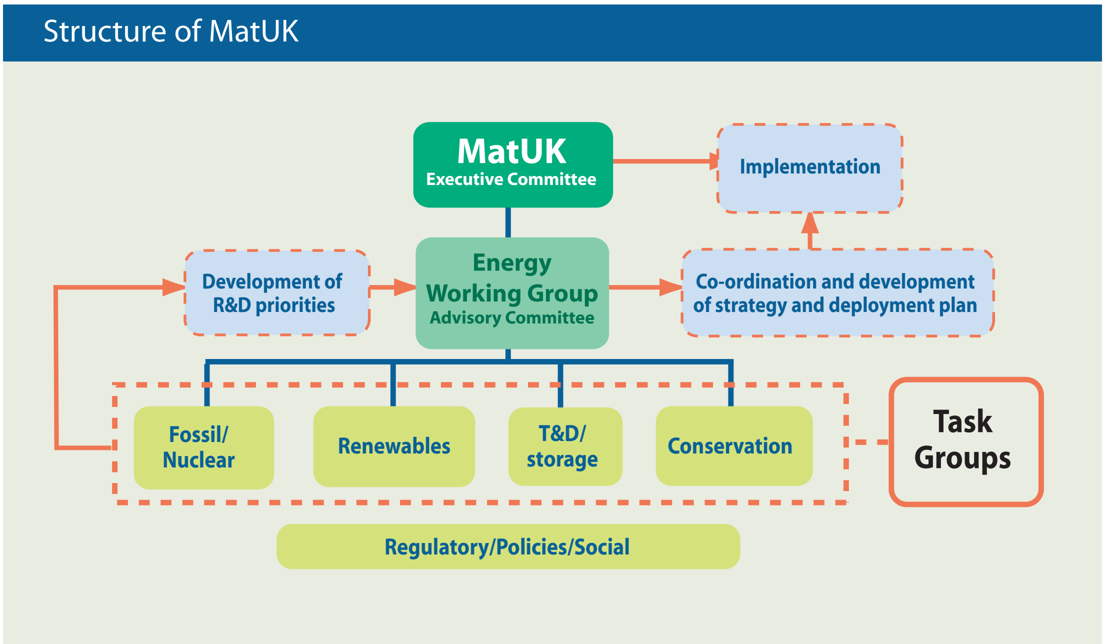


Fig 1
Structure of the Energy Materials Working Group

6. Dissemination

1. Dissemination to the wider community will be through communication routes including:-

a. MatUK and the materials KTN's and their associated websites

b. The newly announced Energy Technology Institute

c. The Institute IoM3 Journal and the recently launched 'Energy Materials' Journal

d. Town meetings

e. Appropriate conferences and meetings

Annex 2 Energy materials

REMIT AND SCOPE OF TASK GROUPS

1. Task Groups (TG)

Task Groups will be set up by the Advisory Committee to take up specific 'time-limited' activities with clear deliverables related to the work of the Group. Task-group membership will be open to any stakeholder or individual experts who can make a useful contribution. The Task Groups will comprise a chairman or co-chairmen (who ideally will be a member of the Advisory Group) and a core team of experts in the relevant field.

Initially, four TGs will be established to develop an R&D roadmap for Energy Materials in the UK covering

- Current status/value to the UK
- SWOT analysis
- Drivers
- R&D needs
- Barriers
- Recommendations

The initial four TG's are:-

TG 1. Power Generation (Fossil & Nuclear):

Co-chairs C. Small, Rolls Royce plc, G. Smith, Oxford University

This will include materials issues related to the following:

- Gas, oil and coal fired power plant
- Nuclear (fission and fusion)power plant
- CO_2 capture technologies

TG 2. Power Generation (Alternative Energy Supplies):

Co-Chairs J. Oakey, Cranfield University, C. Bagley, TWI

This will include materials issues related to the following:-

- Biomass, waste and co-firing
- Solar
- Wind
- Wave & tidal
- Fuel cells
- Hydrogen

TG 3. Energy Transmission, Distribution and Storage:

Co-chairs Z. Melham, Oxford Instruments, A. Hyde, Areva

This will include materials issues related to the following:

- The transmission and distribution of energy and fuels including electricity, gas and oil including networking issues.
- Storage issues associated with oil, gas, CO_2, hydrogen and electricity
- Issues associated with transportation of fuels
- Specific issues associated with distributed power

TG 4. Energy Conservation:

Chairs P. Ramsey, Pilkington through chair of Construction Materials Working Group

In the first instance this will only include materials issues related to the following:

- The built environment

It is envisaged that generic topics such as :

- Regulatory, legislative and policy considerations which may affect the energy materials supply chain including environmental legislation and raw materials supply
- Socio-economic aspects relating to the usage of energy and how these impact on the Sector and materials in particular.
- Regional strengths, opportunities and issues.
- Training & Skills (specific to Energy Materials only)

will be captured and then shared with other relevant Working Groups of MatUK through a common representation on both Groups.

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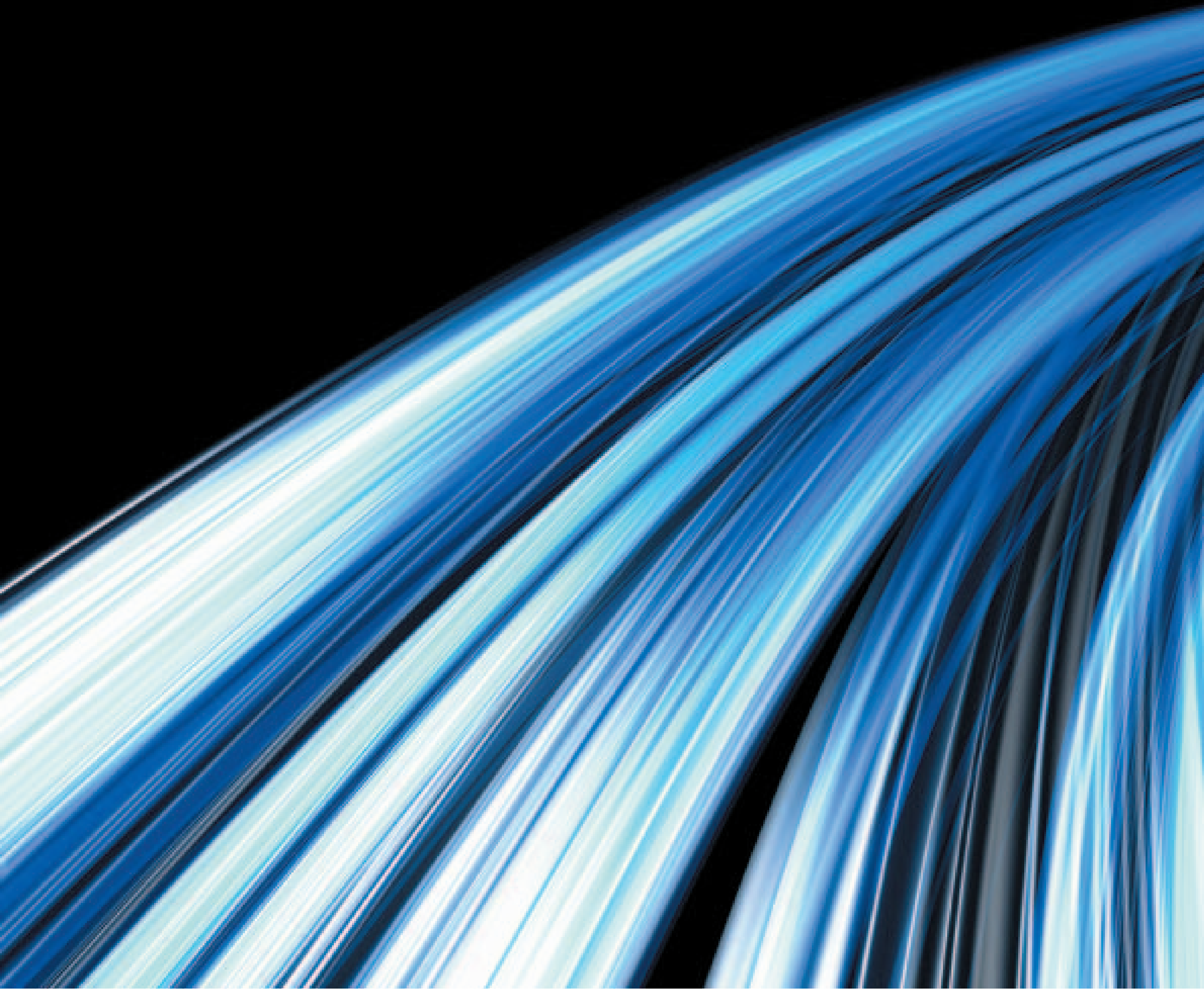

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