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Enabling technologies for industrial energy demand management ☆

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ABSTRACT

This state-of-science review sets out to provide an indicative assessment of enabling technologies for reducing UK industrial energy demand and carbon emissions to 2050. In the short term, i.e. the period that will rely on current or existing technologies, the road map and priorities are clear. A variety of available technologies will lead to energy demand reduction in industrial processes, boiler operation, compressed air usage, electric motor efficiency, heating and lighting, and ancillary uses such as transport. The prospects for the commercial exploitation of innovative technologies by the middle of the 21st century are more speculative. Emphasis is therefore placed on the range of technology assessment methods that are likely to provide policy makers with a guide to progress in the development of high-temperature processes, improved materials, process integration and intensification, and improved industrial process control and monitoring. Key among the appraisal methods applicable to the energy sector is thermodynamic analysis, making use of energy, exergy and 'exergoeconomic' techniques. Technical and economic barriers will limit the improvement potential to perhaps a 30% cut in industrial energy use, which would make a significant contribution to reducing energy demand and carbon emissions in UK industry. Non-technological drivers for, and barriers to, the take-up of innovative, low-carbon energy technologies for industry are also outlined.

1. Introduction

1.1. Background

The 2007 Energy White Paper (Department of Trade and Industry, 2007) accepted that Britain should put itself on a path to achieve significant carbon reductions, mainly by adopting a range of energy efficiency measures and renewable energy technologies. Techniques for carbon capture and storage (or 'carbon sequestration') were also identified as an important element in any energy research, development and demonstration (RD&D) programme. Targets for new renewable electricity supply were set at 10% by 2010 and 20% by 2020. It is going to be difficult for renewables (principally wind power) to fill the 'electricity gap'. The UK Government is supportive of building a new generation of nuclear reactors to replace those currently undergoing, or approaching, decommissioning (Department of Trade and Industry, 2007). This, together with carbon capture and storage technologies and an increased reliance on imported natural gas for combined cycle gas turbine plants, might represent the future of the electricity supply side.

Carbon dioxide (CO_2) accounts for some 80% of the total greenhouse gas emissions in the UK (Department of Trade and Industry, 2000). On the supply side, the energy sector is responsible for around 95% of these emissions, whereas on the demand side the industrial sector accounts for around 30%. The switch from coal to natural gas stimulated by energy market liberalisation has had a favourable, but relatively short term, effect on greenhouse gas emissions. Consequently, the legally binding post-Kyoto EU target of reducing a basket of greenhouse gases to 12.5% below 1990 levels over the period 2008–2012 will require only modest governmental intervention, over and above falls in emissions stimulated by energy market liberalisation. But the UK adopted a tighter 'domestic' goal in 1997 aimed at a 20% cut in CO_2 emissions below 1990 levels by 2010. Recent trends in national CO_2 emissions indicate that it is unlikely that this national target will be met, and this has recently been recognised by the UK Government. However, in the medium term, even greater carbon reductions will be required in order to stabilise the global climate system. The Royal Commission on Environmental Pollution (2000), for example, has argued that the UK should take the lead, by adopting a target of reducing CO_2 emissions by some 60% from 1997 levels by about 2050. The UK Government is presently committed, through its 2007 Energy White Paper, to developing a sustainable energy economy in the 21st century and

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to taking a lead in reducing CO_2 emissions among the industrialised countries (i.e. those of the Organisation for Economic Co-operation and Development). An aspirational target of reducing these emissions to 60% of their existing figure by 2050 has been adopted in line with the Royal Commission on Environmental Pollution recommendation. The only way in which this fall could be achieved is by significantly reducing primary energy consumption to 45–75% of the present demand (Hammond, 2003), depending on the energy technology mix (fossil fuels, nuclear power or renewable energy technologies). This requires the widespread adoption of energy-saving measures across the economy that, in turn, would necessitate action by many individual stakeholders.

It is in this context that this state-of-science review sets out to provide an indicative assessment of enabling technologies for reducing UK industrial energy demand and carbon emissions out to 2050. In the short term, during the period that will rely on the adoption of current or existing technologies, the road map and priorities are relatively clear. But the prospects for the commercial exploitation of innovative technologies by the middle of the 21st century are highly speculative. Emphasis is therefore laid on the range of technology assessment methods that are likely to provide policy makers with a guide to the potential for improvements. Key among the appraisal methods applicable to the energy sector is thermodynamic analysis: energy, exergy and 'exergoeconomic' techniques. They provide an indication of the maximum improvement potential available from different enabling technologies. These approaches are supplemented by useful techniques such as environmental life-cycle assessment (LCA), environmental cost–benefit analysis and the generation of cost curves.

1.2. Character of the industrial sector

The industrial sector in the UK is the only one that has experienced a significant fall of roughly 40% in final energy demand since the first oil price shock of 1973/1974 (see Fig. 1). This was in spite of a rise of over 40% in industrial output in 'value added' terms. However, the consequent aggregate reduction in energy intensity (MJ/£ of gross value added) masks different underlying causes:

- *End-use efficiency*: It has been estimated (Engineering Council, 1998) that around 80% of the fall in industrial energy intensity between 1965 and 1995 was induced by the price mechanism.

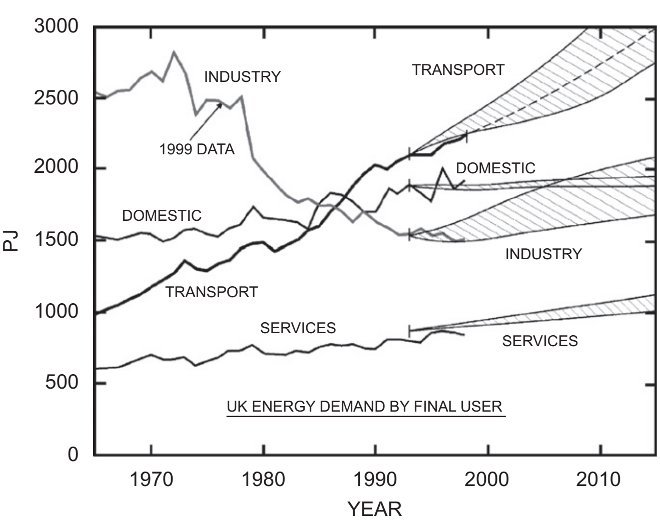

Fig. 1. UK energy consumption by final-user sectors: *hatched area*, EP65 projections (Hammond, 2000).

- *Structural changes in industry*: The relative size of the industrial sector has shrunk, with a move away from heavy industries (Hammond, 1998), particularly in manufacturing and mining, as well as the adoption of more energy-efficient technologies (like electric arc processing). Many industrial sub-sectors have undergone major rationalisations, thus enabling significant energetic and financial economies of scale.
- *Fuel switching*: Coal use in UK industry has declined steadily since the early 1960s in favour of 'cleaner' fuel (Hammond, 1998; Hammond and Stapleton, 2001). Oil use also fell rapidly from 1973 onwards, with a couple of step changes associated with the two price hikes in the early 1970s and early 1980s (see Fig. 1). Both natural gas and electricity consumption increased to market shares of some 25% and 33%, respectively. They are cleaner, more readily controllable and, arguably, cheaper for the business concerned.

The industrial sector is very diverse in terms of manufacturing processes, ranging from highly energy-intensive steel production and petrochemicals processing to low-energy electronics fabrication. Whereas the former typically employs large quantities of (often high-temperature) process energy, the latter tends to be dominated by energy uses associated with space heating. Future Energy Solutions and the Carbon Consortium (2005) identified around 350 separate combinations of sub-sectors, devices and technologies in their recent study of the potential for carbon reduction from UK industry. Each combination offers quite different prospects for energy efficiency improvements and carbon reductions, which are strongly dependent on the specific technological applications. This large variation across industry does not facilitate a cross-cutting, 'one size fits all' approach to the adaptation of new technologies in order to reduce energy demand, but, rather, requires tailored solutions for separate industries. Conversely, certain behavioural or good-practice measures are suitable for adoption across the board precisely because of their explicit independence from the type of technology employed.

In the period up to 2030, the European Commission expects that the EU25 economy will continue to be more focused towards 'high value added' products, which are less material- and energy-intensive, as well as undergoing restructuring in favour of services (European Commission, 2002). It believes that the potential for reducing CO_2 emissions emanating from industry is likely to be limited. Others take a more optimistic view: see, for example, Hammond and Stapleton (2001) and von Weizsacker et al. (1999). Best available electrical technologies and heat pumps have been proposed by the Commission as attractive and cost-effective options, while acknowledging that this will incur additional costs over and above the baseline scenario out to 2010; perhaps 14–30% for energy-intensive industries and 9–21% for others.

2. Technology assessment techniques

2.1. Integrated appraisal of energy systems

Methods for the appraisal of industrial energy systems and their environmental valuation play an important role in the context of sustainability assessment. They are at the heart of methods for quantifying economic and social costs and benefits, as well as the direct ecological impacts that are an inevitable side effects of material 'progress'. Concepts such as the physical life cycle of products and processes (Azapagic et al., 2004; Burrows et al., 1998), and the need for clearly defined system boundaries, are key elements in environmental problem solving. However, some economists would claim that methods from their 'normative' discipline can be extended to incorporate all of society's