ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME

International Renewable Energy Agency

Biomass
for Heat and Power

Technology Brief

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

About IEA-ETSAP

The Energy Technology Systems Analysis Programme (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976. It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/economy/environment/engineering (4E) analytical capability.

Its backbone consists of individual national teams in nearly 70 countries, and a common, comparable and combinable methodology, mainly based on the MARKAL / TIMES family of models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses.

ETSAP promotes and supports the application of technical economic tools at the global, regional, national and local levels. It aims at preparing sustainable strategies for economic development, energy security, climate change mitigation and environment.

ETSAP holds open workshops twice a year, to discuss methodologies, disseminate results, and provide opportunities for new users to get acquainted with advanced energy-technologies, systems and modeling developments.

Insights for Policy Makers

Biomass—defined as "organic matter derived from plants or animals available on renewable basis"—is used for energy applications covering a variety of practices and technologies, ranging from traditional heat production for cooking and/or space heating to modern combined heat and power generation or biofuels production. In 2012 bioenergy accounted for about 10% or 51 EJ of global energy demand—notably larger than any other single renewable energy option. Of these 51 EJ, the vast majority (27 EJ) came from the use of biomass in traditional wood-stoves in developing countries. This figure has remained rather constant over the years. In terms of high-efficiency biomass use and the carbon-neutral nature of biomass combustion, growth in bioenergy utilisation is currently observed in biomass-based electricity generation systems, accounting for approximately 6 EJ. Fluidised bed combustion, biomass co-firing in large-scale coal power plants and biomass-based medium-to-small combined heat and power (CHP) plants comprise widely-applied technology options for power generation. Especially biomass co-firing reduces greenhouse gas emissions from coal-fired power and enables efficiencies higher than those for 100% biomass power plants.

As biomass is distributed worldwide, one of the advantages of biomass utilisation for energy is that almost every countries can utilise their own biomass resources. On the other hand, the energy density of biomass is lower than that of fossil fuels. Although the biomass pre-treatment process has been developed technically, proper collection and transportation is still required for its efficient utilisation. Seasonal/annual fluctuation in biomass supply, due to its biological nature and environmental diversity, is another important characteristic. Taken together, these indicate that securing good quality feedstock at affordable prices over a plant's lifetime is crucial for biomass power projects. The multi-dimensional role that biomass plays is one of its unique characteristics. It is currently utilised for food, feed, fibre and energy supply, all using the same land for its production. It also supports different types of ecological aims, including biodiversity, greenhouse gas (GHG) emission reductions and landscape development. Bioenergy utilisation can dynamically change those relationships and produce either positive or negative impacts, both locally and globally.

To enhance the multi-dimensional role of biomass' while mitigating the possible trade-offs associated with bio-energy deployment, an effective policy *mix* is needed rather than a single stand-alone policy or individual policy measures. National targets are a common measure introduced in order to ensure bioenergy markets over the medium term. A number of countries (*e.g.,* Brazil, Germany, the UK) have introduced biomass power generation targets. However, the relatively higher cost of bioenergy can be a barrier to achieving this target. Under such circumstances, economic incentives, such as Feed-in-Tariffs (FITs) or tax credits, are required, at least at the initial stage of development. The important issue to be acknowledged when these economic incentives are introduced is that they may entail financial burdens and hinder the technology's development over time if incentives are set too high. A careful examination of technology costs and trends is important so that economic measures are applied efficiently and effectively. "Tariff degression"— introducing progressive tariff reductions—is an approach to support technology cost reductions while providing economic incentives to bioenergy developers. It is crucial for investors and project developers alike that a viable bioenergy market is assured over the project's lifetime. Currently, most of the market for bioenergy has been opened and expanded in association with government policy. Thus, policy stability is the first criterion for investors and project developers to evaluate the bioenergy market during the project's lifecycle.

One of the main challenges related to bioenergy is the management and optimisation of potential benefits and trade-offs, such as GHG savings, biodiversity, employment opportunities and energy/food security. A comprehensive approach which covers all the sustainability issues from their economic, environmental and social perspectives is needed. There are many ongoing initiatives, such as the Global Bioenergy Partnership (GBEP) sustainability indicators and various certification systems for sustainable forest management. Discussions on sustainability criteria for solid biofuel are ongoing in EU Member Countries. More efforts are required to establish a common approach through collaboration among governments, the research and private sectors and civil society.

Technical Highlights

- **Process and Technology Status –** In 2012, the total bioenergy supply was over 51 EJ, comprising some 10% of the total world's energy supply. An estimated 50% of this biomass energy is consumed in developing countries for traditional uses (*i.e.,* heating and cooking) with a very low efficiency (IRENA, 2014), while modern biomass use for electricity production currently supplies 1.5% of the electricity demand on a global scale, corresponding to about 280 TWh of electricity (IEA, 2012). High-efficiency biomass uses, such as **fluidised bed combustion**, **co-firing with fossil fuels**, **CHP co-generation** and **gasification** are rapidly increasing worldwide. The overall efficiency of biomass-based CHP plants for industry or district heating ranges from 70%-90% (IEA, 2012). A range of biomass pre-treatment and upgrading technologies, such as **pelletisation**, **torrefaction** and **pyrolysis**, have been developed in order to improve biomass characteristics and to make handling, transportation and conversion processes more efficient and cost-effective. Biomass-fired power and CHP plants can be characterised by their burner and boiler technology. Water-cooled, vibrating grate (VG) boilers are an established technology for power generation from wood residues. Based on natural circulation, these boilers are designed to burn low-heating-value (*i.e.,* LHV of about 13.8 MJ/kg) wood residues with 30% humidity. The typical power plant capacity is on the order of 10 MWe. Fluidised bed and bubbling fluidised-bed combustion (BFBC) boilers for solid biomass are today's commercial technologies that ensure high efficiency, low emissions and high fuel flexibility but require high initial investments for larger scale applications (over 20 MWt). Continued improvements in CHP technology have enabled a new generation of plants that offer advanced steam parameters and high efficiency. Circulating fluidised bed combustion (CFBC) boilers offer a further option for biomass-fired CHP. The choice between BFBC and CFBC depends *inter alia* on the fuel used. CBFC boilers are used in large CHP or power plants, with a capacity of hundreds of MWe, but also in small-scale power generation with unconventional fuels, such as waste coal and biomass, with lower fuel properties and higher fuel flexibility. Biomass co-firing in coal-fired power plants also offers high efficiency between 36%-44%. However, co-firing in coal power plants requires significant boiler retro-fitting, as well as specific equipment and space for biomass logistics. Tailoring of flue gas cleaning equipment is also needed, especially for significant amounts of biomass co-firing. As compared to coal firing, biomass co-firing may reduce NO_x emissions since biomass has a lower nitrogen content. Wet biomass (*e.g.,* manure or other waste) could also be utilised in small-scale CHP plants using biogas from anaerobic digestion. Today the use of biogas is common practice in many European countries.

- **Costs –** The investment cost of biomass-based power generation and CHP ranges from less than USD 4 000/kW to USD 7 000/kW. The cost of anaerobic digestion power systems ranges from USD 2 574-6 100/kW. The cost for retro-fitting coal power plants for the biomass co-firing ranges between USD 140-850/kW. The total annual Operation and Maintenance (O&M) cost of biomass power plants is typically 3%-5% of the capital cost for large capacity, 5%-6.5% for small capacity and 2.5%-3.5% for co-firing power plants. The feedstock cost has an important impact (40%-50%) on the total electricity production cost. Typical biomass feedstock costs (excluding transport) vary from negative to no-cost for waste, from USD 0-4/GJ for processing residues, from USD 4-8/GJ for locally collected feedstock and from USD 8-12/GJ for internationally traded feedstock.

- **Potential & Barriers –** Biomass availability is a key aspect for bioenergy. Biomass-based power and CHP are widely used in regions that have ample wood resources, forestry or agricultural residues. A business plan, including costs of the biomass resource collection and logistics, is needed to ensure that CHP from solid biomass is economically viable. For large-scale biomass co-firing in coal-fired power plants, a location close to large resource sites or large harbours is key to facilitating biomass supply and delivery. Biomass use for CHP may be in competition with other, non-energy uses of agricultural and forestry residues or woody industrial waste (*i.e.,* pulp and paper). Increasing competition between different uses may increase the price of biomass. Biomass market stability is a critical issue, even in regions with policy supports (*e.g.,* FITs). Sustainability, environmental and social aspects (*i.e.,* GHG reductions, food security, biodiversity, impact on soil and water) could, if not properly addressed, present significant barriers to biomass use. Governments may improve the sustainability of bioenergy by establishing the appropriate criteria, indicators, certifications and technical guidance to assess and monitor its impact.

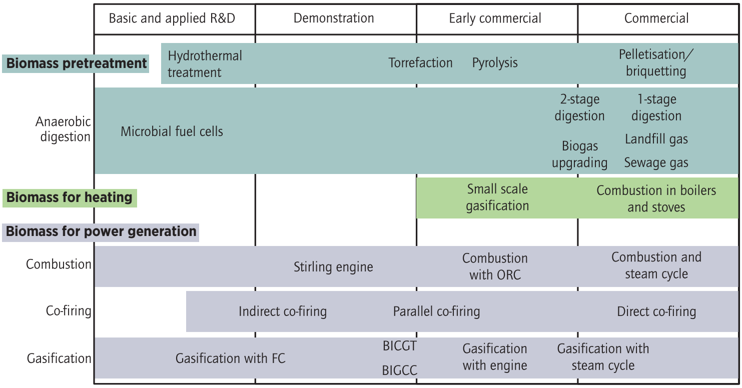
Process and Technology Status

Biomass use for energy applications includes a number of traditional practices and modern technologies, from traditional heat production for cooking and space heating to modern combined heat and power generation or biofuels production processes.

World bioenergy supply has gradually increased over recent years. In 2010, the total bioenergy supply was over 50 EJ, corresponding to about ten percent of the total world energy supply (IRENA, 2013).

Some 70% of biomass energy is consumed in developing countries for traditional uses with very low efficiency (10%-20%) while modern uses of biomass for heat and power generation include mainly high-efficiency, direct biomass combustion, co-firing with coal and biomass gasification. These modern uses are rapidly increasing all over the world. Biomass currently supplies about 1.5% of the electricity demand, equal to 280 TWh (IEA, 2012). Today's overall efficiency of biomass-based combined heat and power (CHP) plants for industry or district heating ranges from 70%-90% (IEA, 2012). The current status of major biomass technologies is highlighted in Figure 1.

Figure 1: Overview of biomass conversion technologies and their current development status (IEA, 2012)



Note: ORC = Organic Rankine Cycle; FC = fuel cell; BICGT = biomass internal combustion gas turbine; BIGCC = biomass internal gasification combined cycle

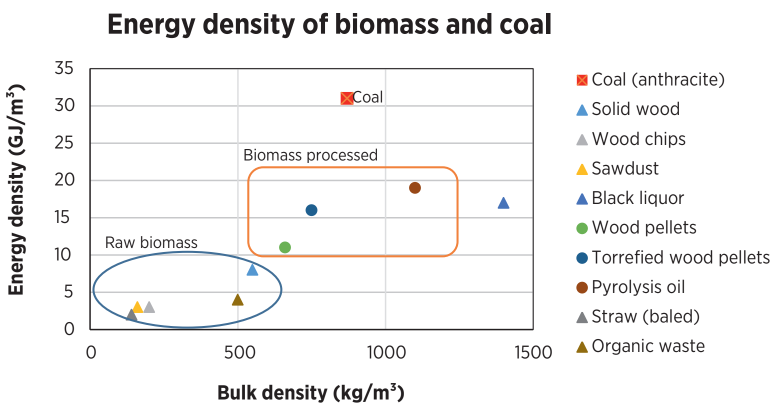
Source: Modified from Bauen et al., 2009

Biomass Pre-treatment for Energy Applications

Direct, traditional uses of biomass for heating and cooking applications rely on a wide range of feedstock and simple devices, but the energy efficiency of these applications is very low because of biomass moisture content, low energy density and the heterogeneity of the basic input. A range of pre-treatment and upgrading technologies have been developed in order to improve biomass characteristics and make handling, transport, and conversion processes more efficient and cost-effective.

Most common forms of pre-treatment include: a) **Drying** to reduce moisture content and transport costs of biomass feedstock and improve combustion efficiency; b) **Pelletisation and Briquetting** to mechanically compact bulky biomass, such as sawdust or agricultural residues; and c) **Torrefaction** (for woody biomass) in which biomass is heated in the absence of oxygen to between 200-300°C and turned into char, with a process that is similar to traditional charcoal production. After torrefaction, woody biomass is usually pelletised, reaching a bulk and energy density that are 25%-30% higher than conventional pellets (Figure 2), and exhibit properties closer to those of coal. **Pyrolysis** is a further thermo-chemical pre-treatment process during which biomass is heated to temperatures of 400-600°C in the absence of oxygen to produce pyrolysis oil (also referred to as bio-oil), along

Fig. 2: Energy density of biomass and coal (IEA, 2012)



Source: IEA Technology Roadmap

with solid charcoal and a by-product gas. Oil from pyrolysis has twice the energy density of wood pellets. This makes it suitable for long-distance transportation. While biomass pre-treatment and upgrading facilitate handling and improve combustion efficiency, the energy density of biomass remains lower than that of coal. Therefore, biomass use is economically viable if resources are readily available locally and coal needs to be imported.

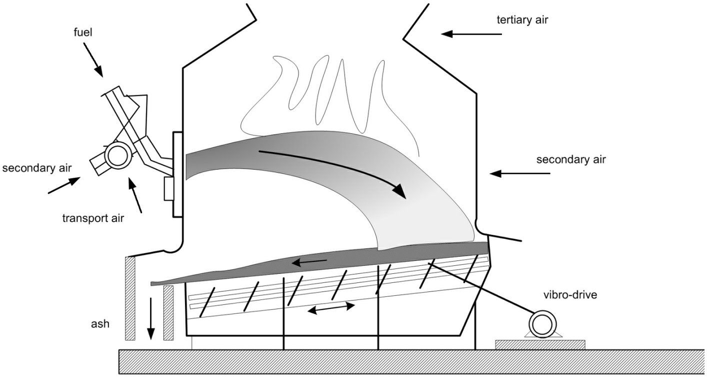
Biomass-based Power Generation and CHP

Biomass-fired power and CHP plants can be characterised by their burner/boiler technology. Depending on the fuel-feeding system, boiler technology can be divided into two main categories: a) fixed bed combustion and b) fluidised bed combustion.

Various technology options are available for fixed bed combustion, including fixed grate, moving grate and vibrating grate, depending on the type of feedstock.

Water-cooled vibrating grate (VG) boilers (Figure 3) for fixed-bed combustion is a well-known technology for power generation from wood residues. Based on natural circulation, these boilers are designed to burn low-heating-value (LHV of about 13.8 MJ/kg) wood residues, with 30% humidity. The typical power plant capacity is on the order of 10 MWe (Vatopoulos, *et al.*, 2012).

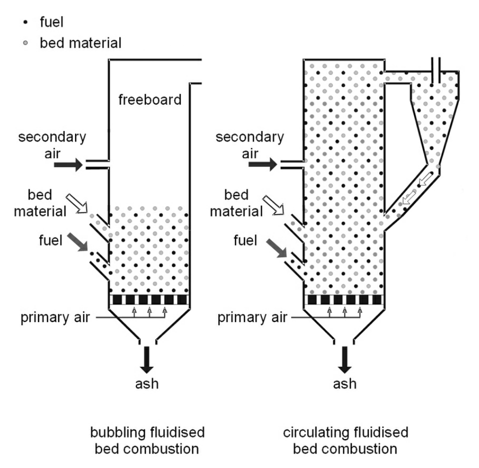
Figure 3: Vibrating grate boiler (IEA, 2008)



Fluidised bed combustion (FBC) technology offers high efficiency, low emissions and high fuel flexibility. Two fluidised bed combustion technologies are applicable for biomass combustion: **bubbling FBC (BFBC) and circulating FDC (CFBC)**. The key feature of fluidised bed combustion is its ability to enhance the mixing of fuel and flue gas by controlling the upward flue gas velocity. However, the initial investment for FBC is higher than for fixed beds. FBC is generally used for large-scale applications (>20 MWt) (IEA, 2008).

Bubbling fluidised bed combustion (BFBC) boilers (Figure 4) for solid biomass and other feedstock are also a proven commercial option. Continued improvements in CHP technology have made a new generation of plants available that offer advanced steam parameters and higher efficiency. In the BFBC boilers, the ascending air speed is sufficiently high to maintain the bed in a state of fluidisation, with a high degree of mixing, but low enough to make most of the solid particles lift themselves out of the bed fall back. The result is a dense bed with a uniform temperature for burning char with minimal over-temperatures. The dense part of the fluidised bed has a void fraction that is close to the minimum fluidisation requirement. Within the dense part of the bed, a bubble phase exists with a low solid content. The bubbles formed from excess air rise through the dense phase. As in gas-liquid systems, the bubble flow in the fluidised bed induces solids transport and mixing in the dense region. The upward velocity of air/

Figure 4: Bubbling and circulating FBC (IEA, 2008)



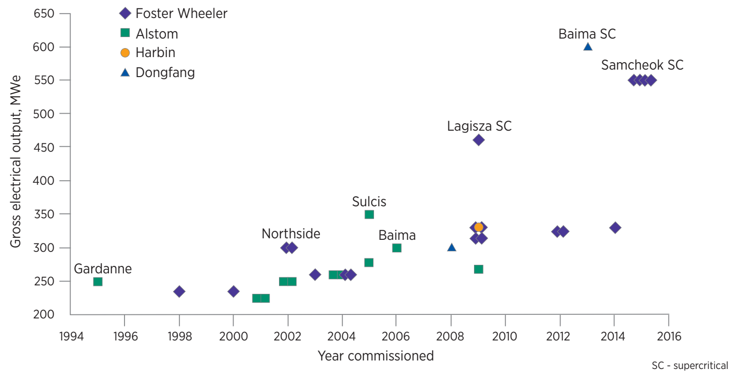
combustion gases is 2–3 m/s and bed heights range from 0.5-1.5 m. Solid materials stay mostly in the well-stirred bed, although small particles will leave the bubbling bed and be thrown up into the freeboard region.

Cyclones and other particulate removal equipment are used to collect them before the flue gas is channelled to the heat recovery systems. Coarse bed material is also withdrawn from the bottom of the bed to maintain high sulphur-capture capacity and to avoid ash contamination that might cause bed agglomeration (PowerClean, 2004).

Circulating fluidised bed combustion (CFBC) boilers (Figure 4) offer a further option for biomass-fired CHP. In CFBC, a distinction between the bed and the freeboard area is no longer applicable. A large fraction of the particles rises up from the bed and is re-circulated by a cyclone. The circulating bed material is used for temperature control in the boiler. The choice between BFBC and CFBC depends *inter alia* on the fuel used. CFBC boilers are used in large CHP or power plants, with a capacity of hundreds of MWe, but are also applied in small-scale power generation using unconventional fuels (*e.g.,* waste coal and biomass with lower fuel properties) due to their high flexibility (Figure 5, IEA, 2013b). They also are the technology of choice for large biomass- or coal-fired CHP plants.

Table 1 presents the technical features – including electric and thermal (heat/steam) capacity – of selected biomass-fuelled CHP and power plants in Europe,

Figure 5: Projected size of CFBC boilers in twenty years (IEA, 2013b)



mostly based on wood, forestry residues or waste wood. Approximately 10% of the plants in Table 1, have a capacity of more than 100 MWe; 70% have a capacity between 10-100 MWe and 14% are in the range of 2-10 MWe.

Biomass-based CHP has been successfully applied in countries such as Germany (RWE, 2009).The optimal size for biomass CHP plants appears to be around 20 MWe, taking into account the optimal size of the biomass sourcing area (<50km) and the number of truckloads per day (<50). Plants with a capacity of 7-20 MWe are used for CHP (in Germany), whereas power plants with a capacity of 50-65 MWe are used solely for power generation (UK).

Table 1: Technical features of biomass power and CHP plants (multiple literature and internet sources)

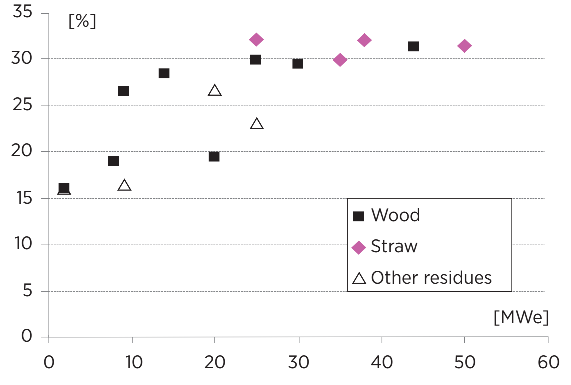
Country	Operator	Year	Tech-nol.	Electric Effic. [%]	Capacity	
					MWe	MWt
Austria	Steyrermuhl	N/A	N/A	N/A	15	
Belgium	A&S	2010	N/A	N/A	24	
Denmark[b]	Dong	2009	BFBC	29.9	35	85
Finland	Salmi	2002	N/A	28.3	14	28
Finland	Fortum	2010	CFBC	23.2	25	50
Finland	Vapo	1996	BFBC	N/A	17	48
Finland[c]	Adven	1990	N/A	N/A	14	41
Germany	RWE	2002	VG	16.5	9	
Germany	RWE	2004	CFBC	19.4	20	65
Germany	RWE	2005	N/A	26.6	20	23
Germany	RWE	2009	N/A	19.0	8	30
Germany	RWE	2012	N/A	N/A	7	30
France	Solvay	2010	N/A	N/A	30	
Hungary	DBM	2009	VG		20	
Hungary[a]	BHD	2010	N/A	31.5	50	
Ireland	Balcas	2005	BFBC	16.0	2.5	10
Ireland	IBS	2004	VG	16.1	1.8	3.5

Country	Operator	Year	Tech-nol.	Electric Effic. [%]	Capacity	
					MWe	MWt
NL	RWE	2002	BFBC	29.9	25	
Portugal	N/A	1999	VG	26.5	9	
Spain[a]	EHN	2003	VG	32.0	25	
Sweden	Oresundskraft	1982	N/A	N/A	65	129
Sweden	Soderenergi	2009	CFBC	N/A	83	200
UK[a]	EPR Ely	2000	VG	32.0	38	
UK	Semb	2007	BFBC	29.5	30	10
UK	E.On	2008	BFBC	31.3	44	
UK	Eco2 Ltd	2009	VG	N/A	14	
UK	Prenergy	2011	N/A	36.0	350	
UK	RWE	2012	N/A	N/A	50	
UK	E.On	2011	N/A	N/A	25	
UK	Eco2 Ltd	2011	VG	N/A	40	
UK	RWE	2011	N/A	N/A	65	
UK	Helius	2012	N/A	N/A	100	
UK	E.On	2013	N/A	N/A	150	
UK	MGT	2012	N/A	N/A	295	
UK	RES	2015	N/A	N/A	100	
TOTAL					**1905**	

a) Based on paper waste instead of wood as fuel
b) Based on straw
c) Based on municipal solid waste

Figure 6 shows the electric efficiency by feedstock type of biomass CHP and power plants presented in Table 1. Biomass-fuelled plants with capacities of 25 MWe or more usually have advanced steam parameters and high efficiencies; for example, 1) the straw-fired, VG-boiler, 25 MWe power plant at Sangüesa, Spain, generates steam at 92 bar/542°C with 32% efficiency; 2) a similar 35 MWe plant at Fynsværket (Denmark) works at 112 bar/540°C, with 29.9% efficiency; 3) the wood-fired, BFBC boiler, 30 MWe power plant at Teesside (UK) works at 92 bar/482°C with 29.5% efficiency; and 4) a similar 44 MWe power plant at Steven's Croft (UK) produces steam at 137 bar/537°C with 31.3% efficiency. Electric

Figure 6: Electric efficiency of biomass CHP



efficiency, however, is not the only critical performance indicator. For example, in Table 1, ten CHP plants with capacities 2-30 MWe have electric efficiencies of about 25%, thermal efficiencies of 50% and overall efficiencies of around 75%. As far as air emissions are concerned, biomass CHP plants have to comply with strict emissions limits. Emissions from specific power plants are provided in Table 2, along with the corresponding EU emissions limits.

Table 2: Emissions of biomass CHP (Grainger Sawmills, 2009; Almeida, 2000; Bioenergy, 2005)

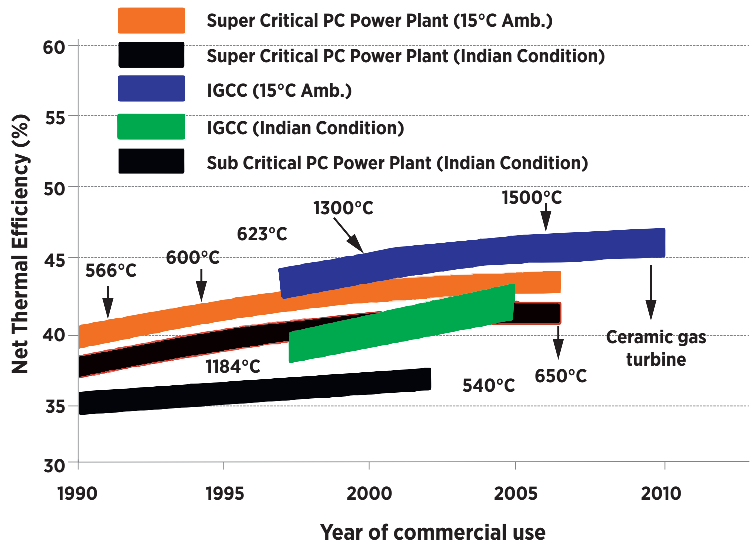
Air pollutant	**Ennisk., IRL**	**Mortágua Portugal**	**Ely, UK**	**EU limit (IPPC)**
mg/m$_0^3$	**Wood resid**	**Wood**	**Straw**	
NO_x	168 [a]	340 [b]	<300 [b]	500 [c]
SO_x	N/A	300 [b]	<300 [b]	N/A
CO	45[a]	200[b]	<250[b]	200[c]
Particles	2.7[a]	100[b]	<25[b]	50[c]

a) Monitoring results of 2008 (Enniskeane, Ireland).
b) Guaranteed or design parameter.
c) Enniskeane plant limits (IRL) (Grainger Sawmills, 2009).

Co-firing of Biomass in Coal-fired Power Plants

Biomass co-firing in coal-fired power plants offers significant advantages: 1) coal-fired power plants are highly efficient (36%-44%, depending on the efficiency of the coal-fired unit (39%-46%); 2) they have coal supply facilities that also facilitate biomass supply; 3) they also have advanced flue gas cleaning equipment, which in some cases may obviate separate cleaning for biomass. According to IEA-ETSAP TB E01 (Coal-Fired Power), today's maximum efficiency of a pulverised coal-fired power (PC) plant is around 46%, with the potential to achieve 50% or more efficiency by 2020. Respective figures for integrated gasification combined cycles (IGCCs) are 46% and 52% (see also Figure 7). Because of the smaller size, neither biomass power plants nor biomass integrated gasification combined cycles (BIGCC) can attain efficiencies as high as co-firing. The BIGCC technology also requires significant research, development and demonstration (RD&D), before its full commercialisation (2020).

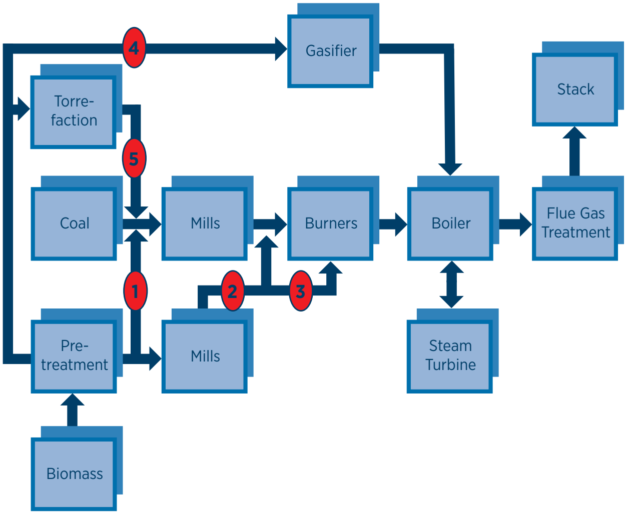
Figure 7: Generation efficiency of coal-based power generation technologies (BHEL, 2008)



Biomass co-firing in coal power plants requires significant boiler retro-fitting, specific equipment and space for biomass logistics and tailoring of flue gas cleaning equipment (*i.e.,* electrostatic precipitator, flue gas desulphurisation and de-NO$_x$, if applicable), especially if significant amounts of biomass are co-fired. NO$_x$ emissions depend significantly on the emission reduction technology, *e.g.,* separated over-fire air (SOFA – Moulton, 2009), or NO$_x$ selective catalytic reduction (SCR). Blasiak (2008) reports NO$_x$ emissions of 150–300 mg/Nm^3, equivalent to 400–800 gNO$_x$/MWh. For a retro-fitted coal-fired power plant in Poland, NO$_x$ emissions are less than 200 mg/Nm^3, equivalent to 500 g NO$_x$/MWh (Higgins, *et al.*, 2009). Biomass co-firing may reduce NO$_x$ emissions compared to coal because of its lower nitrogen content.

Figure 8 summarises the co-firing technology options, which include direct co-firing, indirect co-firing and parallel co-firing: **Direct Co-firing** with pre-mixed biomass and coal, co-milling and co-firing (Routes 1 and 5); **Direct Co-firing** with pre-milled biomass to the coal firing system or furnace (Routes 2 and 3); **Indirect Co-firing** with biomass gasification and fuel gas combustion (Route 4); and **Parallel Co-firing** with biomass combustion in a separate combustor and boiler and utilisation of the steam within the coal power generation systems

Figure 8: Co-firing options (Cremers, 2009; Livingston, 2009)



Anaerobic Digestion of Wet Biomass with CHP.

Anaerobic digestion for biogas production from wet biomass is a small-scale biomass CHP application. Figure 9 shows the stages from wet biomass to bio-methane. The use of biogas is gaining importance in the Netherlands, the United Kingdom and Italy (IEA, 2009). Biogas may also be upgraded to mix with natural gas and be used in natural gas grids or to power vehicles as compressed natural gas (CNG). Also, anaerobic digestion of wet manure and co-digestion of wet manure, along with agricultural residues, may be economically viable for the generation of heat and power using internal combustion gas engines. Figure 10 shows the electric and thermal efficiencies of anaerobic digestion CHP in the Netherlands.

Figure 9: Wet biomass anaerobic digestion (HAS, 2003)

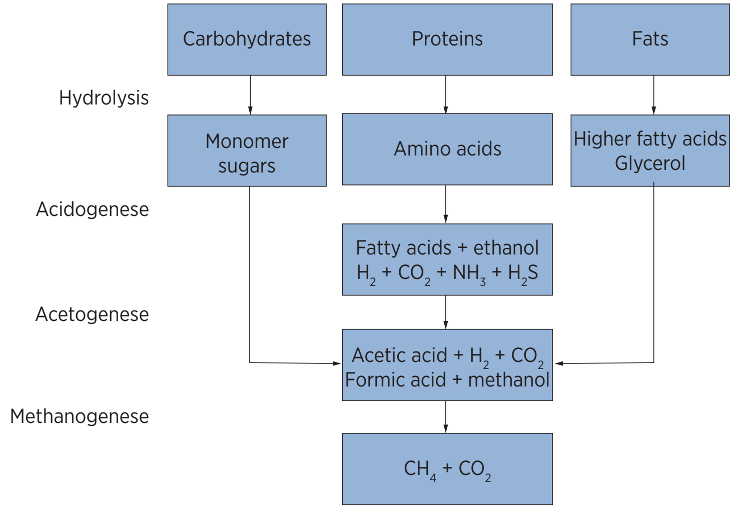
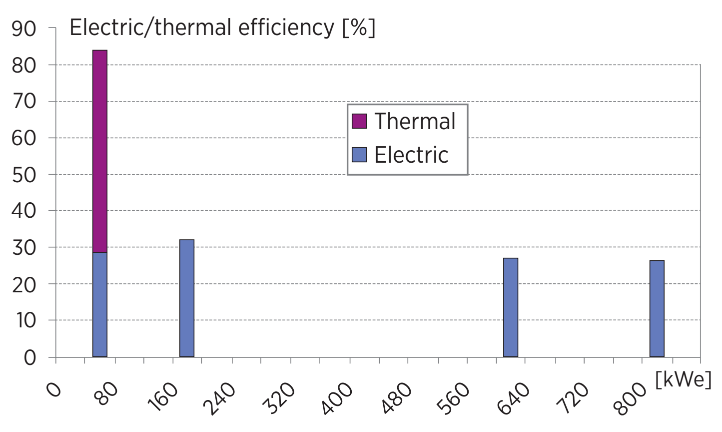


Figure 10: Gas engines efficiency for CHP generation from anaerobic digestion biogas in the Netherlands Tilburg, et al., 2008; ODE-VI, 2005; HAS, 2003)



Costs

The cost of biomass-based heat and power generation mainly consists of the fuel, investment, and O&M costs. The fuel (biomass) cost has the largest share (40%-50%) of total electricity production costs (IRENA, 2012).

The biomass cost varies, depending on sourced feedstock, collection and transportation, particularly when over long distances. Biomass feedstock costs (Table 3), excluding transportation, can be negative or zero for waste, or else range from USD 0-4/GJ for process residues, from USD 4-8/GJ for locally collected feedstock and from USD 8-12/GJ for internationally traded feedstock (IEA, 2012). The low energy density of biomass feedstock tends to limit the transport distance, which in turn limits the size of biomass power plants.

The investment cost of biomass power generation also varies by technologies. Similar to conventional power plants, the investment cost for biomass power mainly consists of engineering, construction and equipment, as well as infrastructure costs (*e.g.,* fuel supply system and grid connection).

Figure 11: Installed capital cost ranges for biomass power generation technologies (IRENA, 2012)

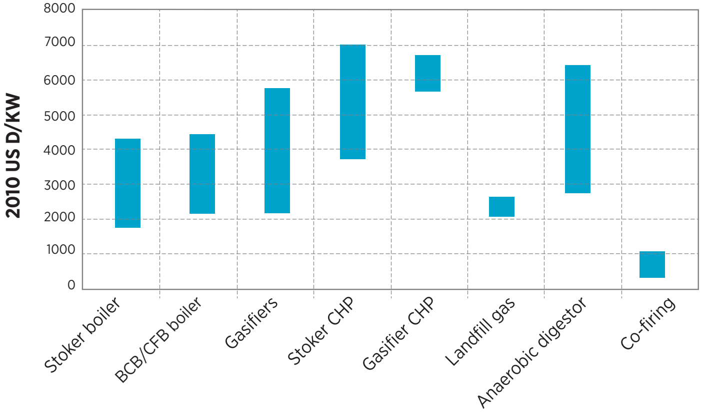


Table 3: Typical feedstock costs and plant capacities (IEA, 2012)

Biomass	**Example**	**Costs (USD/GJ)**	**Capacity (MWe)**
Waste	● Organic MSW ● Sewage sludge- Manure/dung	< 0	0.5 – 50
Process Residues	● Timber residues ● Black liquor ● Bagasse ● Rice husks ● Food waste	0 – 4	0.5 – 50
Locally Collected Feedstock	● Agric. residues ● Forestry residues ● Roundwood thin ● Energy crops	4 – 8	10 – 50
Internat. Feedstock Trading	● Roundwood ● Wood chips ● Biomass pellets ● Biomethane ● Pyrolysis oil	8 – 12	> 50

Table 4: Fixed and variable O&M costs for biomass power (IRENA, 2012)

Technology	Fixed O&M (% capital cost/yr.)	Variable O&M (USD/MWh)
Stokers/BFB/ CFC boilers	3.2 – 4.2	3.8 – 4.7
	3 – 6	
Gasifier	3	3.7
	6	
AD systems	2.1 – 3.2	4.2
	2.3 – 7	
LFG	11 – 20	n.a.

The investment cost of biomass-based CHP and power generation is from below USD 4 000/kW to USD 7 000/kW (Figure 11). The investment cost for anaerobic digester power systems ranges from USD 2 574-6 104/kW. The investment cost for retro-fitting coal power plants for biomass co-firing is between USD 140- 850/kW.

The O&M costs (Table 4) consist of fixed (*e.g.,* labour, planned maintenance, routine replacement of equipment, insurance) and variable (*e.g.,* non-biomass fuel, ash disposal, unplanned maintenance, unplanned replacement of equipment) components. The total annual O&M costs for biomass power plants are typically given as a percentage of the capital cost and range from 3%-5% for large capacity, from 5%-6.5% for small capacity, and from 2.5%-3.5% for co-firing power plants (IEA, 2012).

The annual fixed O&M costs of anaerobic digester power plants range from 2.1%-7% of the investment cost while a typical variable O&M cost is estimated at about USD 4.2/MWh (IRENA, 2012).

The levelised cost of electricity (LCOE) from biomass power ranges from USD 70-290/MWh for CHP, from USD 60-150/MWh for anaerobic digester power systems and from USD 40-130/MWh for co-firing (IRENA, 2012).

Potential and Barriers

The biomass energy market offers a significant growth potential. In the New Policies Scenario of the IEA World Energy Outlook 2013 (IEA, 2013a), global biomass-based power generation is assumed to increase from 424TWh in 2011

Table 5: Barriers for bioenergy development

Barriers	Description
Resource availability	● Quality assurance for feedstock ● Long term contract for feedstock supply ● Logistics for feedstock collection/transport ● Competing land/water demand for non-energy purpose
Cost and market	● Higher feedstock cost than fossil fuel ● Higher upfront capital investment ● Concern to immature/unstable market hinder investment
Sustainability	**Environmental** ● Direct / indirect land use change could increase lifecycle GHG emissions ● Land degradation due to land use change ● Possible negative impact to biodiversity ● Water resource availability **Social** ● Land ownership ● Employment opportunity ● Social equity

to 1204 TWh in 2030. IRENA analyses show that existing bioenergy technology options can increase the total biomass power supply to 2220 TWh in 2030 (IRENA, 2014), mainly industry CHP. Assuming this potential is fully realised, a number of economic, environmental and social impacts could be expected, such as increased energy access, increased employment and income opportunities in rural areas, GHG emissions reductions, and so on. However, barriers exist against the widespread use of biomass for heat and power generation (Table 5).

Resource availability. Securing good quality feedstock at affordable prices over a plant's lifetime is a key issue for biomass power projects. This comes mainly from fluctuations in biomass supply availability, seasonally or annually, so that setting up long-term supply contracts may not be easy. Seasonal fluctuation depends on the type of feedstock and developers need to consider installation of storage facilities or combination with another type of feedstock that has a different supply season. Yearly fluctuations also relate to annual changes in production and market demand for agricultural commodities. Most food and fiber crops are grown and sold on an annual basis, often for widely varying commodity prices.

Bioenergy production uses the same land which can be used to produce different types of commodities. The set-up of long-term contracts will reduce a farmer's flexibility to grow different types of biomass annually, based on prevailing market situations (IEA 2007).

Logistical costs of feedstock collection may reduce biomass' technology potential (RWE, 2009). Biomass feedstock must be available in reasonable quantities within an acceptable distance to make the project economically viable. For large-scale biomass co-firing in coal-fired power plants, a location near a large deep-water harbour is an important advantage for economic competitiveness (Hunton & Williams, 2009). In addition, other high value-added, non-energy uses of biomass may compete with bioenergy production.

Costs and Markets. In countries with advanced bioenergy policies, such as European countries, the bioenergy market is regulated and supported by policy measures, such as national targets or feed-in-tariff (FIT) incentives. In other areas, the cost gap between biomass and coal is currently too large to allow for cost-effective bioenergy. In some countries, subsidies to fossil fuels also create a financial barrier for bioenergy (IEA, 2012). Investors often tend to seek a shorter payback period of 2-4 years, which favours power plants with low capital cost, albeit usually with a high fuel cost. Large bioenergy heat and power plants usually have a relatively high capital cost compared to gas or coal plants (IEA, 2007). The lacking of assurances of long-term policy support for bioenergy, together with relatively higher capital costs and feedstock prices, also discourage investment in bioenergy projects.

Sustainability. Sustainability is becoming an ever more important issue in bioenergy projects. Sustainability includes *environmental* issues (*e.g.,* GHG emissions, land degradation, water resource availability and biodiversity) and *social* issues (*e.g.,* land ownership, employment opportunities and social equity). An increasing number of countries, as well as private entities and stakeholder groups, have established initiatives in biofuels sustainability, including the introduction of sustainability criteria and indicators for GHG emissions, food security, biodiversity, impact on soil and water, certification schemes and technical guidance to assess/monitor the impact of bioenergy (FAO, 2013).

All these issues can be significantly affected by governmental policies. Establishing an appropriate regulation framework and support measures are crucial to ensure sustainable bioenergy development.

Table 6 – Summary Table: Key Figures and Data for Biomass-based Technologies

Technical performance	**Typical current international values and ranges**		
Energy input	Biomass		
Output	Electricity or Combined Heat and Power		
Technologies	Biomass CHP **BP**	Anaerobic digestion CHP **ADCHP**	Co-firing in coal-fired power plant, **CBP** (retro-fit)
Electric efficiency, %	16 – 36	26 – 32 (eff. gas engine)	36 – 44
Total efficiency in case of CHP, %	40 – 85	40 – 85 (eff. gas engine)	Not applicable
Construction time, months	Minimum 18; Typical 24; Maximum 30		
Technical lifetime, years	25		
Load (capacity) factor, %	76 – 91	75 – 80	80 – 90
Max. (plant) availability, %	93	80	90
Typical (capacity) size, MWe	50	0.5 (0.3 – 10)	100
Installed (existing) capacity, GW_e	30	4	10
Average capacity aging	Differs from country to country.		
Costs (USD 2010)			
Investment cost, including interest during construction, USD/kW	3 550 – 6 820	2 574 – 6 104	140 – 850
O&M cost (fixed and variable), % of installed cost	3-5% (Large scale), 5%-6.5% (Small scale)		2.5%-3.5%
Fuel cost, USD/GJ	Waste: <0, Processing residues: 0-4, Locally collected feedstock: 4-8, Internationally traded feedstock: 8-12		
Interest rate, %	10		
Levelised Cost of Electricity, USD/MWh	70 – 290	60 – 150	40 – 130

Data Projections	2010			2020			2030	
Technology	BP	ADCHP	CBP	BP	ADCHP	CBP	BP	ADCHP
Net Efficiency (LHV)	32	32	40	35	33		38	35
Investment costs, incl. interest during construction, USD/kW	3750	4500	335	3100	3700	300	2750	3300
Total production cost, USD/MWh	110	160	90	100	140	85	90	130
Market share, % of global electricity output	~ 1	<<1	<<1	1–2	~ 1	~ 1	~ 3	~ 2

IEA (2012): Technology Roadmap, Bioenergy for Heat and Power

IRENA (2012): Renewable Energy Technologies: Cost Analysis Series “Biomass for Power Generation”

IRENA (2013): Statistical issues: bioenergy and distributed renewable energy

References and further Information

Almeida, T. (2000), "The Analysis Report of Plant – 13. CBE", Altener, *http://ec.europa.eu/energy/res/sectors/documents/final_reportsaltener_afbnet/part2_cofiring/final_plant_reports/plant_no_13.pdf*.

BHEL (Bharat Heavy Electricals Ltd.) (2008), "Advanced Clean Coal Technology – Perspectives for India", *www.igeos.pl/doc/coaldialogue/WEC-Coal_Slides. ppt* #443,1, Slide 1.

Bioener (2005), "Sangüesa Power Plant" Bioener ApS, Valby, Denmark, *www.bioener.dk/data/media/bioener_side19_20.pdf*.

Blasiak, W. (2008), "Fuel Switch from Fossil to 100% Biomass on PC Boiler", POWER-GEN Europe, 3-5 June, Milan, *www.nalcomobotec.com/files/PowerGen_Europe_2008_Biomass_Cofiring.pdf*.

Cremers, M.F.G. (2009), "IEA Bioenergy Task 32 – Technical Status of Biomass Co-firing", KEMA, Arnhem, 11 August, *www.ieabcc.nl/publications/09-1654%20D4%20Technical%20status%20paper%20biomass%20co-firing.pdf*.

EPRI (Electric Power Research Institute) (2008), "Program on Technology Innovation: Integrated Generation Technology Options", Electric Power Research Institute (EPRI), Palo Alto, California, pp. 90, *www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001018329&Mode=download*.

FAO (Food and Agriculture Organization) (2013), "A Global Assessment of Sustainability Issues, Trends and Policies for Biofuels and Related Feedstocks", *www.fao.org/docrep/017/i3126e/i3126e.pdf*.

Grainger Sawmills (2009), "2008 Annual Environmental Report", Grainger Sawmills Ltd, Enniskeane, Ireland, March, *www.epa.ie/licences/lic_eDMS/090151b2802a392a.pdf*.

HAS (2003), "Mestvergisting op boerderijniveau – Vergunningverlening en Haalbaarheid van Vergisting van Mest en Biomassa (Manure Fermentation at Farm Level - Authorisation and Feasibility of Manure and Biomass Digestion)", HAS Kennistransfer, in Ppdracht van NOVEM, 's Hertogenbosch, January, *www.mestverwerken.wur.nl/Info/Bibliotheek/pdf/MestvergistingOpBoerderijniveau.pdf*.

Higgins, B., *et al.* (2009), "Biomass Co-firing Retrofit with ROFA for NO_x Reduction at EdF-Wrocław Kogeneracja", Energy Efficiency and Air Pollutant Control Conference, Wroclaw, *www.nalcomobotec.com/files/Mobotec_Wroclaw_Biomass_Cofiring.pdf*.

Hunton and Williams (2009), "Renewable Energy Quarterly", Volume IV, June pp. 9-11, *www.hunton.com/files/tbl_s47Details/FileUpload265/2585/renewable_energy_quarterly_vol4_june2009.pdf*.

IEA (International Energy Agency) (2007), *IEA Good Practice Guidelines – Bioenergy Project Development & Biomass Supply*, IEA, Paris.

IEA (2008): *The Handbook of Biomass Combustion and Co-firing*, IEA, Paris.

IEA (2009), "Bioenergy – A Sustainable and Reliable Energy Source, a Review of Status and Prospects", IEA, Paris, *http://indiaenvironmentportal.org.in/files/Bioenergy_a%20sustainable_and_reliable_energy_source.pdf*.

IEA (2012): "Technology Roadmap: Bioenergy for Heat and Power", *www.iea.org/publications/freepublications/publication/bioenergy.pdf*.

IEA (2013a), "World Energy Outlook 2013", Chapter 6, *www.worldenergyoutlook.org/media/weowebsite/2013/WEO2013_Ch06_Renewables.pdf*.

IEA (2013b), "Profiles, Techno-Economic Analysis of PC Versus CFB Combustion Technology", IEA-Clean Coal Centre, *www.iea-coal.org.uk/documents/83231/8837/Techno-economic-analysis-of-PC-versus-CFB-combustion-technology,-CCC/226*.

IRENA (International Renewable Energy Agency) (2012), "Renewable Energy Technologies: Cost Analysis Series: Biomass for Power Generation", *www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-BIOMASS.pdf*.

IRENA (2013), *Statistical Issues: Bioenergy and Distributed Renewable Energy*, IRENA, Abu Dhabi.

IRENA (2014), "REmap 2030 Full Report", *http://irena.org/remap/REmap_Report_June_2014.pdf*.

Livingston, W.R. (2009), "The Direct Co-Firing of Biomass at High Co-Firing Ratios", Doosan Babcock Energy, presented at Hamburg, June, *www.ieabcc.nl/meetings/task32_Hamburg2009/cofiring/06%20Livingston.pdf*.

Moulton, B.W. (2009), "Principles of Burner Design for Biomass Co-Firing", 34th International Technical Conference on Coal Utilization and Fuel Systems Clearwater, Florida, May 31, *www.fwc.com/publications/tech_papers/files/TP_FIRSYS_09_02.pdf*.

ODE-Vl (2005), "Biogas – Haalbare Kaart Voor Duurzame Landbouw, (Biogas - a Viable Option for Sustainable Agriculture)", ODE Vlaanderen, *www.ode.be/images/stories/Brochures/bmg_fo_biogas_051201.pdf*.

Pfeiffer, E., and M. van de Ven (2009), "Developments in Fluid Bed Combustion and Gasification", IEA, Hamburg, 30 June.

PowerClean (2004), "Fossil Fuel Power Generation – State-of-the-Art", Report by the PowerClean R, D&D Thematic Network, 30 July, *www.irc.ee/6rp/valdkonnad/P6/energia/Powerclean_state_of_the_art_final.pdf*.

Prenenergy (2006), "Port Talbot Renewable Energy Plant – Environmental Statement", PrenergyPower, UK, 05 October, *www.prenergypower.com/nontechnicalsummary.pdf*.

RWE (2009), "Fact Book Renewable Energy", RWE, Germany, April, *www.rwe.com/web/cms/mediablob/de/315844/data/179662/55988/rwe/verantwortung/RWE-Factbook-Renewable-Energy-April-2009-englisch-.pdf.*

SEI (Sustainable Energy Ireland) (2005), "Co-firing with Biomass", SEI, Dublin, *www.sei.ie/Renewables/REIO_Library/Biomass/CoFiringwithBiomassFinalfnl.pdf*.

Tilburg, X., van, et al. (2008), *Technisch-Ekonomische Parameters van Duurzame Elektriciteitsopties in 2009-2010 – Eindadvies Basisbedragen Voor de SDE Regeling (Technical-Economic Parameters of Renewable Electricity Options in 2009-2010 - Final Advice Basic Amounts of the SDE),* ECN-E—08-090, ECN, Petten, December.

Vatopoulos, K., et al. (2012), "Study on the state of play of energy efficiency of heat and electricity production technologies", JRC Scientific and Policy Reports, EU, *http://setis.ec.europa.eu/system/files/4.Efficiencyofheatandelectricityproductiontechnologies.pdf*.

Venäläinen, I., and R. Psik (2003), "460 MWe Supercritical CFB Boiler Design for Łagisza Power Plant", Foster Wheeler Energia Oy, Finland, February, *www.fwc.com/publications/tech_papers/files/TP_CFB_03_02.pdf*.

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