



Bioenergy

review



Technical paper 4

Biomass in power generation

Committee on Climate Change
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Ute Collier, CCC

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Introduction and key messages

The CCC bioenergy review provides an assessment of the potential roles for bioenergy given lifecycle emissions and other sustainability concerns, and also considers alternative uses for bioenergy feedstocks. The main report is available on our website:

<http://www.theccc.org.uk/reports/bioenergy-review>.

More detailed analysis on biomass in power generation is covered in this technical paper. Three further technical papers are available on the website, covering:

- Technical Paper 1. Is bioenergy low-carbon?
- Technical Paper 2. Global and UK bioenergy supply scenarios
- Technical Paper 3. Appropriate use of scarce bioenergy.

The Government's Renewable Energy Roadmap includes an important role for power generation from bioenergy. This paper, as part of our bioenergy review, sets out our analysis of the role of solid biomass-fired generation in the power sector to 2020. It includes an assessment of the sustainability of potential biomass supply for power generation and the costs of different large-scale options for generating power from biomass.

The key messages from our analysis are:

- **Sustainability.** The role of biomass in power should be dependent on the availability of sustainable supply (i.e. not top-down targets). In order to ensure sustainable supply, strengthening of the regulatory framework under the Renewables Obligation is required.
- **Conversion/co-firing and new dedicated.** Where available, near-term use of biomass in power should be where it is most economic, which our analysis indicates is in co-firing and conversion, not new large-scale dedicated plant. There may also be a role for small-scale projects, particularly those which supply combined heat and power, accessing locally sourced woodchips or wastes (which are not generally used for conversion and enhanced co-firing).

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- **Support for biomass power generation.** Support under the Renewables Obligation should focus on co-firing and conversion. For new dedicated biomass projects, support should be limited to small-scale plants, and combined heat and power plants (CHP). Alternatively, at a minimum, any support for new large-scale dedicated plant should be limited to a very small number of projects.
 - **Longer-term role for biomass power generation.** In the longer term, we identify an important role for biomass generation with carbon capture and storage (CCS) as a way of achieving negative emissions, but no role for large-scale biomass power generation without CCS.

We set out our analysis in 4 sections:

1. Sustainable supply of solid biomass compared to potential demand
2. Using scarce biomass resources in power generation
3. Potential and costs of biomass generation options
4. Conclusions and policy implications

1. Sustainable supply of solid biomass compared to potential demand

Current demand for biomass

There is a growing global market for wood pellets as a bioenergy feedstock, driven primarily by European demand for residential and commercial heating and by use in power generation and heat supply to contribute to European Union (EU) renewable and climate change targets.

- Between 2000 and 2010, world wood pellet consumption increased from 2 to 16 million (oven-dried) tonnes (Mt).
- Of the 16 Mt of wood pellets consumed for heat and energy purposes in 2010 globally, 13 Mt were consumed in Europe, of which the UK accounted for just over 1 Mt¹.

Future demand for biomass

An assessment of plans for renewable energy penetration over the next decade suggests that the EU will significantly increase its demand for solid biomass, with the UK a major driver of this demand:

- Plans submitted by individual EU member states (National Renewable Energy Action Plans, NREAPs, 2010)² indicate collective ambition for generating 150 TWh of electricity and 900 TWh of heat from solid biomass by 2020. This implies that EU power generation alone would require around 90 Mt of solid biomass in 2020³.
- The UK's Renewable Roadmap (2011) suggests plans for just over 40 TWh of solid biomass power generation. Work for our fourth carbon budget advice suggested around 25 TWh of solid biomass heat output in 2020. This could require approximately 23 Mt of solid biomass for the power sector, and just over 6 Mt for heat (i.e. around 30 Mt in total, equivalent to the total current UK wood demand by all sectors)⁴.

Plants co-firing large amounts of biomass with fossil fuels, or converted coal plants running on biomass will require high-quality pelletised biomass feedstock, although a wide range of feedstocks are available for use in power generation (Box 1).

Current and potential future sustainable supply of woody biomass

While pellets can be processed from various biomass feedstocks, including energy crops and dry agricultural residues, the near-term market is likely to be predominantly supplied by forest biomass, given the presence of existing markets and infrastructure for the timber sector and limited market penetration of the alternative feedstocks. Assessments of the potential supply available to meet the 2020 EU renewables targets have thus focussed on forest biomass resource estimates.

1 Pöyry (2011), Pellets – Becoming a Global Commodity? Global market, players and trade to 2020.

2 Individual Member State National Renewable Energy Action Plans, accessed at http://ec.europa.eu/energy/renewables/transparency_platform/action_plan_en.htm

3 Assuming a calorific value of 17 GJ/tonne of feedstock and a conversion efficiency of 80% for heat and 36% for power.

4 Assuming 17GJ/tonne, and conversion efficiency of 36% for power and 80% for heat.

Box 1: Biomass feedstocks for power generation

The size, scale and type of plant can determine the appropriate biomass feedstock:

- Co-firing and converted coal plants usually require high-grade 'clean' wood pellets, with a high energy density (e.g. 16-18 GJ/tonne). Although pellets can be processed from a variety of feedstocks (e.g. agricultural residues and energy crops), generators of converted coal plants are likely to require pellets from timber feedstock (e.g. Canadian forest biomass) with a high core wood content.
- New dedicated plant may be more flexible and can be designed to accept a wider range of feedstocks:
 - **Woodchips.** These are generally cheaper than pellets as they require less processing. As a result, they have a lower energy density (e.g. 12 GJ/tonne).
 - **Agricultural residues.** These include feedstocks such as straw and chicken litter. Although straw may be co-fired with coal in pelletised form, new plant may be designed with grate combustion technology which can use unprocessed straw (e.g. bales).
 - **Waste fuels.** These include waste wood and biodegradable components of solid waste (municipal, commercial and industrial). Plants using such feedstock are required to comply with waste emissions regulations (e.g. additional emissions abatement equipment), usually resulting in a lower efficiency of the plant (typical efficiency of a waste wood plant is 32%, and for energy from waste plants 22%).
 - **Energy crops.** At present, the cost of developing energy crops for power is relatively high, with concerns over the stability of supply at least in the near term. Therefore, use of energy crops in power is limited – although greater incentives are in place (dedicated plants using energy crops receive 2 ROCs, compared with 1.5 ROCs for solid biomass).

In the bioenergy review and this paper we focus on power generation from combustion of solid woody biomass, which is the most significant form of biomass power expected to be deployed at scale over the next decade.

Forest Research (AEA, 2011)⁵ estimate in a medium scenario that UK domestic production of forest biomass could be 4 Mt by 2020. Globally, their analysis identified a medium potential of 200 Mt of forestry and forest residues available in 2020, representing 1,000 TWh on a primary energy basis⁶. This encompasses forest sector by-products, or residues arising from current forest management operations including small round wood and sawmill co-products. The extent of sustainable forest biomass is thus dependent on timber harvested for wood and other uses (e.g. pulp and paper). The bulk of the forest resource is likely to come from North America, Europe and Russia.

We focus here on these categories of forest biomass but recognise that additional forest biomass is potentially available, for example, deadwood arising from natural disturbances (including fires and insect outbreaks), and/or increased forest management (clear felling and/or thinning of virgin forests) provided forests are well-managed to repay carbon stocks and maintain other environmental objectives (e.g. biodiversity and soil preservation).

⁵ AEA (2011) UK and Global Bioenergy Resource – Final report.

⁶ See also our Technical Paper 2 describing our approach to developing global and UK bioenergy supply scenarios. The Forest Research estimate takes into account expected future demand for wood in construction and internationally (e.g. in Asia), together with constraints such as recoverability of resource, and transportability. However, competition between uses of these residuals by the pulp, paper, panel board sector and bioenergy sector are not taken into account.

High EU and UK ambition compared to potential supply

Meeting EU 2020 plans for biomass use in the power sector alone would require continued EU dominance of the global market for pellets, with plans representing 45% of the 2020 global resource identified above (90 Mt out of 200 Mt); including heat demand suggests demand well beyond estimated supply (Figure 1).

UK power generation demand of 23 Mt would go well beyond the 4 Mt of domestic resource available (Figure 2), and represent 12% of the global resource. While it is not implausible that the UK could access such a large share of the global resource by 2020, it is clearly a stretching scenario. Achieving it is contingent on the sustainable expansion of the pellet industry (e.g. capacity keeping pace with demand and frameworks being put in place to ensure biomass is imported from countries with sustainable forest management practices).

Over the longer term there is uncertainty over the continued availability of global supply, as countries are likely to make increasing use of domestic forest biomass to meet their own renewable energy targets. It is thus less plausible that the EU continues to dominate the market for forest biomass in a post-2020 world.

Sustainability risks for woody biomass

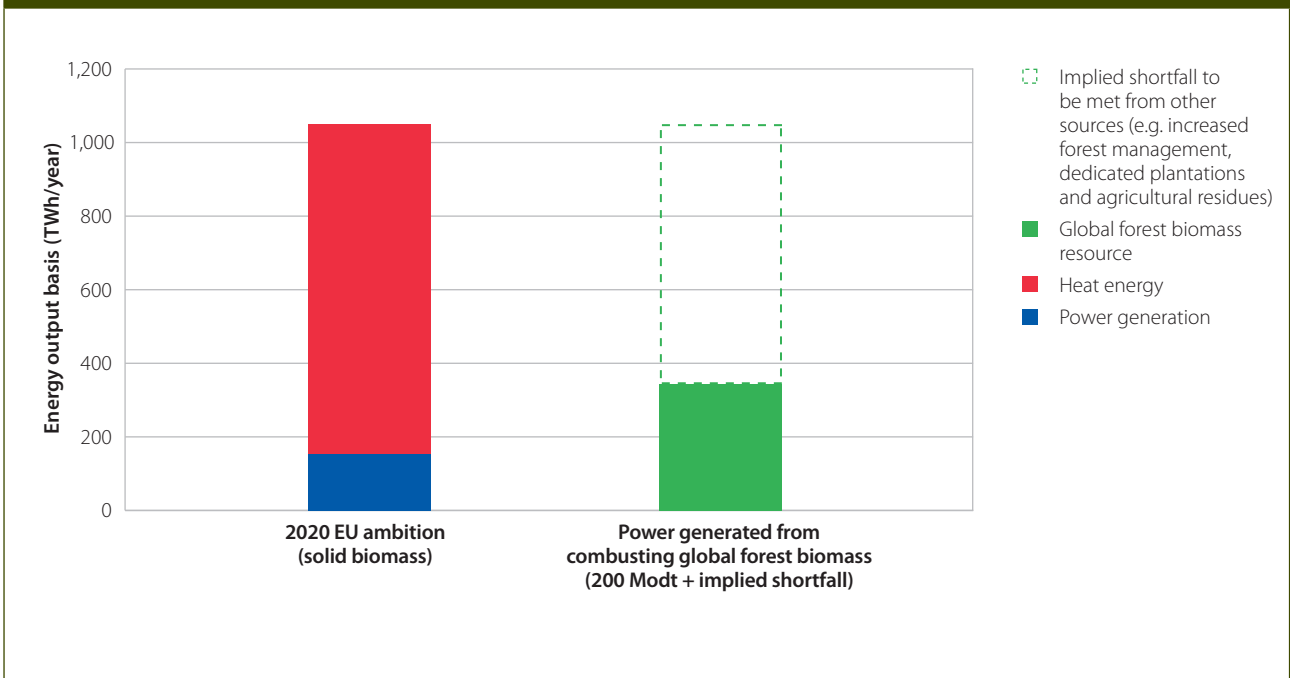
Ambitious EU targets are at the limits of potential global supply of sustainable biomass over the next decade, as estimated by Forest Research. The risk, therefore, is that biomass is imported from countries where frameworks to ensure sustainable forest management are less robust, in which case emissions benefits would be eroded.

In terms of the appropriate role for bioenergy in the UK power sector, our analysis suggests that it should be dependent on the availability of sustainable supply (i.e. not top-down targets). In terms of UK policy, it points to strengthening of the regulatory framework under the Renewables Obligation to ensure sustainable supply.

Our full recommendations to mitigate risks of unsustainable biomass are set out in the main report of the bioenergy review. Further analysis of the sustainability risks is contained in Technical Paper 1, 'Is bioenergy low-carbon?'⁷

⁷ Available at www.theccc.org.uk. See section 5, Emissions from forest biomass.

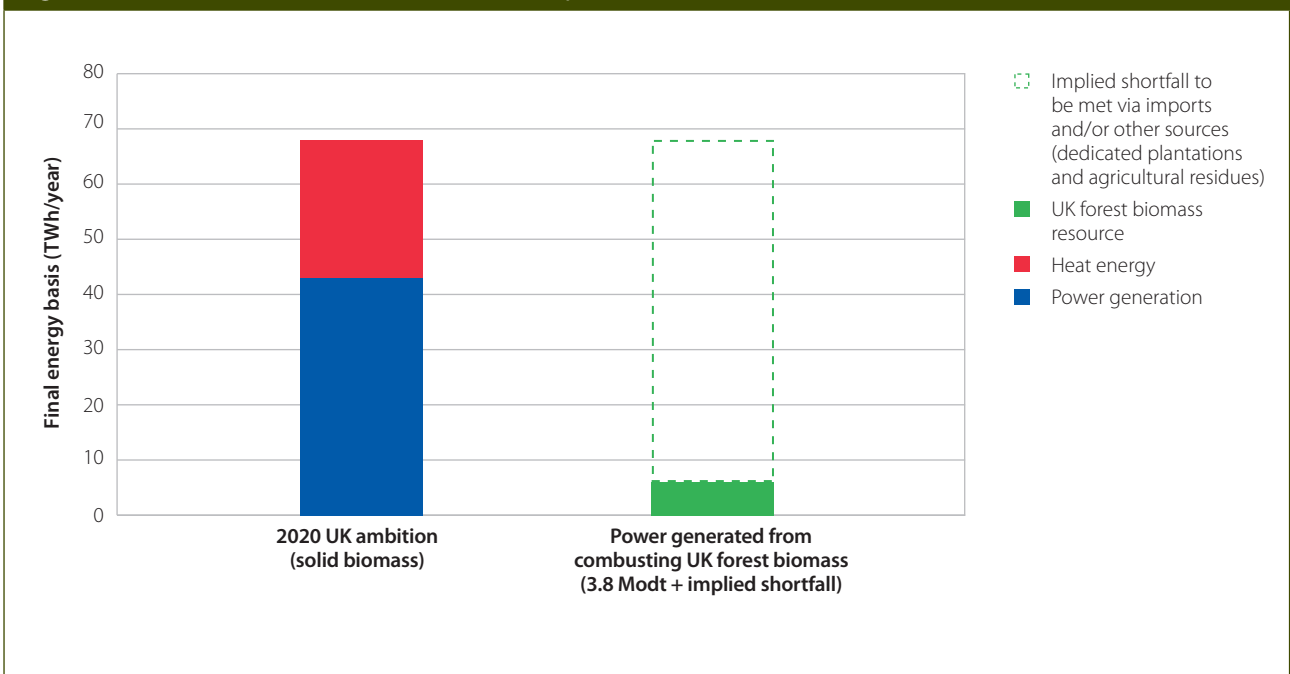
Figure 1: EU solid biomass ambition for heat and power in 2020 versus global supply of forest biomass



Sources: European Environment Agency (2011), Renewable energy projections as published in the National Renewable Energy Action Plans of the European Member States; AEA (2011), UK and Global Bioenergy Resource.

Notes: (i) Figures presented on a final energy basis assuming a conversion efficiency of 80% for heat and 36% for power. (ii) Focuses on sustainable forest biomass (e.g. residuals of timber industry under AEA's business-as-usual assessment (2011)) rather than increased management of forests and dedicated plantations. Indicates a significant increase in sustainable supply over a relatively short time period is required to meet EU ambition. (iii) Forest biomass assumed converted to pellets, with a calorific value of 17 GJ/oven-dried tonne (odt) of feedstock.

Figure 2: UK solid biomass ambition for heat and power in 2020 versus domestic forest biomass resource



Sources: UK Renewables Roadmap (2011); CCC (2010), Fourth Budget Report; CCC (2011), Renewables Review; AEA (2011), UK and Global Bioenergy Resource.

Notes: (i) Figures presented on a final basis assuming a conversion efficiency of 80% for heat and 36% for power. (ii) UK forest biomass resource reflects a medium scenario in AEA assessment (2011), reflecting a bioenergy price of £6/GJ and overcoming easy constraints. (iii) Pellets produced from forest biomass assumed to have a calorific value of 17 GJ/oven-dried tonne (odt) of feedstock.

2. Using scarce biomass resources in power generation

Biomass versus other sources of low-carbon generation

Biomass power generation is one of a range of low-carbon options for power generation. Its long-term role and the appropriate near-term support will depend on its characteristics relative to other options for low-carbon power, specifically in terms of cost, lifecycle emissions and predictability/despatchability.

We recommend in the main report of the bioenergy review that sustainability standards should be tightened to ensure that lifecycle emissions for biomass power generation will be no more than 200 g/kWh. This would offer a significant saving versus unabated fossil fuel generation, but is likely to be higher than some low-carbon alternatives (e.g. lifecycle emissions across other renewables are generally well below 50 g/kWh, and for nuclear are estimated at around 20 g/kWh)⁸.

Biomass power generation is both predictable and despatchable (i.e. it can generate electricity on demand), which gives it an advantage over intermittent forms of renewable power generation. Whilst this is a useful characteristic, our previous detailed work on intermittency suggests that costs associated with intermittency need not be prohibitive at the renewable shares envisaged to 2020⁹.

Given higher lifecycle emissions, and potentially limited benefit from despatchability, biomass power generation would have to be significantly lower cost than available low-carbon alternatives to warrant a significant role in the energy mix. We set out our evidence on costs in section 3, but first consider the potential role for biomass generation in the long term and the options for deployment in the near term.

Role for biomass power generation in the long term

In the long term, costs for less mature renewables such as offshore wind and emerging technologies such as marine are expected to come down significantly with UK deployment¹⁰. However, biomass power generation has less potential for learning to reduce capital costs and is likely to see costs rise as increasing demand for constrained feedstock resource (from other sectors and other countries) feeds through to higher fuel prices. Our modelling of appropriate use for scarce biomass suggests the biomass price will increase significantly to 2050 reflecting its increasing value as emissions constraints tighten¹¹.

Beyond 2020, nuclear and (subject to demonstration) CCS are also likely to be available for large-scale deployment, offering more alternatives for low-cost low-carbon power generation. Unless used in conjunction with CCS, it is therefore clear that biomass should

⁸ As noted in our May 2011 Renewable Energy Review, drawing on the Parliamentary Office of Science and Technology (2006) Carbon Footprint of Electricity Generation.

⁹ See for example, our Renewable Energy Review, where we showed that renewable shares as high as 65% in 2030 (compared to 2020 ambition of 30%) in principle could be managed with successful demand-side response, increased interconnection and flexible back-up generation without incurring prohibitive costs. Whilst there remain uncertainties in this area that warrant continuing detailed research, the conclusions are likely to be robust for the 30% penetration envisaged for 2020.

¹⁰ For example, our renewable energy review set out potential for offshore wind costs to halve by 2030.

¹¹ See chapter 4 of the bioenergy review (Figure 4.5) and accompanying Technical Paper 3: Appropriate use of scarce bioenergy.

not have a significant role as a low-carbon option for electricity generation in the long term. This is confirmed by our appropriate use modelling, which does not feature biomass power generation beyond 2030 without CCS.

In the long term, if CCS can be successfully applied to biomass power generation, it offers a route to negative emissions through sequestering biogenic emissions. Our appropriate use modelling suggests that biomass with CCS is likely to be desirable if available since the stored emissions can be used to offset emissions in sectors that are particularly hard or expensive to reduce.

Options for biomass generation in the near term: co-firing, conversion and dedicated

Biomass can be used to generate power through co-firing in existing coal plants, through converting those plants to run exclusively on biomass or by building new dedicated biomass plants. Each has the advantage of being despatchable, with no clear justification for a major premium for one option over another, despite each offering slightly different values to the power generation mix:

- Co-firing and conversion may displace more carbon, reducing the costs of buying emissions permits elsewhere in the power sector.
 - Co-firing and conversion will displace emissions from existing coal generation, at an intensity of 900-1000 gCO₂/kWh, whereas new plant is likely to be displacing new gas-fired capacity, at 380-430 gCO₂/kWh.
 - The value of the extra displaced CO₂ at a £30/t carbon price¹² in 2020 is worth around £20/MWh in 2020.
 - However, we note that to the extent that subsidy for co-firing could incentivise coal plants to run more, it could lead to higher emissions. Such perverse incentives may be more likely for enhanced co-firing given the higher proportion of generation that will be subsidised and the higher subsidy available (i.e. the Government has proposed 0.5 ROCs¹³ for standard co-firing and 1 ROC for enhanced co-firing).
- Efficiency and learning are likely to be similar for both new and converted plant (Box 2).
- There may be benefits for new dedicated plants in terms of accessing feedstock, security of supply, residual value in the 2020s, and potentially increased opportunities for demonstration of biomass with CCS, but any such benefits are small (Box 3).
- New dedicated plants may also be seen as lower risk than conversion, easier to deliver in practice and a route to increasing diversity in the generation mix (Box 4). While co-firing is fairly common, conversion is currently limited to a few examples (Box 5). More generally, as an established, commercially-proven technology, biomass generation may be considered less 'risky' than Round 3 offshore wind and marine projects.

¹² i.e. the Government's carbon price floor trajectory, rising to £30/t in 2020 (2009 prices)

¹³ ROC = Renewable Obligation Certificate. Each ROC is worth around £45/MWh for renewable power generated.

Biomass applications using CHP (combined heat and power) offer a significant advantage in terms of their efficiency in converting biomass resource into energy output (e.g. they effectively have an overall efficiency of 60%, rather than around 36% for dedicated biomass plants). This would allow a greater contribution to the renewable energy target from a given amount of sustainable bioenergy resource, and therefore may be desirable depending on costs and deliverability. Whilst there are many examples of successful biomass CHP projects internationally (e.g. in Germany, Austria and Scandinavia), potential in the UK may be limited by access to heat loads and the lack of existing district heating networks.

Box 2: Efficiency, learning and supply chain development

Efficiency. Higher plant efficiencies allow power to be generated with a lower feedstock requirement, which may be advantageous even at higher costs given likely constraints on the availability of sustainable biomass. Although there is an efficiency penalty associated with converting coal plant to biomass, conversions of new, efficient large coal plant could have comparable efficiency to dedicated biomass.

- Existing coal plants have an efficiency of 34-39%, with older plants generally less efficient.
- With a 4% efficiency penalty, converted plants would have efficiencies of 32-37%.
- Dedicated biomass plants are likely to have an efficiency of around 36%, which is comparable to the expected efficiency of conversions of newer coal plant.

As we set out in our 2011 Renewable Energy Review, these efficiencies for use of biomass in power are lower than those typically achieved for biomass used in the heat sector. In the context of the 2020 renewables target therefore, biomass used in power will contribute less towards meeting the target than if it were used in the heat sector. However, where there is limited scope for use in heat, biomass in the power sector may be an effective way to reduce carbon emissions (given the high emission intensity of displaced coal), and could help build supply chains in sustainable bioenergy production.

Learning and supply chain development. As noted in section 2, biomass power is a relatively mature technology, and large savings are not expected on the capital costs. However, insofar as there could be learning through the operation and maintenance of plant, this could be achieved from operating converted plants as much as from new dedicated plants. Similarly, for both dedicated and converted plant, the supply chain (i.e. for feedstock) will need to mobilise.

Box 3: Feedstock, security of supply and value in the 2020s

Feedstock options. Co-firing and converted plant will generally need high-quality biomass, delivered in pellet form (Box 1). Whilst this is also the preferred feedstock for new dedicated plants, it is possible to design new plants to run (at a lower efficiency) on a wider range of feedstocks including waste wood and wood chips. Whilst the potential cost saving is likely to be small (e.g. £1-2/GJ), this may be desirable if these feedstocks cannot be used effectively in other applications. Small-scale plants may have an added benefit of sourcing this feedstock locally, thereby having lower lifecycle emissions.

Security of supply. New dedicated plant alongside existing coal plant will increase available capacity and hence security of supply, whilst conversion will reduce available capacity (due to the efficiency penalty associated with burning biomass rather than coal). This will also require some extra payment to the converter to make up for the residual value of their coal asset. The value of this is unlikely to be much above £10/MWh (see Box 7).

Value in 2020s. If by the 2020s new sources of biomass were to become available (e.g. breakthroughs), then there would be some value to the option to keep open a new plant in 2025 or to provide low-carbon flexibility at reduced running hours. To the extent that there is an important role for biomass CCS in the longer term, there may be some value in having some new dedicated plant on the system in the 2020s, providing CCS could be demonstrated and retrofitted on it.

Box 4: Risks and delivery

Risks. Although there are examples of projects around the world (Box 5), biomass conversion is relatively new. There is therefore a risk that in practice it may not work as efficiently as expected (i.e. building new dedicated plant may be lower risk).

Practical delivery. In section 3 we show that there is theoretically large potential from full conversion, though some of this may not be practical to deliver. A recognised pipeline of dedicated projects is also available. However:

- There will likely be transport limitations for both new plant and conversions, especially for inland plants. Given the lower volumetric energy density of biomass relative to coal, constraints on the transport network are greater (i.e. 10 million tonnes of coal is equivalent in energy terms to 18 million tonnes of wood pellets). Mott MacDonald's high level assessment is that current port and rail infrastructure would reach a limit at around 17 million tonnes of wood pellets (i.e. at 30 TWh, assuming 17 GJ/t and 35% conversion efficiency).
- New biomass projects could be built in the most practical and economic location (e.g. close to domestic fuel sources or portside if importing fuel). They therefore have an advantage – that will be reflected in their costs – over some coal plants (which were often sited based on proximity to coal fields).

Diversity

- Biomass power is predictable and dispatchable, (i.e. theoretically available to generate electricity on demand).
- The majority (80%) of projects in the pipeline are small projects (i.e. less than 50 MW) making up 17% (800 MW) of pipeline capacity. Many of these will connect directly to the distribution network therefore avoiding losses in transmission.
- A large number of new biomass projects in the pipeline (3 GW, 65% of capacity) are from independent developers, in contrast to conversion which favours owners of legacy coal plant.

Box 5: UK and international evidence on biomass conversion

UK and wider EU experience

A small number of coal plants have converted, or are in the process of doing so:

- GDF Suez recently completed the conversion of a plant in Belgium, generating 180MW primarily from Canadian wood pellets.
- RWE is converting Tilbury to a dedicated 750MW biomass plant, primarily burning wood pellets imported from a purpose-built facility in the USA.
- Drax has announced interest to convert one of its six 660MW units, pending the outcome of the Renewable Banding consultation.

We understand that a further number of plants in the UK are considering conversion, but are yet to make public announcements.

International experience

Whilst conversion of large-scale coal plants has not been very common in the UK or Europe, there have been a number of projects worldwide (albeit operating on a relatively smaller scale).

- Dominion Resources is converting three of its coal plants in the US, generating over 150MW using waste wood.
- DP CleanTech is converting a coal-fired CHP plant in Thailand to burn waste wood and eucalyptus bark to provide 20MW of electricity to a nearby bioethanol plant.

Conclusions on value of biomass options

As a predictable and despatchable source of electricity, biomass power generation offers some benefits over other renewables. However, given higher lifecycle emissions, limited long-term value and competition for biomass resources from other sectors offering higher conversion efficiencies, alternative forms of low-carbon power are likely to be preferable where available, unless biomass power is available at significantly lower costs.

Within the options for large-scale biomass power generation (i.e. co-firing, conversion and new dedicated) there is no clear evidence that any should be supported at a significant premium over the alternatives where available. There are advantages to small-scale dedicated plants that are able to use resources that otherwise would go unused and the application of CHP could in principle maximise the contribution to renewable energy targets.

In order to identify the appropriate role for biomass use in power generation, it is therefore important to establish the availability and costs for the different options, to which we now turn.

3. Potential and costs of biomass generation options

This section sets out the potential and economics of the large-scale biomass generation options – co-firing solid biomass with fossil fuels, enhanced and full conversion of existing coal plant to solid biomass, and new dedicated biomass plant. It also includes our underpinning assumptions, starting with our assumptions on fuel prices.

Fuel price assumptions

We base our analysis on a range of feedstock costs and transport costs, recognising that the biomass price is very uncertain, given that the market for biomass is relatively immature and quite different to that for other fuels (e.g. gas and coal):

- There is no established spot or futures market for biomass feedstock. Fuel is more commonly negotiated on a bilateral basis between suppliers and generators. Consequently, reported spot prices (e.g. Argus Biomass Index) may not reflect the price generators are actually paying.
- To reduce risks, generators will seek to secure feedstock on long-term contracts, thereby protecting them from price spikes and volatility. In turn, suppliers may be reluctant to sign long-term contracts as they will be unable to reflect changes in their costs or opportunities. As a result, parties may agree contracts that are linked to factors such as raw material prices, the retail price index, etc.
- To increase security of supply and reduce risks, some generators have chosen to establish joint ventures with supply companies (for example, RWE has invested in a pellet plant in the USA¹⁴).

Therefore, it is very difficult to observe trends for prices and predict prices in the future. We have used a high-low range for prices which remain flat over the projection period and are broadly in line with recent price trends.

- In a central scenario, we assume a high quality (i.e. 17 GJ/t) pellet feedstock, at £7.1/GJ (remaining flat over time), with a high-to-low range of £6.2-8.2/GJ (Table 1). Whilst this may be a reasonable assumption for the near term, we expect prices to rise significantly in the longer term as demand from other sectors/countries increases because of tightening emissions constraints.
- To take into account higher (lower) freight and discharging costs for existing coal plants located inland (portside), a small adjustment is made in the coal conversion calculations. This varies from £-0.40/GJ for portside locations (e.g. Tilbury, Kingsnorth) to £+0.35/GJ for inland stations (e.g. Rugeley).

¹⁴ The plant in Georgia is the largest in the world, and expected to supply fuel for co-firing in RWE coal plants in the Netherlands, and for use in Tilbury in the UK, which will reopen in 2012 as a converted coal plant.

Table 1. Biomass fuel price assumptions (£2010)			
	High	Central	Low
Fuel price, £/GJ	8.2	7.1	6.2

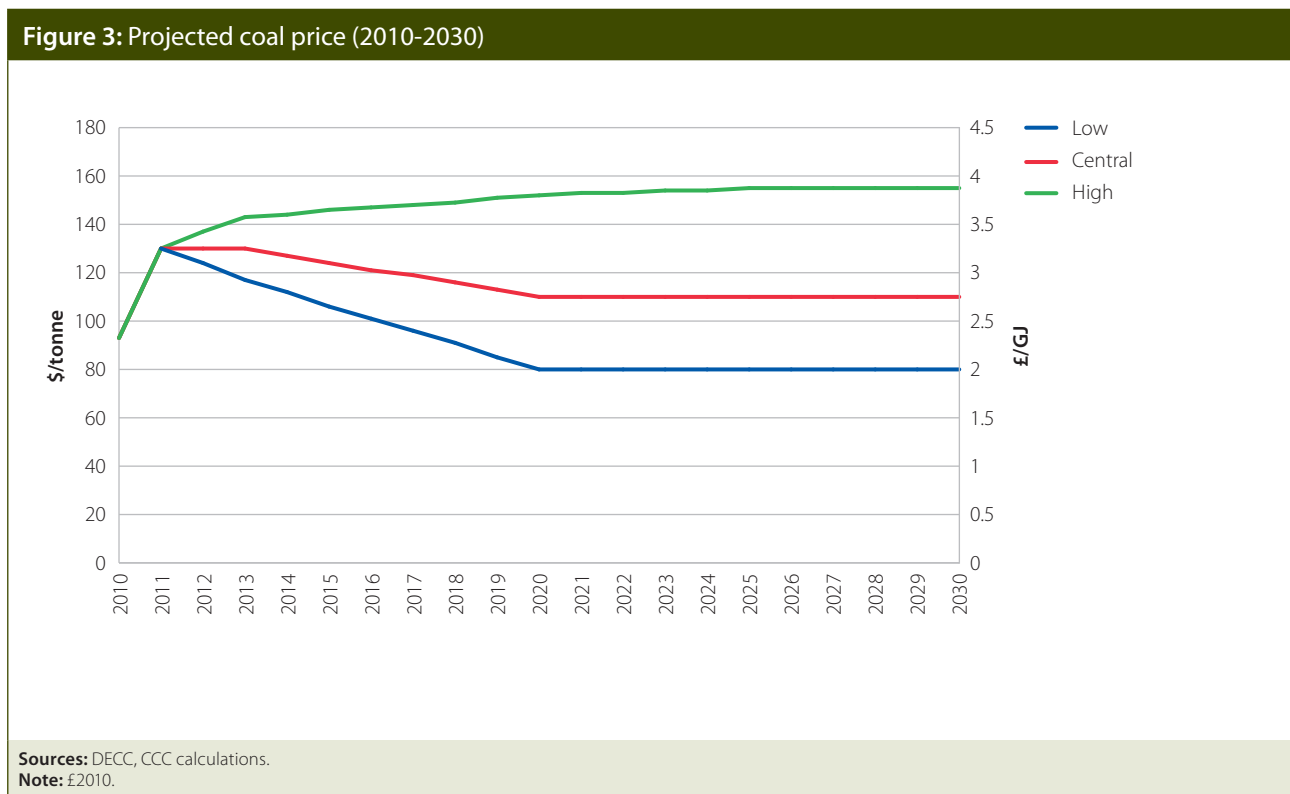
Source: CCC.

Further investment in new capacity and development of supply chains will help reduce the price. On the other hand, increasing demand from other sectors/countries in the longer-term will increase the price.

Given our appropriate use modelling, looking further ahead we expect biomass prices to rise significantly beyond 2030 as emissions constraints tighten.

For coal, we use the latest DECC projections for fuel costs (Figure 3):

- We assume a central scenario of \$130/t in 2011 falling to \$110/t from 2020 onwards.
- Assuming an exchange rate of 1.54 (i.e. 2010 average) this equates to £3.3/GJ and £2.8/GJ in a central case, with a high-low range of £2-4/GJ in 2030.



Co-firing with fossil fuel

Co-firing solid biomass with fossil fuels at low levels (e.g. 5%) may not incur any capex requirements and is driven purely by the fuel costs. Based on our assumptions for fuel cost and plant efficiencies this is comparable with the cost of burning coal facing a carbon price of £30/tCO₂ consistent with the Government’s carbon price floor trajectory for 2020 (Figure 4).

However, the potential from co-firing is limited, given expected declines in coal generation over the next decade (Figure 5), reflecting increasing carbon prices and tightening environmental constraints (e.g. the LCPD and IED – Box 6).

Figure 4: Cost of co-firing solid biomass and coal (including a carbon price) under low, central and high fuel price assumptions

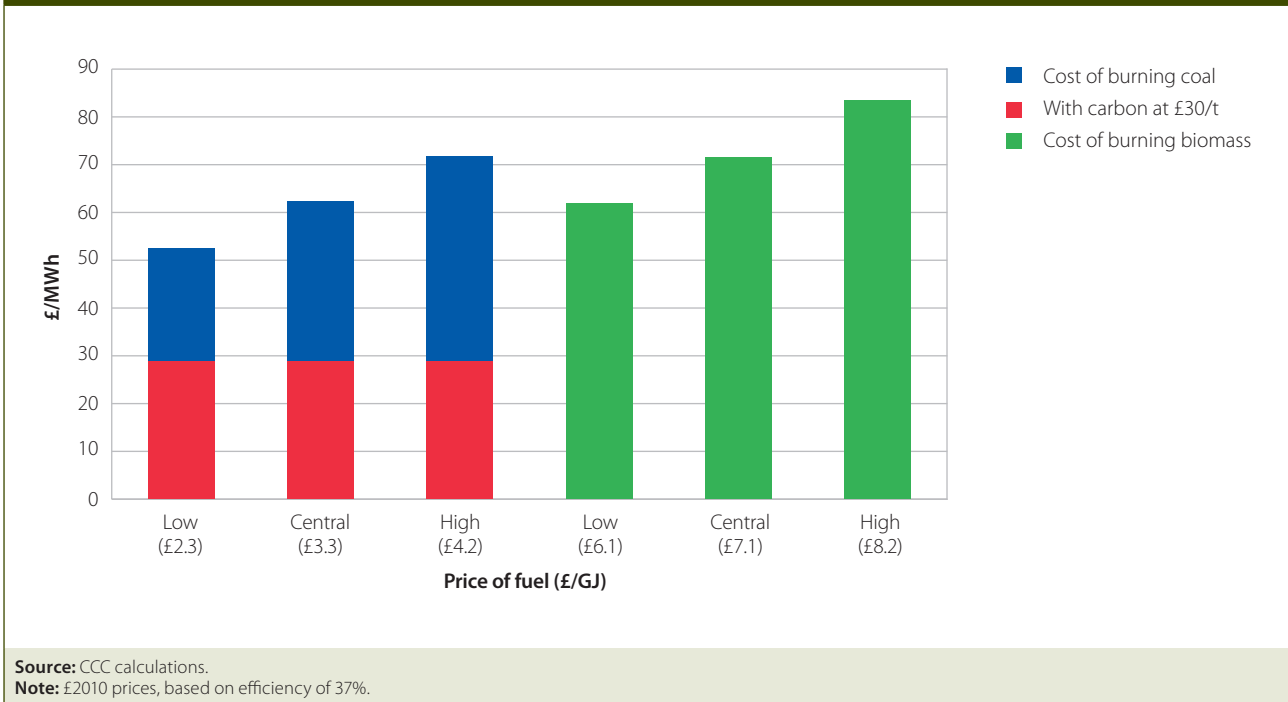
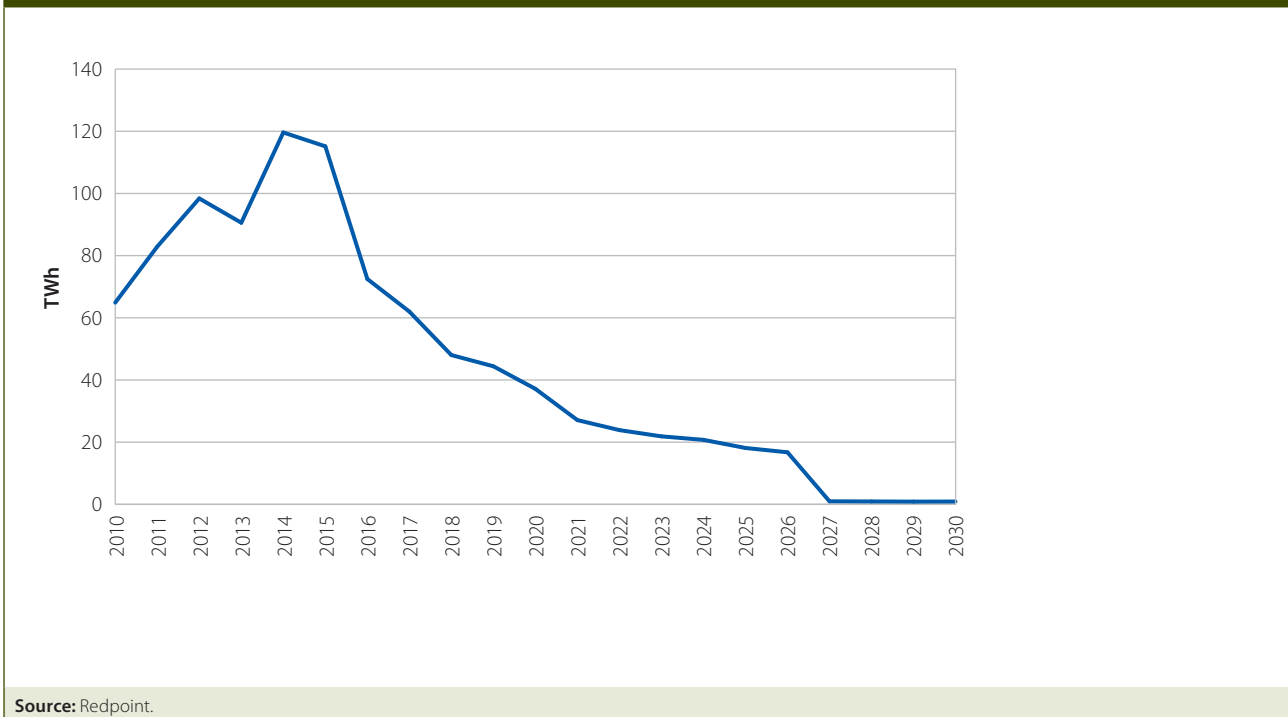


Figure 5: Coal generation (2010-2030)



Box 6: Large Combustion Plant Directive and the Industrial Emissions Directive

The Large Combustion Plant Directive (LCPD), introduced in 2001, regulates emissions of nitrogen oxide (NO_x), sulphur dioxide (SO₂) and particulates from power plants greater than 50MW across the EU.

- Plants that have chosen to opt out may continue to run until 2016, but can only operate for 20,000 hours (2008-2015). If they reach this running hour restriction before 2016, they may be forced to cease operations.
- Plants that have chosen to opt in must comply with Emissions Limit Values (ELVs) for the three pollutants. This may involve undergoing full biomass conversion.

In 2010 the LCPD was combined with six other existing directives to form the Industrial Emissions Directive (IED).

- Plants that have opted out of the LCPD can continue to operate for longer if they agree to 'Part 2' emissions limits (Table B1). These emissions limits are more stringent than for plants opting into the LCPD and are likely to require installation of Selective Catalytic Reduction (SCR) equipment and particulate controls (baghouses), as well as flue gas desulphurisation (FGD) if plants burn coal.
- Plants that have opted in to both the LCPD and IED do not face restrictions on hours of operation but must agree to 'Part 1' emissions limits (Table B1). If plants convert fully to biomass, FGD will not be required.
- Plants that have opted in to the LCPD but not opted into the IED will have their hours of operation capped at 17,500 hours from 2016 to 2023 (equating to an annual capacity factor of approximately 25% over the eight year period).

Table B1: Emission limit values under the Industrial Emission Directive

	Part 1		Part 2	
	Coal	Biomass	Coal	Biomass
NO _x	200	200	150-200	150
SO ₂	200	200	150-200	150
Particulate Matter	20	20	10	20

On basis of 0°C, 1 atmosphere, dry and 6% O₂

Source: Mott MacDonald, European Commission

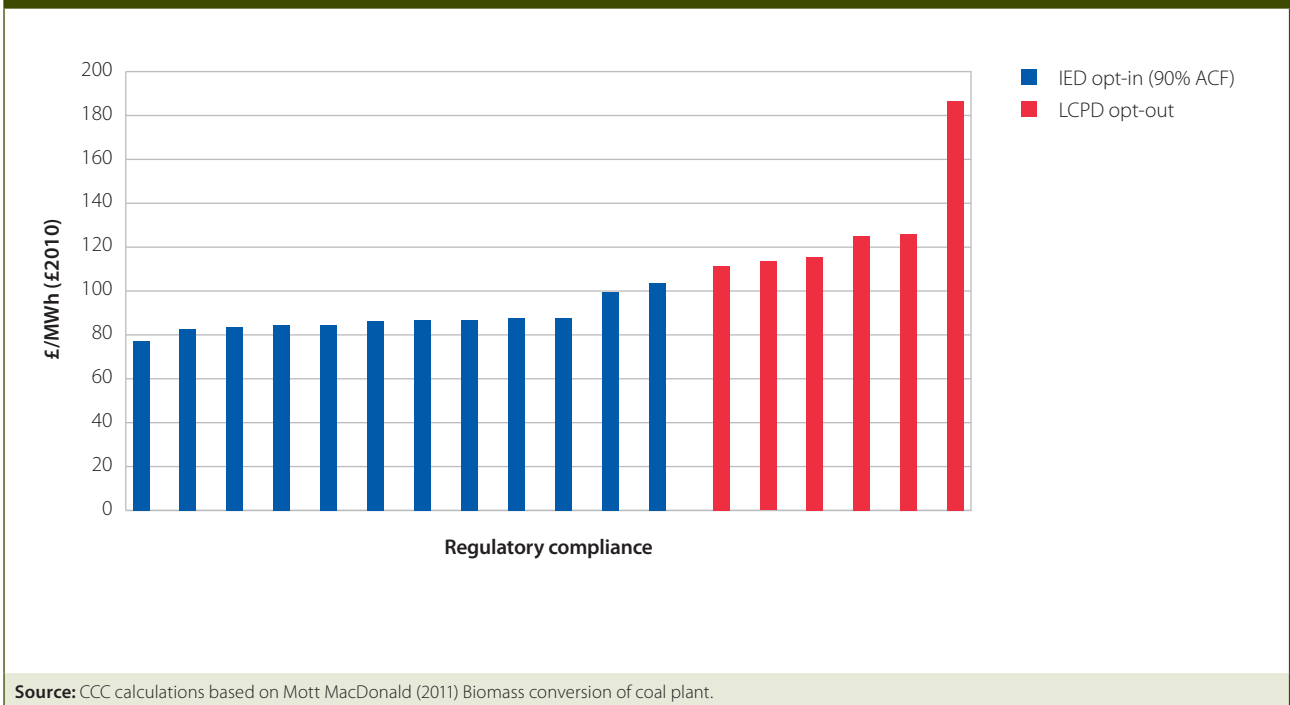
Conversion of existing coal plant to biomass

To go beyond the limited potential offered by small amounts of co-firing requires capital investment.

Analysis that we commissioned from Mott MacDonald (MML) (Box 7) indicates that the economics of converting the UK's existing coal plants to biomass are potentially favourable and that these offer a significant opportunity for renewable generation (e.g. over 100 TWh of generation may be available at around £80-90/MWh, compared to offshore wind costs of £100-150/MWh in 2020):

- Figure 6 shows the levelised cost of conversion of the 18 plants considered in the MML study, under central fuel prices and assuming plants opted in to the LCPD also opt into the IED and run at full load operation (i.e. 90% Annual Capacity Factor (ACF)). It shows a large number of opt-in plants at £80-90/MWh, with opted-out plants unsurprisingly facing higher costs, given shorter lifetimes.

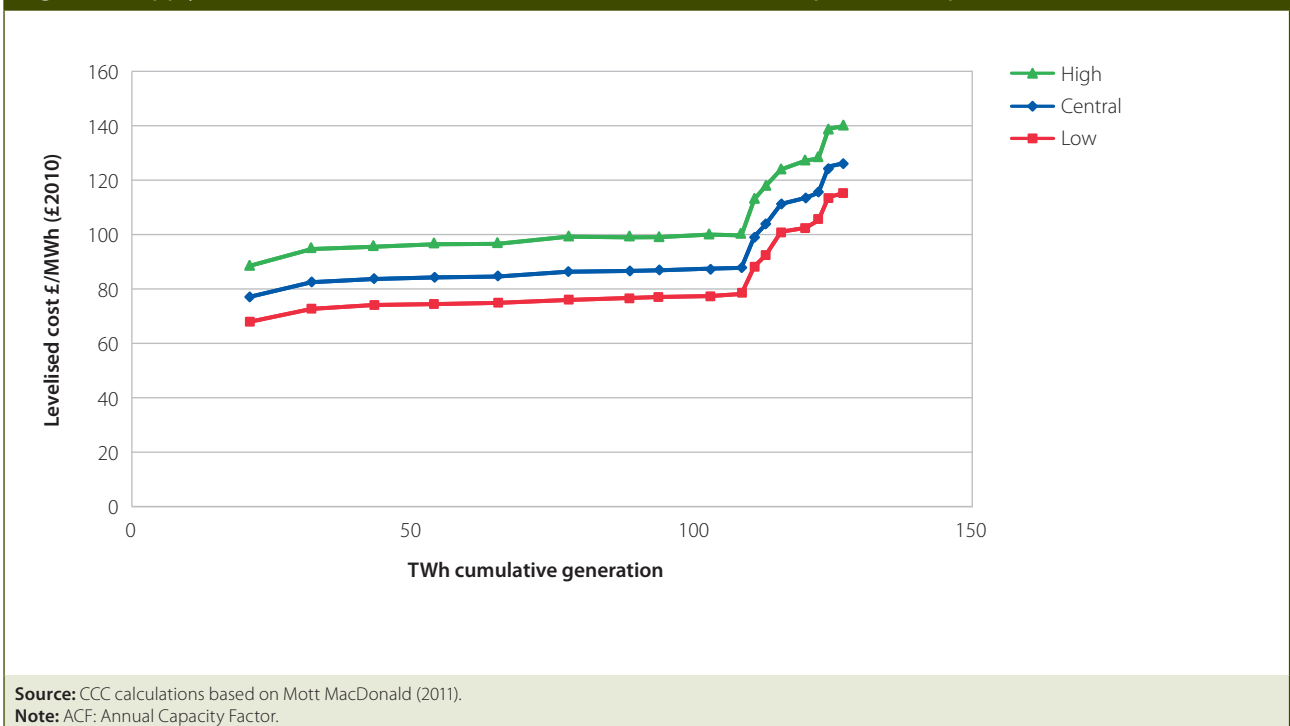
Figure 6: Levelised cost of biomass full conversion by plant – central fuel prices, IED opt-in, 90% ACF



Source: CCC calculations based on Mott MacDonald (2011) Biomass conversion of coal plant.

- Figure 7 plots the same costs (i.e. 90% ACF) against cumulative TWh of generation, and shows the variation under high/low fuel prices. Assuming full-load operation, there is a large amount (over 100 TWh) of generation available at £80-90/MWh, with ± £10/MWh variation in cost under low/high biomass prices.

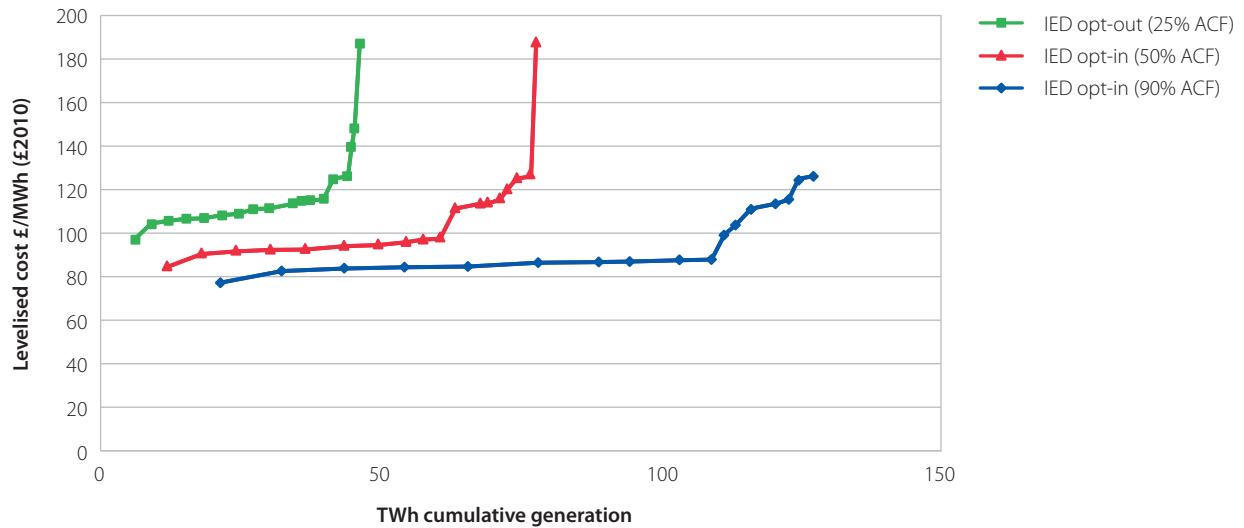
Figure 7: Supply curve of biomass full conversion under alternative fuel prices, IED opt-in, 90% ACF



Source: CCC calculations based on Mott MacDonald (2011).
 Note: ACF: Annual Capacity Factor.

- Figure 8 compares full load operation against 50% ACF and opting out of IED (25% ACF). For plants opted into IED costs increase by around £10/MWh at 50% ACF. If plants chose not to opt in the IED, although this will reduce capex, overall levelised costs are higher as the investment is annuitised over limited running hours.

Figure 8: Supply curve of full biomass conversion, IED opt-in/out (central fuel prices)



Source: Mott MacDonald (2011).
 Note: ACF: Annual Capacity Factor.

Box 7: Economics of converting existing coal plants

The capital cost of full conversion (including compliance with environmental legislation) could amount to around £200/kW for a typical 2 x 500 MW station, i.e. 12% of a new coal plant's EPC costs, with a variation of $\pm 25\%$ and small economies of scale. This does not include the cost of portside and transportation infrastructure, which may be significant and would vary on a plant-by-plant basis. To take account of this the delivered fuel price is adjusted $\pm £0.4/\text{GJ}$ depending on plant location.

Given the lower energy density and combustion dynamics associated with solid biomass, conversion leads to a de-rating of capacity and a small reduction in the efficiency of the base plant. MML assume a derating of 30% with an efficiency penalty of 4%, i.e. a 1 GW coal plant with 37% efficiency upon full conversion would become 700 MW at 35.5%.

To calculate levelised costs, we have explored the following:

- **LCPD opt-out:** For plants opted out of the LCPD (6 plants) (Box 9), annual capacity factors (ACF) are calculated by dividing the remaining running hours expected by end-2011 by three – i.e. the number of years the plant is assumed to run on biomass (2013-2015). Plants that have relatively few running hours remaining (e.g. Cockerzie) have low ACFs (13%), which will drive significantly higher annuitised costs than for those with more hours left (e.g. Ironbridge, 46% ACF).
- **LCPD opt-in:** Plants that are opted in to the LCPD are then subject to IED. There are effectively two options:
 1. **IED opt-in:** Plants may choose to opt in the IED, and will be required to invest in equipment to comply with NO_x and PM emissions limits (Box 9). Environmental costs are assumed to comprise a one-off £20m investment, plus £75/kW for SCR and Baghouses. In return for this investment, plants do not face any constraints on operation. We have explored two sensitivities:
 - **Full load operation** (90% ACF)
 - **50% ACF** (reflecting market constraints on dispatch, e.g. if there is a significant amount of wind at low/zero short-run marginal cost also on the system, or if less feedstock is available cost-effectively than expected).
 2. **IED opt-out:** If a plant chooses not to opt in to IED, it avoids the additional costs of environmental compliance. However, in return they face limited hours of 17,500 between 2015 and 2023, which (if spread equally over the 8-year period) implies an ACF of 25%.

We calculate levelised costs using a 10% discount rate, and assume a 10-year life for LCPD opted-in plants, with sensitivities at a range of fuel prices and load factors.

Residual value of coal plant

Our cost estimates for conversion exclude any allowance for the earnings that would have accrued to plant had it operated as a coal plant (i.e. the 'residual value'). This is likely to be small for existing coal plants, given limited lifetime and higher running costs relative to new plant. Moreover, the cost of a new Combined Cycle Gas Turbine plant depreciated over baseload operation would amount to an additional £15-20/MWh, thereby providing an upper limit of the potential residual value to consumers. For converted plants that go on to operate at baseload, the residual value could amount to around £10/MWh, assuming that it operates at peak or mid-merit. Even allowing for such residual value, the cost of conversion is considerably lower than the cost of new dedicated plant.

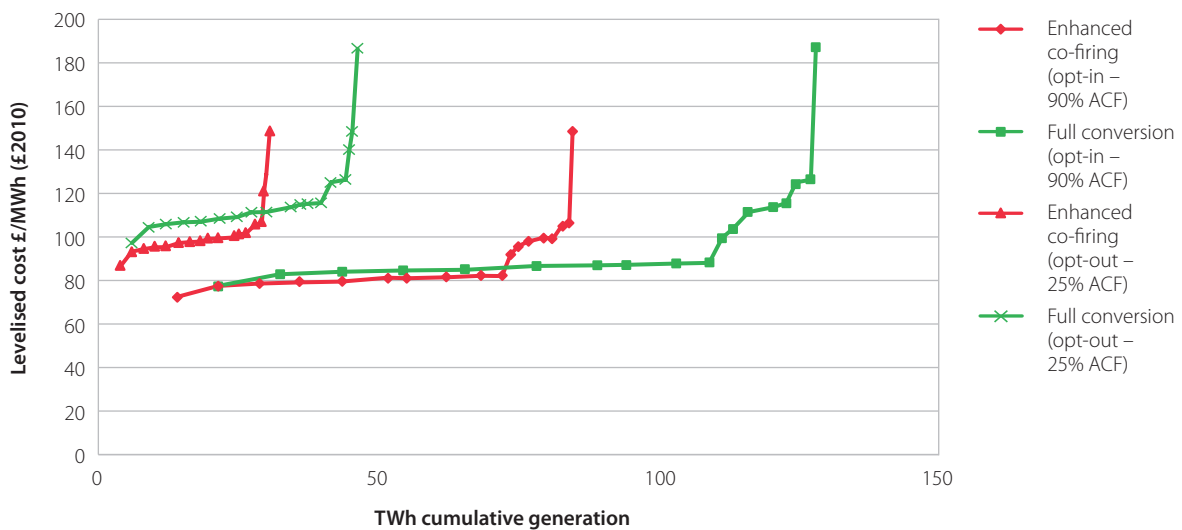
The MML analysis also considered the costs of enhanced-cofiring on a 50:50 (energy input) basis. Costs are broadly similar to full conversion, with potential generation of roughly half the potential from full conversion (i.e. over 50 TWh) (Box 8).

Box 8: Enhanced co-firing

Enhanced co-firing is an intermediate option between co-firing small amounts (e.g. no more than 10%) and full conversion. Mott MacDonald (MML) considered this on a 50:50 input basis:

- Enabling a higher share of co-firing could require considerable additional capex. MML estimate that this could be more expensive (in terms of £/kW of biomass capability) than full conversion, given the requirement for duplicate fuel handling systems, storage equipment and plant modifications.
- Offsetting this, the de-rating of units is lower, e.g. 7.5% versus 30% as assumed for conversion. Furthermore the efficiency penalty is also lower (e.g. 0.5% versus 4% for full conversion).

Figure B8 Supply curve – enhanced co-firing and full conversion



Source: CCC calculations based on Mott MacDonald (2011).
 Note: ACF: Annual Capacity Factor.

New dedicated biomass

Analysis of the capital cost involved in building a base plant from scratch (Box 9) indicates a higher cost for new dedicated biomass plants than for co-firing and conversion of existing coal plants, based on an equivalent methodology and fuel price assumptions:

- **Capital costs (capex).** Based on capex assumptions compiled for our Renewable Energy Review, at a 10% discount rate we estimate the levelised cost of new large-scale solid biomass plant in the region of £115-150/MWh by 2020 (Figure 9). As noted above, the scope for learning in biomass generation is far less than for other renewables such as wind, marine and solar generation, with only limited reductions in capex expected to 2050.
- **Financing cost.** Costs could be higher if investors apply a higher discount rate than 10%, given uncertainty over biomass fuel costs and the expectation that these will rise significantly in the longer term (as set out in section 3). Although other fuel costs are also uncertain (e.g. gas, oil), markets for these fuels are well-established and liquid, whereas the market for biomass feedstock is immature. Developers may therefore be less able to hedge or secure long-term contracts, increasing the risks of a biomass investment. Figure 10 shows sensitivities combining high-low fuel prices and capex with high-low (9-13%) discount rates. It shows that the cost range for projects starting today broadens to £120-160/MWh under central fuel prices, with approximately \pm £10/MWh in variation under the low/high biomass price assumption. Discount rate assumptions are less important for co-firing and conversion given the lower capital costs involved.
- **Alternative cost estimates.** An assessment for DECC by Arup and Ernst & Young estimates costs at the high end of this range (£150-160/MWh) in 2020, reflecting a slightly higher estimate of capital cost and a high assumed discount rate of 12.7%.

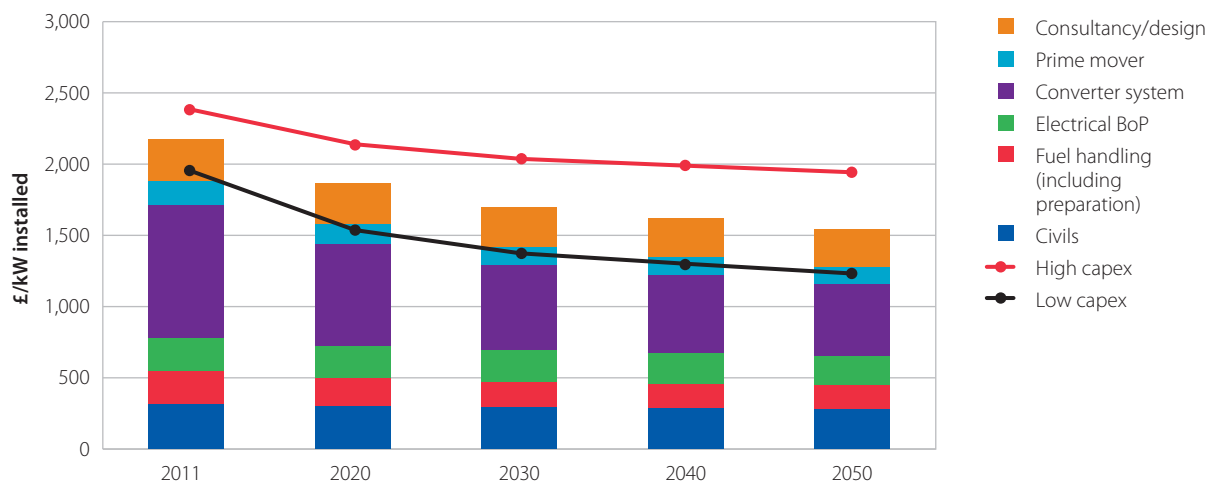
Box 9: Economics of new dedicated biomass

Cost analysis for our renewables review was also commissioned from MML. The cost estimates for new dedicated biomass were based on circulating fluidised bed (CFBC) combustion technology. MML estimated:

- Capital costs (capex) currently in the region of £2,000-2,400/kW (Figure B9), based on one 150 MW unit, with a conversion efficiency of around 36%.
- Given that the technology is reasonably well established, capital costs are not expected to decline as rapidly as for less mature technologies like offshore wind.
- Operating costs for plant starting today are in the order of £60,000/MW (i.e. 3% of EPC costs), with small cost reductions expected over time.

An assessment by ARUP/E&Y for DECC suggested slightly higher costs, with the median estimate for projects >50 MW reaching financial close in 2015 in the order of £2,400/kW, high – low range £2250-2790/kW¹⁵. Operating costs are also higher, i.e. >£100/kW or 5-6% of the capital costs¹⁶.

Figure B9: New dedicated large scale biomass (CFBC) capital costs, 2011–2020

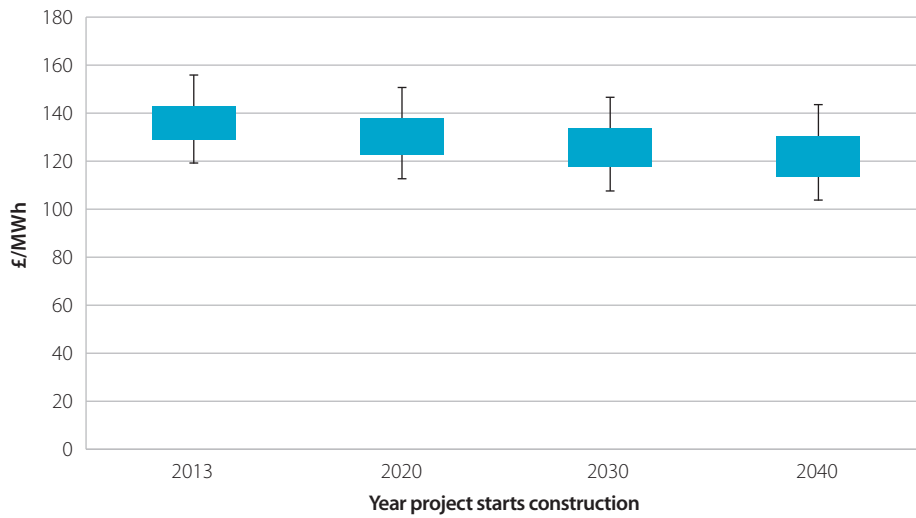


Source: CCC calculations based on Mott MacDonald.
Note: £2010. BoP: Balance of Plant.

¹⁵ Rounded to the nearest £10.

¹⁶ ARUP (2011) Review of the generation costs and deployment potential of renewable electricity technologies in the UK.

Figure 9: Levelised cost of new dedicated biomass with a 10% discount rate (2011-2040)



Source: CCC calculations based on Mott MacDonald.

Notes: 10% discount rate, £2010. Solid bars represent the high/low capex under central fuel prices, thin extending lines show sensitivity to combined high/low capex and fuel prices.

Figure 10: Levelised cost of new dedicated biomass, high-low discount rate range (2011-2040)



Source: CCC calculations based on Mott MacDonald.

Notes: £2010. Solid bars represent the high/low capex figures combined with medium discount rate and central fuel prices, thin extending lines show sensitivity to combined high/low capex and fuel prices with high/low discount rate range.

Conclusions on potential and costs

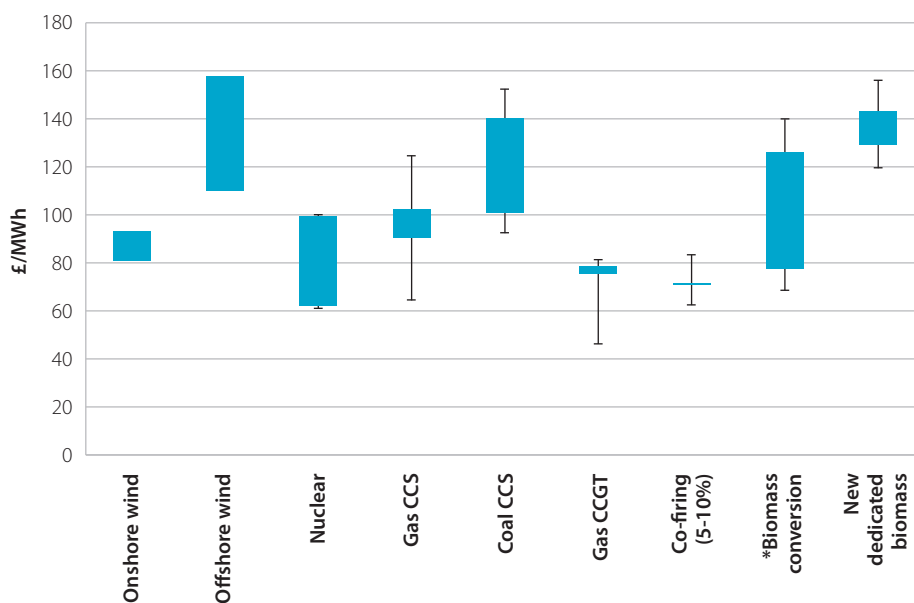
Figure 11 sets out the relative costs of the large-scale biomass options assessed above (i.e. co-firing, conversion and new large-scale dedicated) against alternative low-carbon sources and unabated gas-fired generation, as estimated for our Renewable Energy Review.

This demonstrates a clear economic advantage for co-firing and conversion over new dedicated biomass and over offshore wind. There is therefore a strong case for supporting the former options as a route to meeting the 2020 renewables target at lower cost, within the limits of the available sustainable resource. Our analysis also indicates that the potential from enhanced co-firing and conversion (i.e. up to 100 TWh) is more than enough to deliver the Government's ambition for additional biomass power generation (i.e. 32-50 TWh in 2020).

The cost of new large-scale dedicated plant is of a similar order of magnitude to offshore wind, suggesting it should not be supported as a significant part of the mix:

- While there are technology policy arguments to justify support for offshore wind (i.e. subsidies are required in the near term to support deployment and drive down costs for future deployment), these are less relevant for biomass, given its maturity and likely limited role in the long term.
- Furthermore, paying a premium for new dedicated plant would be questionable from a carbon perspective, particularly under the current sustainability framework (e.g. it would be preferable to pay slightly more for offshore wind, and to gain a much higher carbon benefit).

Figure 11: Cost of large-scale biomass power and other low-carbon technologies



Source: CCC calculations based on Mott MacDonald (2011).

Notes: £2010. Costs are for projects starting in 2011 and entering operation after 2015. 10% discount rate. CCS and gas CCGT includes a carbon price rising to £30/tCO₂ in 2020. Thermal plants are assumed to run at baseload (i.e. 90% annual capacity factor). Solid bars represent the high/low capex range and central fuel prices; thin extending lines show sensitivity to combined high/low capex and fuel prices. *Conversion costs for 17 out of the 18 plants considered in the study.

We therefore recommend that the Government should explicitly state that support under the Renewables Obligation for new dedicated biomass plant will only be provided for small-scale plants. Alternatively, and at a minimum, any support for new large-scale dedicated biomass should be limited to a very small number of projects. This recommendation reflects our assessment of the current proposals for renewables support and the different opportunity offered by small-scale plants:

- Although the Government has stated its intention to focus on co-firing and conversion, the proposed levels of support risk bringing forward new dedicated capacity, which would add considerable additional cost to consumers (in the order of £175 million/GW/year of new plant added if it displaces cheaper uses of scarce biomass supply – Box 10).
- As noted in section 2, there may be opportunities for small-scale dedicated biomass plants that are able to use feedstocks that have low lifecycle emissions and/or may otherwise be unused (e.g. waste wood) and that may have potential to apply CHP, generating a larger contribution towards renewable energy targets.

Box 10: Proposed support for enhanced co-firing, conversion and new dedicated plant

The Government has stated that its focus will be on co-firing and conversion, and has proposed levels of support in the ROC Banding Consultation for England and Wales¹⁷ consistent with the underlying economics of these options. However, it has also proposed a premium of 0.5 ROCs for new dedicated biomass (i.e. 1.5 ROCs, worth around £70/MWh for new plant, versus 1 ROC, worth around £45/MWh for enhanced co-firing and conversion).

As Figure 11 shows, that could be sufficiently high to bring forward investment in large-scale plant (including the wholesale electricity price it would give revenue of around £140-145/MWh, compared to our estimated range for costs of £130-145/MWh), of which there is around 3.7 GW currently in the project pipeline. At the rates of support proposed, one outcome could be competition with co-firing and conversion for scarce fuel supply, with possible displacement of these options at an annual consumer cost of £175 million/GW/yr of new plant added.

Alternatively, and if investment in new dedicated biomass were to be additional to co-firing and conversion, this could displace investment in offshore wind. The financial saving would be very low at levels proposed in the ROC banding review (e.g. around £20-25/MWh) but emissions reductions could be 80%+ lower than from offshore wind under current sustainability criteria.

¹⁷ DECC (2011) Consultation on proposals for the levels of banded support under the Renewables Obligation for the period 2013-17. www.decc.gov.uk.

4. Conclusions and policy implications

The key messages from our analysis are:

- **Sustainability.** The role of biomass in power should be dependent on the availability of sustainable supply (i.e. not top-down targets). In order to ensure sustainable supply, strengthening of the regulatory framework under the Renewables Obligation is required.
- **Conversion/co-firing and new dedicated.** Where available, near-term use of biomass in power should be where it is most economic, which our analysis indicates is in co-firing and conversion, not new large-scale dedicated plant. There may also be a role for small-scale projects, particularly those which supply combined heat and power, accessing locally sourced woodchips or wastes (which are not generally used for conversion and enhanced co-firing).
- **Support for biomass power generation.** Support under the Renewables Obligation should focus on co-firing and conversion. For new dedicated biomass projects, support should be limited to small-scale plants, and CHP plants. Alternatively, and at a minimum, any support for new large-scale dedicated plant should be limited to a very small number of projects.
- **Longer-term role for biomass power generation.** In the longer term we identify an important role for biomass generation with CCS as a way of achieving negative emissions, but no role for large-scale biomass power generation without CCS.



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