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Combined heat and power in industry and buildings ☆

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ABSTRACT

Combined heat and power (CHP) has huge potential to deliver energy savings and emissions reductions, and in many cases cost reductions too. But the market and regulatory framework is the key to delivering large-scale installations, and government has a poor record in delivering an appropriate framework.

Technology is central to the future competitiveness and therefore uptake of CHP. It could lead to more efficient CHP electricity generation, permit the use of lower-carbon, renewable fuels, and enable the development of new products for new end uses, including micro-CHP and CHP in heat networks. The market for CHP has been difficult in the past few years, largely as a result of government market reforms. The UK's level of CHP skills, for installing current technologies and developing new ones, is low. The key issue is the creation of the right market framework to deliver CHP, and part of this is support for the energy services approach.

1. Introduction

Combined heat and power (CHP) is the simultaneous generation of usable heat and power, usually electricity, in a single process. The term CHP is synonymous with cogeneration, a term often used in other Member States of the European Community and the USA. CHP can use a variety of fuels and technologies across a wide range of sites and sizes of scheme. The basic elements of a CHP plant comprise one or more prime movers (a reciprocating engine, gas turbine, or steam turbine) driving electrical generators. The steam or hot water generated by this process is used in industrial processes or for space and water heating. CHP is typically sized to make use of the available heat produced in the process of generating electricity (BERR, 2007).

CHP is typically connected to the lower voltage distribution system ('embedded'). As well as reducing losses in transmission and distribution, it can provide important network services such as black start when the electricity networks go down, improvements to power quality, and the ability to operate in island mode if the grid goes down.

1.1. Existing CHP capacity

According to the *Digest of UK Energy Statistics*, UK CHP capacity has almost doubled in the past 10 years, with around 6000 MWe (megawatts of electricity generating capacity) currently installed on around 1500 sites (BERR, 2007). Much of this capacity is on large industrial sites providing process heat at high temperature for refining, chemicals and paper production, food processing and similar uses, often operating continuously for over 8000 h per year. CHP in buildings accounts for 71% of the sites, but only 6% of the capacity. In 2006, CHP provided around 7% of the total electricity generated in the UK. Across the commercial and industrial sectors, electrical output from CHP accounted for around 12% of electricity consumption (BERR, 2007).

1.2. The potential for CHP

There are a wide number of studies of the potential for CHP in different applications, and using different economic assumptions.

In 1997, ETSU estimated the potential for CHP in 2010 at 10,000–17,000 MWe (ETSU, 1997). Cambridge Econometrics' projection for 2010 was 6600 MWe rising to 8600 MWe by 2020, although this modelling did not include the larger CHP opportunities, and excluded many policy drivers (Forum for the Future and Cambridge Econometrics, 2000). Defra has estimated the potential to be 10,000–12,000 MWe (Defra, 2007).

District heating with CHP serves less than 0.1% of UK households. However, in the original 15 countries of the EU, 23 million people live in homes served by district heating. In Finland and Denmark around half the population live in schemes served by district heating. The potential for CHP in community heating is

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very sensitive to assumptions. The UK potential has been estimated at less than 1000 MW or more than 18,000 MW, depending particularly on discount rates (BRE, 2003). Up to 20% of UK homes could be served by community heating, with 27% of the potential in London, and 66% in half a dozen major cities. The Department of Energy 'Energy Paper' series explored the theme several times. Energy papers 20 (DEn, 1977), number 35 (DEn, 1979), and number 53 (DEn, 1984) together identified significant potential in nine major conurbations. The Greater London Authority is making efforts to develop community heating systems (GLA, 2006).

The potential for micro-CHP has been estimated to be around 12 million homes in the UK (FaberMaunsell, 2002). There may be little overlap between this and community heating, which is a dense urban technology while micro-CHP is a suburban technology, suited to locations where density is too low to make a heat network cost-effective. The potential for both technologies interacts with a range of other microgeneration opportunities (BERR, 2005).

The potential for biomass heat-only plant and for larger CHP applications has been explored by Bauen et al. (2004), RCEP (2004), Carbon Trust (2005) and E4Tech (2003). The potential for energy from waste in large CHP applications is separate and additional (ICE & RPA, 2005).

An EU-scale study (ESD et al., 2001) suggested a CHP potential of 7500–27,200 MWe for the UK and 107,000–252,000 MWe for the EU25 countries across four policy scenarios for all types of CHP, including industrial, district heating and micro-CHP.

A number of issues can affect decisions to invest in CHP. They can include government policy towards climate change and carbon emissions, energy policy including trading arrangements, planning and power station consents policy, and fiscal incentives.

The wide range of figures for the UK's CHP potential reflects a range of different views of the future. The studies use a range of possible values for the cost of carbon, carbon reduction targets, future energy prices and discount rates. These are affected by the policy environment, the commercial environment, perceptions of risk, and the cost of money.

2. The role of technology

In the long term, technological change will influence the amount of CHP installed.

Its first role is to improve the efficiency of electricity generation. CHP uses the waste heat from the generation of electricity to supply process or space and water heating needs. The energy used, and thus the costs and the carbon savings, are principally dependent on electrical efficiency, because central electricity generation is so inefficient, and secondarily on improved heat recovery. This means that any improvement in the efficiency of electrical generators, especially small ones, benefits CHP as well as conventional power generation. In contrast, the ability to maximise the recovery of heat is principally driven by site-specific issues, the correct sizing of plant to the heat demands of a specific site, and operational regimes. It is optimised by good practice rather than by technology.

Technology can also allow lower-carbon and renewable fuels to be used, enabling CHP to benefit from incentives for renewables. It can also permit the development of new products for new end uses, especially small applications.

These three themes are now explored. It is worth bearing in mind that CHP is a global technology and much of the technology development is international. At the EU level, the CHAPNET website is intended to build a critical mass of knowledge, expertise and strategic direction on CHP research, technology and demonstration in Europe with a vision of 20 years in the future. The International Energy Agency (IEA) has also been active in the field, as has the US Department of Energy.

2.1. *Improvements in electrical efficiency*

Engines can use internal or external combustion. Internal combustion or conversion devices include reciprocating engines, gas turbines and fuel cells. Other prime mover technologies can use a combustion of solids or liquids in conventional boilers based outside the device, and use hot gases or steam to generate power. They include steam turbines, Stirling engines, and Organic Rankine Cycle engines.

2.1.1. *Combined cycle gas turbines*

Combined cycle gas turbines (gas turbines where the hot gas exhaust is used to produce steam to drive a steam turbine) are more efficient than a steam or gas turbine operating alone. Combined cycle technologies accounted for two-thirds of UK CHP electrical capacity in 2006 (BERR, 2007), and could account for a significant portion of the growth in CHP, especially on industrial sites, including those which currently operate steam-cycle or open-cycle gas turbine CHP. Electrical power efficiencies of up to 50–56% (HHV[1]) are claimed, but are yet to be proven on a year-round basis under normal power station operating conditions. Improvements in combined cycle operation, and the development of smaller units (displacing open-cycle gas turbines, steam-cycle or reciprocating engines), would improve the efficiency of CHP.

2.1.2. *Fuel cells, including in combined cycle systems*

Fuel cells are a valuable technology for CHP at a number of scales from the kilowatt level up to tens of megawatts. On a large scale, they may be used in combined cycle with gas turbines, or with steam turbines where the fuel source could be natural gas, biomass, or coal after gasification. Each combustion technology operates at a given temperature, and emits exhaust gases and, in some cases, partially combusted fuel. By making the output from one device the input to another one, system efficiency can be optimised at a higher level than for any individual component operating alone. Theoretical electrical power efficiencies of 58–67% are claimed for a range of fuel cell technologies in a range of combinations, from a few hundred kilowatts to tens of megawatts (see, for example, Rath et al., 1995). The combination of components and their optimisation in different systems at different scales under different operating conditions is a key area for research.

Fuel cells can also be used at very small scale, for example at the 1 kW level. This technology is reportedly close to market, with British Gas securing 37,500 units from Ceres Power over the four-year period from 2011 (Ceres Power, 2008).

2.2. *Alternative fuels*

Around a fifth of the fuel used in CHP is already classified as non-conventional. Much of this is the by-product of industrial processes. There is good potential for industrial sites to produce more non-conventional fuels, especially biofuels and fuels derived from waste. Routes to lower-carbon CHP include:

- Digestion, pyrolysis or gasification of solid or liquid biomass fuels to burn in internal combustion engines or for use in fuel

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[1] HHV means higher heat value. UK Energy Statistics are reported on a HHV basis, whereas power station efficiencies are often claimed by manufacturers on a lower heat value (LHV) basis. The lower heat value ignores fuel used to evaporate water from combustion products, and, in ignoring this fuel, achieves a higher claimed efficiency. So a HHV of 51% equates to a LHV of 56%.

cells. This is an area of international work at IEA level (see IEA website). The digestion of farm or food wastes is under development. A wide range of substances including many components of household waste can be pyrolysed (heated to high temperatures and pressure in the absence of oxygen, which gives off a combustible gas). Gasification is seen as a viable route for woodchips or other solid biofuels. These technologies are easiest at a large scale of at least 1 MW. Smaller-scale devices pose difficulties in maintaining reliability and efficiency at a reasonable cost.
- Attempting to get solids to behave like gases, with fluidised bed combustion and some turbine developments. This allows the use of fuels other than gas.
- Development and commercialisation of smaller external combustion engines which can utilise biomass or other low-carbon fuels. There are a number of these in the early stages of commercialisation (Talbotts websites; Bios Bioenergiesysteme GmbH websites).
- Use of solar energy. By concentrating solar radiation on a device and creating a hot working fluid, a steam turbine or impulse reaction turbine can generate power, while the heat can be used for other processes (Cogen Europe, 2004).

Digestion, pyrolysis and gasification for internal combustion processes achieve higher electrical efficiencies (25–35%) than external combustion engines (10–20%). However, the smaller external combustion engine may prove to be more reliable at a smaller scale, perhaps below 500 kW. The UK Biomass Energy Centre has produced a useful overview of technologies, projects, and web links (UK Biomass Energy Centre website), and OPET has done much to publicise research technology and demonstration across Europe (OPET, 2004). Much of the experience is Nordic or Austrian.

2.3. *Improvements in particular applications*

2.3.1. *Mini- and micro-CHP*

Micro-CHP is taken to mean technologies which could serve a single dwelling. There is no agreed size limit but 10 kW of electrical power might be appropriate. Mini-CHP is taken to be in the range of a few kilowatts to 100 kW and may serve a group of dwellings or a commercial site. Technologies appropriate to this scale include Stirling engines, reciprocating engines and fuel cells. Micro-CHP technologies are already commercially available in the UK.[2] Smaller engines have been close to market for a number of years, but are yet to be launched in a significant way.

A range of issues need investigation including:

- Improvements to the electrical efficiency of the prime mover. At present there is little incentive to export electricity from a CHP installation, so there is little commercial incentive to improve electrical efficiency. Improving generating efficiency is important for improving environmental performance.
- Improvements to the operating strategy of the device. This can be done to optimise its lifetime, for example by minimising the number of use cycles for many technologies including fuel cells, and to optimise economic and environmental benefit. Most CHP is currently heat-led, so that it is only run when there is a use for the heat, and the electricity is a by-product. There is tension between these operational criteria. Striking the best balance is an iterative process and could involve the incorporation of heat storage or the use of some heat-only operation.
- Improvements to the economics of the product by reducing the cost of the device, through value engineering, economies of scale, and reducing commercial and regulatory risks and uncertainties.
- The infrastructure for selling, installing and maintaining micro-CHP, possibly as part of an energy services package, is still to be developed.

2.3.2. *Heat network-based CHP*

CHP can serve individual dwellings, or a larger group of buildings via a heat network. District heating is a common approach in northern and central Europe, where it often serves more than 50% of homes. A key issue for policy and for developers is when an individual building solution is appropriate, and when a larger community solution with a heat network is the right choice. Current understanding (based on FaberMaunsell, 2002 and BRE, 2003) is that heat networks are a solution appropriate to dense urban areas, and micro-CHP is a suburban technology more at home in semi-detached and detached homes. Given the wider European interest in district solutions, there is much research at the IEA level.[3]

2.3.3. *Distributed generation issues*

CHP is most environmentally beneficial when heat generated is utilised on site. This means that devices need to be sized to avoid producing more heat than is needed. This implies that for large-scale uptake devices need to be embedded in the electrical network, close to heat users. Research to enable embedded generation is under way by BERR. It will include new ways of analysing the industry, changes to electrical network design, changed systems of connecting new generation, and new payment mechanisms. The internet is likely to play an important role (BERR website).

2.4. *Capabilities assessment*

Innovative CHP skills are in short supply in the UK. There was an exodus of skilled people from the CHP industry in 2001, caused by the introduction of new electricity trading arrangements, falling electricity prices, and high gas prices. With little in the way of new installations, few resources are going into new technologies, either in commercial organisations or in universities.

There are a few exceptions. The UK has an interest in the emerging fuel cell market. Imperial College and its spin-out company, Ceres Power, is one example of successful innovation. However, UK resources are dwarfed by US and Japanese efforts. The abandoning of MicroGen by BG Group is another indicator of a struggling market. More conventional power generating technologies are dominated by international names such as ABB (Swedish and Swiss in origin), Siemens (German), and GE (USA), although Rolls-Royce of the UK is also a player in this market. Smaller devices do not yet have dominant market players in the UK or elsewhere.

3. The role of policy

Having the right technology at the right price is not sufficient to ensure that efficient or low-carbon solutions are adopted.

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[2] Engines from 5–30 kW are available from Baxi Dachs http://www.baxitech.co.uk/, http://www.ecpower.co.uk/, and http://www.energ.co.uk/.

[3] See http://www.iea-dhc.org/0106.html, which has in recent years explored benefits of large versus smaller schemes, optimising efficiency (heat storage and transport), materials and construction (http://www.iea-dhc.org/0199.html) and district cooling through absorption refrigeration and ice storage (http://www.iea-dhc.org/0105.html).

Far from it. The uptake of a technology is strongly dependent on the policy and market framework. Innovation theory has much to say on how markets can be transformed towards low carbon (Hinnells and Boardman, 2008). Yet there is more to be understood, particularly in the complex domain of CHP. In addition to technology-based R&D, a range of further work is needed on how innovation happens and how costs are reduced with increasing uptake (technology learning or learning curves). This would help to drive policy in the right direction, for policy clearly has an important role.

Energy policy focuses on security, diversity, sustainability and affordability. CHP contributes to many of these objectives through improved efficiency of fuel use. In particular, a CHP plant provides primary energy savings compared to the separate generation of heat and power. CHP typically saves around 500,000–760,000 tonnes of carbon per 1000 MWe installed capacity, based on DTI methodology and compared to equivalent conventional plant (BERR, 2007). With a strong energy policy framework, and climate change concern, CHP should be prospering.

While CHP entails higher capital costs than separate sources, it is more energy efficient than the separate generation of heat and power. Savings in energy and money mean that, in many applications, higher capital costs can be paid back over time, depending on assumptions about future energy prices and the cost of borrowing. Energy prices include the relative cost of fuel (principally natural gas) and the value that can be realised for electricity, especially if it is exported back to the network. The difference between the price of electricity and the price of gas required to generate that electricity is known as the ‘spark spread’. This represents the revenue available to finance annual fixed costs, capital costs, investment and profits and needs to be high enough to incentivise new CHP build.

Energy price considerations vary for schemes of different sizes and in different industries. In recent years, rising gas prices and competitive electricity prices have meant that the spark spread has been regarded as too small to provide an adequate return on investment, especially compared to other calls on capital in industry, commerce, and the public sector. Many, but not all, energy-intensive industrial sites already have some CHP capacity. A good portion of the remaining market is for smaller industrial, commercial and private buildings, where complex energy management decisions are less easily handled.

CHP is a complex investment, requiring power generation capacity to be installed where users are more used to seeing simpler heat generating capacity. Heat users are concerned about increasing cost, complexity and risk. Power generators do not want to build and manage many small projects on heat users’ sites, preferring to build one large central plant on their own sites. Often, the solution is an energy services arrangement, where the generator can offer some combination of design, build, finance, operation, and maintenance of CHP plant, providing heat and power to the host site or to a community. For businesses, this enables the host company to concentrate on its core business, to divest itself of the risk associated with trading in the energy market, and to use off-balance sheet financing for the project.

In this complex and uncertain world, a clear market framework is needed to drive investment if it is desirable for energy policy reasons. Since 1997 the present government has had a target of 10,000 MWe of CHP capacity by 2010. It outlined a series of support measures in its CHP strategy (Defra, 2004). They have included exemption from the Climate Change Levy, eligibility for Enhanced Capital Allowances, and promotion through the Carbon Trust. However, it has been obvious since 2000 that the 10,000 MW target is extremely unlikely to be met. The positive effect of some policy measures has been outweighed by other market reforms which have been damaging, including the effects of new trading arrangements for electricity in 2001, and the failure to operate a clear power station consents policy favouring CHP and renewables since 1999. Industry has had little confidence in the policy framework surrounding CHP and is reluctant to invest. This situation will take a lot to turn round, and there is little sign of the political will to do this.

In terms of sustainable energy policy, CHP is a Cinderella technology, and is a victim of the division in energy policy between UK Government departments. BERR (Department for Business, Enterprise, and Regulatory Reform) leads on energy policy matters, including the regulation of the energy market, planning consent for new projects, renewables and new technologies. Energy-efficiency policy has been split between BERR and Defra (the Department for Environment, Food and Rural Affairs). CHP has been classified as an energy-efficiency issue, putting Defra in the lead. Technologies which are clearly in the domain of BERR have prospered, such as renewables and microgeneration, while CHP has seen much political posturing (including commitments to 10,000 MW targets in three successive election manifestos) which has not translated into policy measures to transform the market.

These targets predate current plans for emissions reductions laid out in the UK Climate Change Bill. In addition, CHP is disadvantaged because the UK has had an electricity policy for many years, but not a heat policy. While Ofgem regulates gas and electricity, heat is not seen as a market, so its regulation and incentivisation have not been on Ofgem’s or the Government’s policy agenda. With the recent BERR call for evidence on heat (BERR, 2008), there are signs that this may change. A strong carbon market and a heat market may mean a clearer set of incentives for CHP. The key issue is the creation of the right market framework to deliver CHP, and part of this is support for the Energy Services approach (DEFRA (website)).

4. Conclusions

CHP has a huge potential to deliver energy savings and thus cost and emissions reductions. The extent of the potential is strongly dependent on a range of assumptions. Technology has a key role to play in the future competitiveness and therefore uptake of CHP through

- improving the efficiency of generation of electricity,
- using lower-carbon, renewable fuels,
- development of new products for new end-uses, including micro-CHP and CHP in heat networks.

The level of skills (both in terms of installing current technologies and developing new ones) in the UK is low, following a difficult market for CHP over the last few years as a result of Government market reforms. The market and regulatory framework is the key to delivering large-scale installations in the first instance, though to date Government has a poor record in delivering an appropriate framework. This may change if carbon, and heat, become effective market in the UK.

References

Bauen, A., Woods, J., Hailes, R., 2004. Biopowerswitch. Prepared for World Wildlife Fund International and Aebiom. 〈http://assets.panda.org/downloads/biomassreportfinal.pdf〉 (accessed 24 March 2008).

BERR, 2005. Potential for Microgeneration: Study and Analysis. Final Report to BERR. Produced by Element Energy and EConnect, with Energy Saving Trust, for Department for Business, Enterprise and Regulatory Reform, London, 14 November 2005. 〈http://www.berr.gov.uk/files/file27559.pdf〉.

BERR, 2007. Digest of UK Energy Statistics. Department for Business Enterprise and Regulatory Reform, London. 〈http://stats.berr.gov.uk/energystats/dukes07_c6.pdf〉 (accessed 24 March 2008).

BERR, 2008. Heat Call for Evidence. Department for Business, Enterprise and Regulatory Reform, London. 〈http://www.berr.gov.uk/files/file43609.pdf〉.

BERR (website) Department for Business, Enterprise and Regulatory Reform, London, publications page. 〈http://www.berr.gov.uk/energy/sources/renewables/publications/page24046.html〉 (accessed 24 March 2008).

Bios Bioenergiesysteme GmbH website. 〈http://www.bios-bioenergy.at/en/electricity-from-biomass/stirling-engine.html〉 (accessed 24 March 2008).

BRE, 2003. The UK Potential for Community Heating with Combined Heat & Power. Client report number: 211-533. Prepared for The Carbon Trust, 21 February 2003. 〈http://www.energysavingtrust.org.uk/uploads/documents/housingbuildings/UK%20CH%20potential%20report_CTFinal.pdf〉 (accessed 24 March 2008).

Carbon Trust, 2005. Biomass Sector Review for the Carbon Trust, London, undertaken by Paul Arwas Associates. 〈http://www.carbontrust.co.uk/PublicSites/cScape.CT.PublicationsOrdering/Templates/PublicationsDetail.aspx?NRMODE=Published&NRNODEGUID=%7bCBCC6FEB-C3D5-45F2-9E8E-BC368A8E3638%7d&NRORIGINALURL=%2fPublications%2fpublicationdetail%2ehtm%3fproductid%3dCTC512NRCACHEHINT=Guest&productid=CTC512〉 (accessed 24 March 2008).

Ceres Power, 2008. Ceres Power and British Gas enter development, supply and distribution agreement for UK residential CHP. Press release from Ceres Power, Crawley, UK, 14 January 2008. 〈http://www.cerespower.com/news/BG%20development%20supply%20and%20distribution%20agreement.pdf〉 (accessed 24 March 2008).

CHAPNET website. 〈http://www.cogen.org/projects/chapnet.htm〉 (accessed 24 March 2008).

Cogen Europe, 2004. A Novel Hybrid Heat Pipe Solar Collector/CHP System Chapnet case study. 〈http://www.cogen.org/Downloadables/Projects/Chapnet_Deliverable_D8b_second_Case_Study.pdf〉 (accessed 24 March 2008).

Defra, 2004. The Government's Strategy for Combined Heat and Power to 2010. Department for Environment, Food and Rural Affairs, London. 〈http://www.defra.gov.uk/environment/climatechange/uk/energy/chp/pdf/chp-strategy.pdf〉 (accessed 24 March 2008).

Defra, 2007. Analysis of the UK Potential for Combined Heat and Power, October 2007. 〈http://www.defra.gov.uk/environment/climatechange/uk/energy/chp/pdf/potential-report.pdf〉 (accessed 24 March 2008).

Defra (website), pages on Energy Services. 〈http://www.defra.gov.uk/environment/climatechange/uk/energy/energyservices/〉 (accessed 24 March 2008).

Den, 1977. District Heating Combined with Electricity Generation in the United Kingdom, Energy Paper 20. HMSO, London.

Den, 1979. The Department of Energy 'Energy Paper' series number 35. HMSO, London.

Den, 1984. Combined Heat and Power District Heating Feasibility Programme: Stage 1, Energy Paper 53. HMSO, London.

E4Tech, 2003. Biomass for Heat and Power in the UK: A Techno-Economic Assessment of Long Term Potential. E4Tech Consultancy, London. 〈http://www.berr.gov.uk/files/file22065.pdf〉 (accessed 24 March 2008).

ESD et al., 2001. The Future of CHP in the European Market, The European Cogeneration Study. A report by Energy for Sustainable Development with Cogen Europe, AEA Technology, KAPE S.A., VTT and SIGMA Elektroteknisk. 〈http://tecs.energyprojects.net/links/final_publishable_report.pdf〉 (accessed 24 March 2008).

ETSU, 1997. Assessment of CHP Potential—Final Report. ETSU report RYCA 18501113. Energy Technology Support Unit, Harwell, Oxfordshire.

FaberMaunsell, 2002. COGEN Europe, E A Technology, ESTIA Consulting, Energy for Sustainable Development, GERG, European Gas Research, and SIGMA Elektroteknisk AS 2002. Micro-Map, Mini and Micro CHP—Market Assessment and Development Plan. 〈http://www.microchap.info/MICROMAP%20publishable%20Report.pdf〉 (accessed 24 March 2008).

Forum for the Future and Cambridge Econometrics, 2000. Combined Heat and Power to 2020—Economic and Environmental Implications of Exploiting the Potential of CHP.

GLA, 2006. Developing an Energy Action Area: A Beginner's Guide. Greater London Authority. 〈http://www.london.gov.uk/mayor/environment/energy/partnership-steering-group/docs/energy-action-area.rtf〉.

Hinnells, M., Boardman, B., 2008. Innovation theory and market transformation. In: Foxon, T.J., et al. (Eds.), Innovation for a Low Carbon Economy: Economic, Institutional and Management Approaches. Edward Elgar.

ICE & RPA, 2005. Quantification of the potential energy from residuals (EfR) in the UK. Undertaken by Oakdene Hollins on behalf of Institute of Civil Engineers and Renewable Power Association, London. 〈http://www.ice.org.uk/knowledge/document_details.asp?Docu_id=1035&faculty=2〉 (accessed 24 March 2008).

IEA website. Thermal Gasification of Biomass. 〈http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=iea\homepage.xml〉 (accessed 24 March 2008).

OPET, 2004. Small-Scale Biomass CHP Technologies: Situation in Finland, Denmark and Sweden. OPET Report 12. European Commission Directorate for Energy And Transport, Brussels. 〈http://www.opet-chp.net/download/wp2/small_scale_biomass_chp_technologies.pdf〉 (accessed 24 March 2008).

Rath, L., Le, P., Sudhoff, F., 1995. Configuration and Performance of Fuel Cell Combined Cycle Options. 〈http://www.osti.gov/bridge/product.biblio.jsp?osti_id=181513〉.

RCEP, 2004. Biomass as a Renewable Energy Source. Report by the Royal Commission on Environmental Pollution, London. 〈http://www.rcep.org.uk/bioreport.htm〉 (accessed 24 March 2008).

Talbotts website. 〈http://www.talbotts.co.uk/BG1000leaflet.pdf〉 (accessed 24 March 2008).

UK Biomass Energy Centre website. 〈www.biomassenergycentre.org.uk〉 (accessed 24 March 2008)