MAKING BIOELECTRICITY ECONOMIC IN THE UK
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ABSTRACT: The UK is attempting to increase the provision of final energy demand by renewables from 1.78% in 2007 to 15% by 2020, with expectations that bioelectricity can make a significant contribution. Policy changes are underway to incentivise thiis transition and this paper considers the impact they are likely to have on the bioelectricity industry. Process modelling and techno-economic analysis is used to demonstrate that some technologies should become significantly more commercially attractive under the new regime. However, the challenges of making energy crop feedstocks commercially viable remain, and, even with historically high fossil fuel prices, biomass combined heat and power will need additional support if the sector is to expand.
Keywords: power generation, policies, economics

1 BACKGROUND

1.1 Bioenergy deployment in the UK

In 2007 the UK produced 1.78% of its final energy demand from renewable sources, compared to a target in the European Renewables Directive of 15% of final energy demand by 2020. [1] Most policy focus in UK renewables to date has been in the electricity sector and 4.90% of electricity in 2007 was renewable. [ibid] The main instrument driving this has been the Renewables Obligation, which was implemented in 2001 and has resulted in an increase in renewable electricity generated of 99.8% since then [ibid] but it still falls far short of the UK government's target of 10% of electricity from renewables by 2010.

Biomass, in all its forms, is an important part of the UK's renewable portfolio, contributing78% of delivered renewable electricity in the UK in 2007 [1]. However, in recent years, its expansion has slowed, with UK bioelectricity capacity growing by only 37.3% from 2003 to 2007, compared to growth for all UK electrical renewables of 64.8% over the same period [2].

Nevertheless the UK government is expecting bioenergy to continue to make a significant contribution to the UK renewables sector, with expectations that bioheat and bioelectricity can deliver up to 4.5% of the UK's energy consumption by 2020 [3].

1.2 UK Renewable Energy Policy

Since 2001 UK support for renewable electricity has been focused on the Renewables Obligation (RO). This requires all licensed electricity suppliers to supply a fixed percentage of their electricity from certified renewable generators, who are awarded Renewable Obligations Certificates (ROCs) for every MWh of power they produce. ROCs can be traded separately from the electricity produced and must be provided by supply companies to the energy regulator, Ofgem, to demonstrate that they have complied with their obligation. Suppliers who fail to meet their obligation are required to pay the "buy-out price" for every MWh for which they are in deficit. This revenue is then recirculated to the renewable suppliers in proportion to the ROCs they have provided, stimulating the market demand for ROCs and ensuring that their market value remains higher than the buy-out price, as long as the overall obligation is not met by suppliers.

The existence of the financial incentive available to renewable generators under the RO is dependent upon suppliers failing to meet the full amount of the obligation and the size of the incentive depends on the extent of the gap between the obligation and the generation actually achieved in a particular year, although the buyout price represents a floor minimum value for ROC's For the period 1 April 2009 to 31 march 2010 the obligation on electricity suppliers is 9.7% and the buy-out price is £37.19. [4]. Many generators enter into direct contracts with supply companies which fix the value of ROCs for a contracted period. For those that do not figure 1 shows how the market value of ROC's at auction has varied during the period of the legislation.

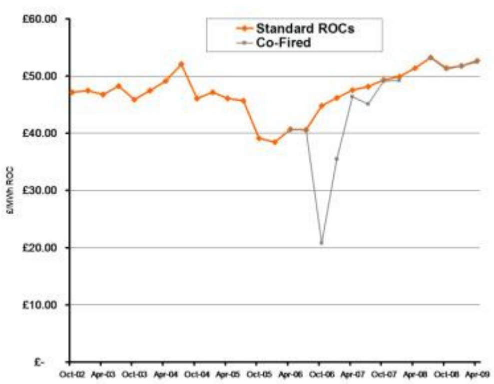

Figure 1: Trends in values of ROC auctions 2002-2009 [5]

One of the reasons why bioelectricity capacity has not increased as much as other technologies in recent years is that the RO offers a single price for all renewable electricity, making it difficult for bioelectricity to compete on a common basis with cheaper options such as onshore wind power. To address the UK government is moving forward with a strategy involving differential payments for different renewable technologies in future. The strategy involves banding of technologies, with fractional or multiple ROCs being awarded for different bands [3]. The resulting bands for bioelectricity systems are summarized in table 1.

Table I: Proposed level of support for biomass under the banded Renewables Obligation

Technology	Level of support (ROC's/MWh)
Landfill gas	0.25
Sewage gas; co-firing of biomass	0.5
Co-firing of energy crops; energy from waste with CHP	1.0
Dedicated biomass	1.5
Fuels created using advanced conversion technologies, dedicated biomass with CHP, dedicated energy crops with or without CHP	2.0

1.3 Introduction to the Supergen bioenergy consortium, its aims and the scope of the work undertaken in theme 1

The work reported here was undertaken as part of the Phase 1 programme of the EPSRC's Supergen Bioenergy Consortium. The Consortium was created to encourage the development of sustainable power generation and supply in the UK from biomass sources. The Phase 1 programme involved eight UK universities as well as a number of industrial partners. Within the programme, Work Package 1 dealt with process and techno-economic analysis of entire energy systems, with the following objectives:

- To examine the costs associated with different power generation options from biomass in the United Kingdom for complete power generation systems from crop planting, through all processing stages to delivery of energy end product.
- To compare the costs of contrasting options in terms of technology, scale and feedstock.
- To examine the circumstances under which such systems could become competitive for widespread deployment in the UK.

2 METHODOLOGY

2.1 Systems considered

For this work 25 different bioelectricity systems were modelled, covering a range of technologies, feedstocks and scales, which are summarized in table 2. Both Power-only (PO) and Combined Heat and Power (CHP) variants of the systems were considered and the ratio of heat to power in energy terms for the CHP systems is shown in table 3.

The analysis presented in this paper focuses on techno-economics, but a wide ranging assessment was carried out on each system, with results reported elsewhere relating to airborne pollutants [(6, employment [7] and integrated assessment against a range of parameters [8].

2.2 Techno-economic assessment

2.2.1 Mass energy balance and efficiency

The process simulation package ECLIPSE was used to compute a mass-energy balance for all of the systems except the pyrolysis ones, for which published data [9] and an ASPEN plus yield and thermal load model was used to predict the bio-oil yield and surplus char production. Wood was assumed to be delivered to the plant in chip form, but allowance was made for all additional parasitic electrical loads via the ECLIPSE simulator or estimates based on published data [10].

2.2.2 Capital cost estimation

The Total Plant Cost (TPC) considered in this work is the sum of all costs that the owner incurs to obtain a fully working plant with the exclusion of site purchase, initial ground works and consenting fees. A "bottom-up" approach to estimating total capital cost was adopted for selected cases and bare equipment costs were estimated according to the step count exponential costing method based on the dominant process variable or a combination of variables. More limited data for pyrolysis cases resulted in use of sizing formula based on published reports that had been produced with co-operation of equipment manufactures. [9, 11, 12] In both cases allowance was made for all additional costs e.g. for biomass pre-processing and storage plants [13, 14, 15],diesel generators and gas turbines suitable for bio-oil, [11, 16 modified in line with Dynamovtive press releases connected to their West Lone pyrolysis plant [17]] pipes, structural elements, instrumentation and civil works, based on typical factors and constants, validated by industrial partners and others.

Having developed a suitable reference case for each technology category the costs of remaining power generation systems were estimated by means of a top-down approach.

2.2.3 Operational costs and revenues

Operational costs include: staff costs linked to an evaluation of staffing patterns at the plants; materials consumption and disposal costs related to the mass-energy balance; maintenance costs fixed at a percentage of the total capital cost, but with appropriate allowance for technology-specific factors eg.higher maintenance costs for gas turbines with liquid fuels that contain ash [19].

One of the most significant materials consumed is biomass feedstock and consultation with industrial partners in the consortium indicated a typical range of £40-60/odt, with energy crop feedstocks falling at the upper end of this band. A cost of £60/t has been assumed for energy crops delivered to the power station, which gives reasonable returns to farmers based on current incentive programmes.

The main revenue for each case is the electricity revenue, which is discussed in 2.3.5. In addition allowance has been made for char sales, with revenue equivalent to biomass on a heating value basis. The revenue obtainable from heat sales is discussed in 2.4.

2.2.4 Economic parameters

The plants were considered to be financed by a 21 year annuity (consistent with projected lifetime of perennial energy crop plantations) with real discount rates (i.e. the interest rate once inflation has been allowed for) of 5%, 10% (base case), and 15%. All costs were converted to sterling and indexed to 2005.

2.2.5 Economic assessment

For purposes of economic assessment the electricity selling price has been varied to obtain a project net present value of 0. This break-even electricity selling price (BESP) has been reported here as an indicator of the relative economic viability of different systems. Section 2.3 describes the revenue that might be available for such systems under new UK policy regimes.

2.3 UK payments for renewable electricity

In order for bioelectricity production to be economically viable for generators the revenue received by the generator must be higher than the break even electricity selling price described in 2.2.5. The electricity revenue received is the payment for the electricity unit plus the value of the related ROCs less the administrative cost associated with trading.

Data recently published by Ofgem [19] showed that UK wholesale electricity prices in November 2008 were between £50 and £62/MWh, depending on the contract term, but, within the last 5 years this had seen lows of around £16/MWh and highs of over £100/MWh. In general there had been an underlying upward trend, with mean values of around £50/MWh for the last 2-3 years, which was reasonably stable for 18 month forward pricing. For our purposes we need to consider the price that a renewable generator will be able to secure on a long term contract from an electricity supply company. This is likely to be lower and for this work a range of £30 to 50/MWh has been considered. However, it is possible that CHP and smaller systems could command a higher £50/MWh price as embedded generators.

The ROC value needs to be added to this and will depend on the market price of ROCs, which in turn depends on the extent to which the UK undershoots its target. This is complicated by the fact that banding is currently being introduced and this will likely impact on the balance of supply and demand of ROCs. The government carried out extensive market analysis to ensure that stability would remain based on projected capacities after this transition. Assuming that this was reasonably robust (or if the change resulted in market upheaval government would act to adjust the bands to correct the imbalance) a reasonable long term ROC value based on projections of figure 1 seems to be between £40 and £55/MWh. Actually trading the ROC's in this way is assumed to incur a cost of 50 p/MWh [20].

2.4 UK Payments for Renewable Heat

One of the key features of recent policy discussion in the UK has been realisation of the need to quantify and reward renewable heat. Historically the ready availability of first coal and then north sea gas has meant that the UK has had relatively low heat prices compared to the rest of continental Europe. This has contributed to slow development of CHP, district heating and renewable heat, including bioheat. A provision was included in the Energy Bill to facilitate renewable heat payment rewards and the government consulted in 2008 on whether a renewable heat obligation or a renewable heat incentive would work best to cost-effectively stimulate the renewable heat market, which has historically been slow to develop in the UK. The new electricity RO levels have already incorporated recognition of the contribution of heat by banding CHP facilities with multiple ROC's. However, there is further scope for enhanced payments for heat from bioelectricity CHP systems. In such a scenario the heat price paid to the provider would comprise a payment for the heat delivered and a premium for its renewable origin. This would effectively facilitate a higher than market rate payment for bioheat, but the level of the premium is not yet established. To evaluate the potential significance of such measures sensitivity of the CHP systems here was evaluated for different heat prices. A base case figure of £3.50/GJ of heat delivered was chosen benchmarked to UK industrial gas prices in 2006. This was set at a level that allowed the customer to profit from the switch to biomass, as he pays the same but no longer incurs the boiler conversion efficiency losses. The level of this incentive (~15%) is in line with that reported to be sufficient to incentivise action. (20). Currently £4.50/GJ is more representative and sensitivities of up to £6/GJ have been evaluated in this paper to assess the scale of premium required to increase economic deployment.

3 RESULTS

The specific capital cost for each system is shown in figure 2.

Figures 3-6 show the break-even electricity selling price, (calculated as described in section 2.3.5) the range of projected market prices achievable (estimated as described in section 2.3) and the wholesale market price for conventional electricity without subsidy/support at the time of writing.

Table 2: Bioenergy systems studied

Power output (Mwe)	0.25		2		5		25	
Mode	PO	CHP	PO	CHP	PO	CHP	PO	CHP
Gasifier (reciprocating engine) - air drying, wood	1	16						
Gasifier (reciprocating engine) – no drying, wood			2	17	3	18		
Gasifier (reciprocating engine) - no drying, miscanthus					4	19		
Gasifier (atmospheric gasification combined cycle) - flue gas drying, wood							5	
Gasifier (pressurized gasification combined cycle) - flue gas drying, wood							6	
Gasifier (pressurized gasification combined cycle) - flue gas drying, miscanthus							7	
Combustion (circulating fluidized bed) - no drying, wood							8	
Combustion (grate) – wood				20	9	21	10	22
Combustion (grate) – miscanthus				23			11	
Combustion (grate) – straw							12	
Pyrolysis (reciprocating engine) – wood					13	24		
Pyrolysis (gas turbine) – wood					14	25		
Co-combustion, 5% of 500 MWe (PF) – wood							15	

Table 3: Table of heat to power ratios for CHP systems

Case	CHP application	Heat to power ratio
16	Hot water space heating 90C out, 50C return	2.4
17	Hot water space heating 90C out, 50C return	1.8
18	Low grade steam (hospitals and food processing plants) outgoing at 5bar from backpressure turbine	1.9
19	Low grade steam (hospitals and food processing plants) outgoing at 5bar from backpressure turbine	1.9
20	Hot water space heating 90C out, 50C return	5.1
21	Low grade steam (hospitals and food processing plants) outgoing at 5bar from backpressure turbine	5.2
22	High grade steam (process industries) outgoing at 10 bar from extraction turbine	0.8
23	Hot water space heating 90C out, 50C return	5.5
24	Hot water space heating 90C out, 50C return heat recovered from engine cooling jacket and exhaust heat exchanger	1.5
25	High grade steam industrial process steam recovered from GT exhaust buy Heat Recovery Steam Generator	2.5

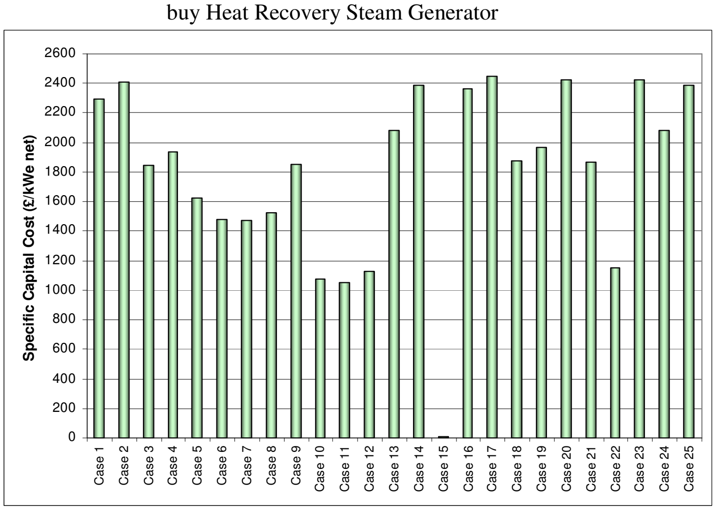

Figure 2: Specific capital cost of systems (£/kWe)

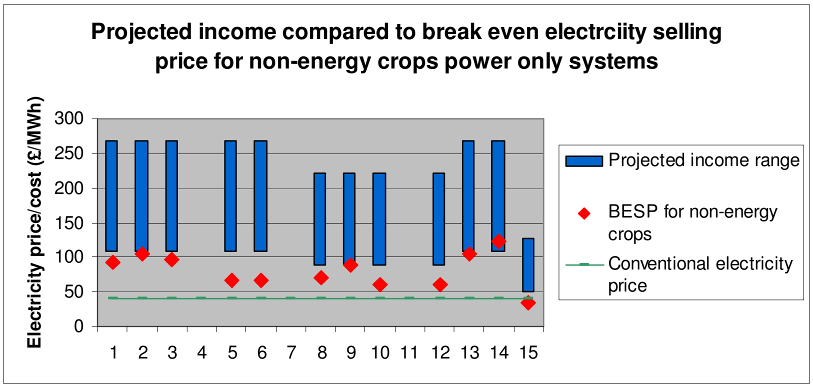

Figure 3: Projected income compared to break even electricity selling price for non-energy crops, power only systems

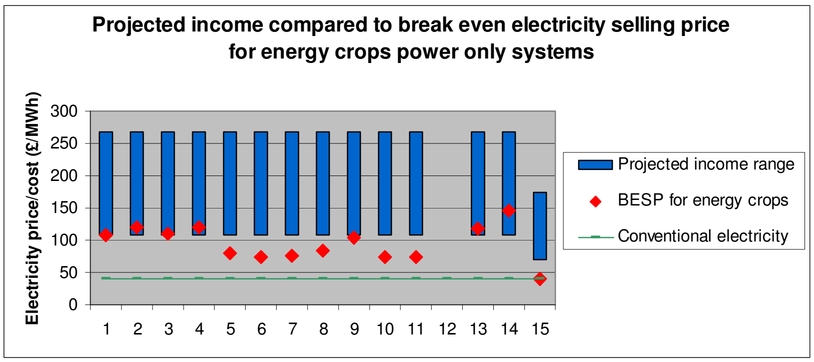

Figure 4: Projected income compared to break even electricity selling price for energy crop power only systems

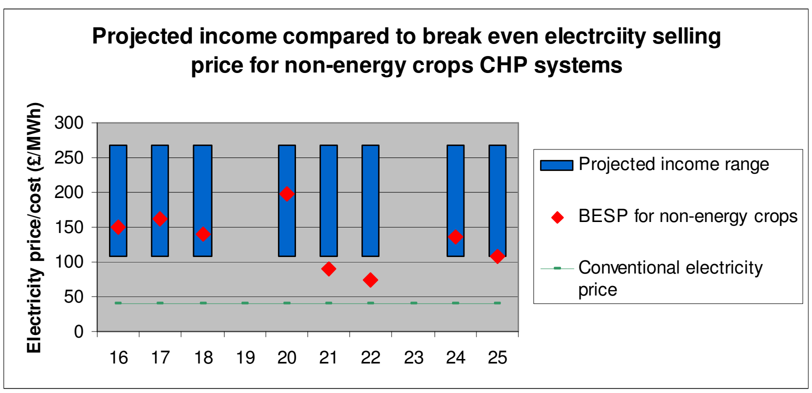

Figure 5: Projected income compared to break even electricity selling price for non-energy crop CHP systems

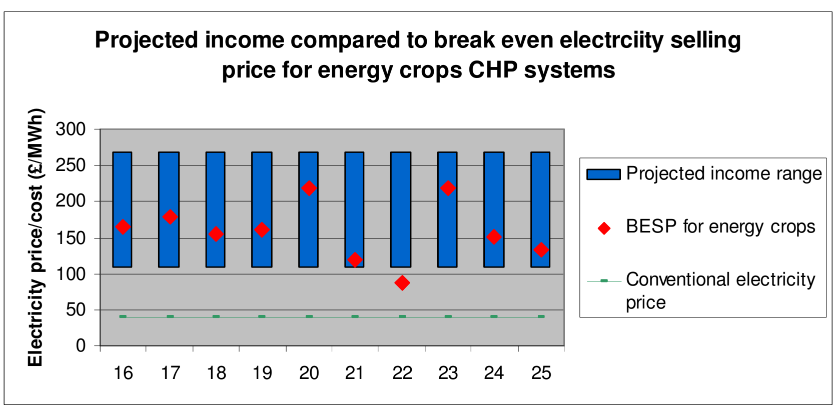

Figure 6: Projected income compared to break even electricity selling price for energy crops CHP systems

3.1 Electricity from non-energy crops

Figure 3 shows a comparison of the projected revenue from electricity sales against BESP for electricity systems using non-energy crop feedstocks

It is noticeable that only co-firing is close to being economic without subsidy. However, in all cases except 14 (pyrolysis with gas turbine) the break even electricity selling price is less than the range anticipated from electricity sales and ROC payments. This indicates that most bioelectricity systems should become feasible under the new payment regime, provided that ROC values do not fall in response to the banding adjustments and feedstock prices do not increase significantly in response to increased demand. There are some cases for which the economics are more finely balanced than others and these tend to be the smaller scale systems. It should be noted that these are the systems that are generally preferred by most stakeholders and community groups (8) and construction at this scale also frequently provides a confidence stepping stone to the larger scale plants from an investment perspective. This may result in the sector developing more slowly than would otherwise be the case and possibly result in a more centralized portfolio, contrary to stakeholder priorities.

3.2 Electricity from energy crops

Figure 4 shows a comparison of the projected revenue from electricity sales against BESP for electricity systems using energy crop feedstocks.

The break-even electricity selling price has risen in all cases where energy crops are utilised, as this has a higher feedstock cost, but the scheme payments have risen only for some cases. Obviously there is a wide range on the projected income and if the markets respond so that payments are made in the upper area of this band (mainly corresponding to a continued shortfall in the total volume of eligible renewable electricity generated) there will be a healthy commercial margin available for project developers. However, economic viability of many systems is more finely balanced than was the case for non-energy crops. In general this is likely to mean developers opting for conventional biomass feedstocks rather than energy crops under the proposed support regime. However, the overall trend in terms of which systems are most likely to prosper is exactly the same. The economic rationale to build and operate a new plant is much more challenging for small plants than large ones.

3.3 Electricity and heat from non-energy crops

Figure 5 shows a comparison of the projected revenue from electricity sales against BESP for CHP systems using non-energy crop feedstocks. At the base heat price of £3.50/GJ, schemes 21, 22 and 25 are most attractive, representing the higher grade steam/industrial demands. The lower load factors typical of servicing space heating demands in the UK significantly impacts on the economics of other schemes, resulting in economic viability, as indicated by the BESP compared to the projected revenue, being significantly more marginal.. Electricity only schemes continue to appear more attractive.

3.4 Electricity and heat from energy crops

Figure 6 shows a comparison of the projected revenue from electricity sales against BESP for CHP systems using energy crop feedstocks. The banding of the incentive scheme does not offer any additional financial incentive to use energy crops in these systems and so in all cases the economics are more marginal than in an equivalent non-energy crop facility.

4 DISCUSSION

It is clear that some large scale bioenergy electricity systems will be encouraged under the new banded ROC regime, but the inducement for smaller schemes, energy crops and bioheat are less clear. Recalling figure 4, a reduction in BESP of about £20/MWh would be sufficient to make most power-only cases more commercially attractive. From figure 5 a greater reduction (£50/MWh or more) is required to make CHP schemes more attractive at the assumed heat price. Some of the options for improving this are discussed below.

4.1 Capital investment

Power plant final capital investment is very instrumental to achieving competitiveness in the electricity market. Figure 7 shows the sensitivity to the specific investment (SI) of the power only technologies (to the left on the graph) varies from 0.23 to 0.49 £/MWh per percentage change in SI. Obtaining a reduction of the required £20/MWh level would require a specific investment reduction of 40-87%. The sensitivity of the CHP technologies (to the right on figure 7) ranges from 0.39 to 1.18 £/MWh per percent change in SI. However, from above, a larger reduction of at least £50/MWh is needed to improve competitiveness, so even greater reductions are required.

It is possible that such reductions could be achieved by technological learning: it has been reported that cost of electricity from biomass in Europe reduced by technological learning with a progress ratio of 85% between 1980 and 1985 (22). Not all of this reduction will be sensibly accessible, as some of it will have already been incurred in mainland Europe and reflected in current UK prices. However, if this rate was seen in the UK by the time the 16th plant of a particular type was built the BESP for electricity could have halved. This would have a significant impact on project viability. Table 4 shows the schemes which would then be viable without any premium payments at all.

It is notable that these are predominantly the larger schemes and the power only systems. Other approaches will be needed to improve CHP take-up. It is interesting that even energy crop prices are justifiable with these significant learning cost reductions, but only at the large scales, which gives something of a dilemma, as their production is generally more suited to local use. Of course the likelihood of such cost reductions being achieved must be taken into account and also the fact that constructing 16 large plants in the UK would represent a substantial proportion of the long-term sustainable capacity – in other words there might not be scope for many subsequent plants once the economic viability threshold has been reached. It must also be acknowledged that grate firing is more proven and much less likely to benefit from a rapid deduction in its construction cost. This seems to suggest a long term future for economic bioelectricity in the UK of a limited number of large scale advanced technology plants, which could operate with energy crops or regular biomass.

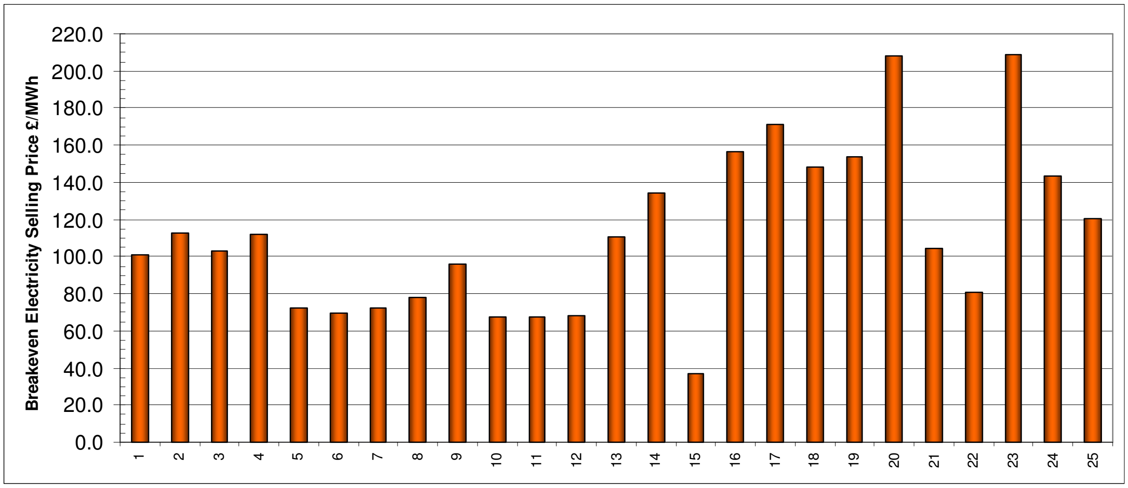

Figure 7: Sensitivity of BESP to changes in specific capital investment

Table 4: Cases which become economically viable with a 50% reduction in capital cost and no premium payment

Case	Description	Viable with regular biomass?	Viable with energy crops?
1	DDG 250kW PO – wood	Yes	
3	CFBG 5 MW PO - wood	Yes	
5	A-IGCC 25 MW PO - wood	Yes	Yes
6	P-IGCC 25 MW PO - wood	Yes	Yes
8	CFBC 25 MW PO-wood	Yes	Yes
9	Grate firing 5 MW PO – wood	Yes	
10	Grate firing 25 MW PO – wood	Yes	Yes
12	Grate firing 25 MW PO – straw	Yes	n/a
21	Grate firing 5 MW – wood (CHP)	Yes	
22	Grate firing 25 MW – wood (CHP)	Yes	

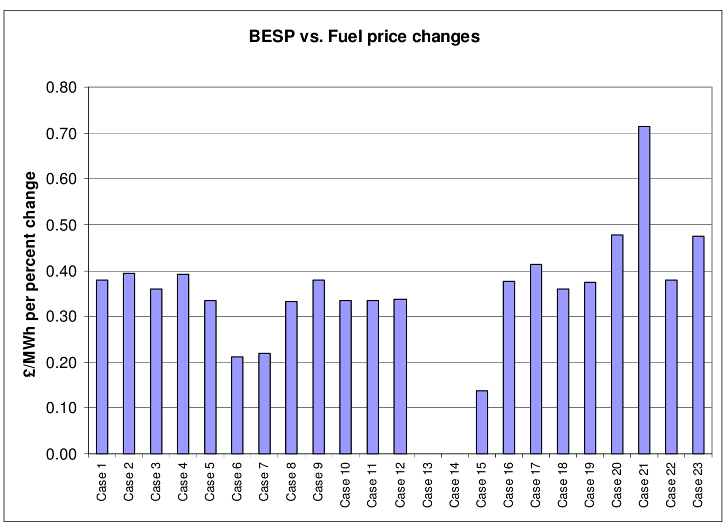

Figure 8: Sensitivity of BESP to changes in price of biomass

It should also be noted that, at 25MW the IGCC plants are at the bottom end of the power range for this technology. If they followed a typical 0.6 scaling factor a 50MWe plant would have an SI 75% lower than the 25MW plant which would give it similar investment cost to the 25MW grates but with a much higher efficiency. This further reinforces a future picture of large-scale systems, at which point, serious consideration must be given to the availability, logistics and sustainability of feedstock supply.

4.2 Fuel cost

The sensitivity of the technologies to variations in feedstock price is shown in figure 8. The BESP varies from 0.21 to 0.71 £/MWh per percent change in fuel price, with the CHP options demonstrating higher sensitivity than the power only options. It has been reported that in Sweden and Finland the cost of primary forest fuel has fallen with a progress ratio of 85-88% (23). If this was repeated in the UK it would be a benefit to grate applications as they have a relatively low thermal efficiency. In the current market this seems unlikely, given the UK's supply-demand balance, but the sensitivity indications are that a valuable reduction could be achieved with relatively modest fuel cost reductions as the supply chain develops.

4.3 Heat value

All of the CHP evaluation described above was carried out with a base heat price of £3.50/GJ. However, there have been substantial increases in these prices in recent years, as shown in figure 9 and evaluation of the implications of higher heat prices is appropriate.

CHP systems can be run in a variety of different operating modes and economic analysis demonstrated that one of the key factors affecting viability was the relatively low load factor ascribed when following UK space heating profile requirements. This can be increased by focusing on users with more constant heat demand profiles or by operating the generating plant at base load and simply rejecting unwanted heat using a dump condenser or similar. This option is examined in some detail for one of the cases below in order to demonstrate the conditions under which the economics become more attractive.

Referring back to figures 5 and 6 a BESP of less than £100/MWh is a realistic target for economically viable systems under the forthcoming support regime, but less than £50/MWh is needed if the systems were to be viable without support in the long term. Figure 10 shows how the BESP varies with load factor for a pyrolysis diesel engine system, which was not viable even under substantial cost reductions above.

Operating power production as base load is seen to reduce the BESP to less than £100/MWh, so that the scheme would become viable under the forthcoming support regime. However, even with a gas price of £6.50/GJ the BESP of over £90/MWh requires substantial support at typical space heating load factors of around 0.4. Becoming competitive without support mechanisms will only be possible at much higher load factors and much higher heat prices. Proposed incentive programmes for renewable bio-heat should, perhaps, be focusing on customers with higher base loads, but even then there will be a need for substantial support of the heat price in the long term.

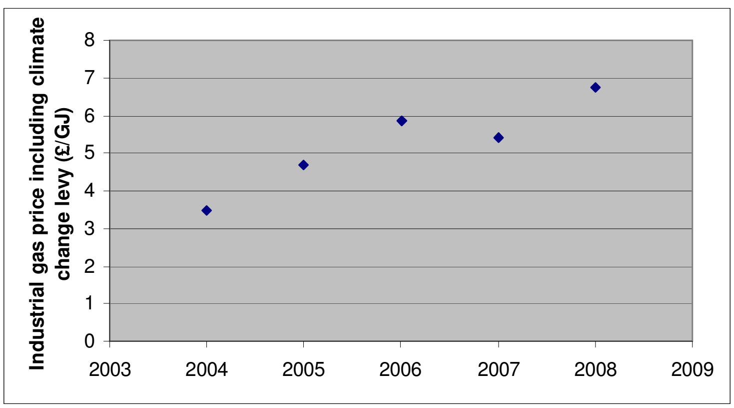

Figure 9: Trends in average UK industrial gas prices (adapted from [24])

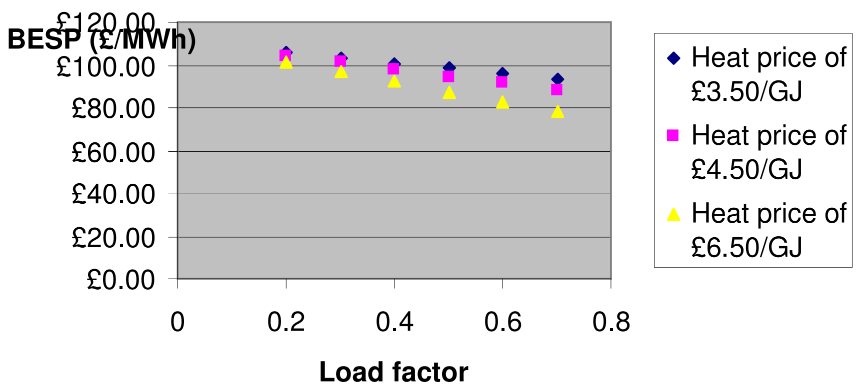

Figure10: Variation in BESP (£/MWh) with changing heat load factors and heat prices.

5 CONCLUSIONS

Banding of the UK's Renewables Obligation will increase the economic attractiveness of many bioelectricity options, particularly larger, power-only facilities operating with non-energy crops.

Advanced technologies have potential to become economically viable within feasible technological learning curve assumptions, particularly at larger scales, but will require a track record of continuous development and replication to achieve this, which may be difficult to achieve if left to an open market.

The proposed mechanisms and the long term technological outlook both favour larger plants, at odds with the general public opinion.

There appears to be little incentive for energy crop use with current proposals. If targets for production/utilisation are to be reached establishment support will be required. Otherwise cheaper alternatives will prevail: most likely imported woodchip.

Even with industrial gas prices at a historically high level, biomass combined heat and power (CHP) is unlikely to become significantly more attractive under the new regime, except for users with a high base load requirement. Significant support of renewable heat is required to make a difference to the overall economics.

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