ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME

International Renewable Energy Agency

Biomass Co-firing

Technology Brief

IEA-ETSAP and IRENA© Technology Brief E21 – January 2013

www.etsap.org – www.irena.org

This brief is available for download from the following IEA-ETSAP and IRENA sites
iea-etsap.org/web/Supply.asp
www.irena.org/Publications

Copyright © IEA-ETSAP and IRENA 2013

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organization dedicated to renewable energy. In accordance with its Statute, IRENA's objective is to "promote the widespread and increased adoption, and the sustainable use of all forms of renewable energy". This concerns all forms of energy produced from renewable sources in a sustainable manner and includes bioenergy, geothermal energy, hydropower, ocean, solar and wind energy.

As of December 2012, the membership of IRENA comprises some 160 States and the European Union (EU), out of which 104 States and the EU have ratified the Statute.

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.

FSC www.fsc.org MIX Paper from responsible sources FSC® C021260
Print CO2 compensated Id-No. 1225221 www.bvdm-online.de
Grüner Strom Label e.V.

Insights for Policy Makers

Biomass co-firing consists of combusting biomass and fossil fuels, mostly coal but also natural gas, in the same power plant. In most cases, biomass co-firing in coal power plants takes place by mixing biomass with coal before burning, but biomass can also be gasified and burned in separate burners, after which the gaseous fuel or steam is mixed with the boiler streams of the coal-fired power plant. The advantage of biomass co-firing is that it reduces greenhouse gas (GHG) emissions from coal-fired power and enables power generation from biomass with the high efficiency achieved in modern, large-size coal-fired power plants, which is much higher than the efficiency of dedicated, 100% biomass power plants. The total energy efficiency can be increased even further if biomass co-firing takes place in combined heat and power (CHP) plants. The other advantage of biomass co-firing is that the incremental investment for burning biomass in coal-fired plants is significantly lower than the cost of dedicated biomass power. At present, co-firing projects in coal-fired power plants exceed the biomass capacity of dedicated biomass plants.

The costs of biomass acquisition and transportation determine to a large extent the economic feasibility of co-firing. The acquisition costs depend on possible competition with other biomass energy uses (e.g. biofuels) or non-energy applications. A stable and cheap flow of biomass is needed to sustain a biomass co-firing project. The biomass feedstock can be sourced from residues or waste streams from forestry, agriculture, pulp and paper, and sugar industries or from dedicated energy crops (e.g. short-rotation coppices). The local availability of large quantities of cheap biomass makes biomass co-firing more economically attractive. If local sources are insufficient, high energy-density, pre-treated biomass (e.g. wood pellets) can be used. In these cases, long-distance transportation and logistics (e.g. an inland harbour) play an important role in the economic viability. In developing countries, the use of waste streams from agriculture and forestry may also create additional value and job opportunities while contributing to rural development.

Coal-fired power stations that provide both power and heat to district heating networks (e.g. in northern Europe) or even industrial facilities may significantly increase the efficiency and the economics of biomass co-firing. Appropriate policies are needed to achieve an efficient use of the available biomass resource by encouraging the use of co-firing in connection with CHP wherever suitable. Policies should also take into account the co-benefits from the use of agricultural residues or demolition waste, which would otherwise constitute a disposal challenge.

Biomass co-firing has an enormous potential to reduce CO_2 emissions as biomass can replace between 20-50% of coal. However, the net reduction of CO_2 emissions and other pollutants depend to a high degree on biomass feedstock's origin and supply chain. In addition, a high percentage of biomass co-firing may reduce efficiency and power output. Nevertheless, the substitution of only 10% of coal in the currently installed coal-fired electrical capacity would result in about 150 GW biomass power capacity, which is 2.5 times higher than the current globally installed biomass power capacity.

Biomass co-firing can be considered as a transition option towards a completely carbon-free power sector. Several European countries, in addition to the United States, already offer policy incentives or have mandatory regulations to increase renewable's share in the electricity sector. This supports the use of biomass co-firing and, as a result, most biomass co-firing projects take place in these countries. The Clean Development Mechanism (CDM) recognises biomass co-firing as a way to reduce CO_2 emissions in developing countries. However, to exploit the co-firing potential without adverse environmental impact, urgent measures and technology preparation are needed in emerging economies (e.g. India and China), where coal-fired power capacity is rapidly growing and large sources of biomass are available. The indicators developed by international organisations to measure the sustainability of bio-energy (including protection of soil and water resources, bio-diversity, land allocation and tenure, and food prices) need to be integrated into the relevant policy measures.

Highlights

- **Process and Technology Status –** Biomass co-firing consists of burning biomass along with coal in coal-fired power plants. Co-firing can play an important role in increasing the use of biomass in power generation and reducing greenhouse gas (GHG) emissions because only a relatively modest incremental investment is needed to retrofit existing coal plants or build new co-fired plants. Compared to power plants burning 100% biomass, co-firing offers several advantages, including lower capital costs, higher efficiency, improved economies of scale and lower electricity costs due to the larger size and the superior performance of modern coal power plants. At present, some 230 power and combined heat and power (CHP) plants use co-firing, mostly in northern Europe and the United States, with a capacity of 50-700 MWe. Co-firing in CHP plants is currently the most competitive option to exploit the biomass energy potential for both electricity and heat production. Biomass feedstocks include forestry and agriculture residues, animal manure, waste and dedicated energy crops. Co-firing technologies include: 1) **direct co-firing,** using a single boiler with either common or separate burners (i.e. the simplest, cheapest and most widespread approach); 2) **indirect co-firing,** in which a gasifier converts solid biomass into a gaseous fuel; and 3) **parallel co-firing,** in which a separate boiler is used for biomass, and its steam generation is then mixed with steam from conventional boilers.

- **Performance and Costs –** The net electric efficiency of a co-fired coal/biomass power plant ranges from 36-44%, depending on plant technology, size, quality and share of biomass. While a 20% co-firing (as energy content) is currently feasible and more than 50% is technically achievable, the usual biomass share today is below 5% and rarely exceeds 10% on a continuous basis. A high biomass share means lower GHG emissions. It is estimated that 1-10% biomass co-firing in coal power plants could reduce CO_2 emissions from 45 million to 450 million tonnes per year by 2035, if no biomass upstream emissions are included. However, high biomass shares involve technical issues, such as securing sufficient biomass, as well as potential combustion problems, such as slagging, fouling (which reduces heat transfer) and corrosion. The overall cost of co-firing is sensitive to the plant location, and the key cost element is the biomass feedstock. The investment cost for retrofitting a coal-fired power plant for co-firing is in the range of USD 430-500/kW for co-feed plants, USD 760-900//kW for separate feed plants and USD 3,000-4,000/kW for indirect co-firing. These costs are still significantly lower than the cost of dedicated 100% biomass power plants. The biomass fuel costs depend on the biomass type, volume traded and geographic location. The costs for globally traded biomass pellets are around € 12/MWh higher than the costs of coal. Advanced pelletisation and – in the near future torrefaction – can increase the energy density of biomass, reduce transportation costs and improve storage performance. Taking into account all cost components and assuming a discount rate of 7%, a typical levelised electricity cost for biomass co-firing ranges from USD 22-130/MWhe, with the actual cost depending on assumptions about location, biomass type, co-firing technology and plant capacity factors.

- **Sustainability, Potential and Barriers –** The substitution of 10% of the global coal-fired capacity by co-firing would result in about 150 GW biomass capacity. In comparison, today's co-firing capacity is estimated at between 1-10 GW (the variability being associated with the actual biomass share in co-firing plants), and the total installed biomass capacity amounted to some 62 GW in 2010. Therefore, a large co-firing potential exists, but a substantial increase would pose problems regarding the availability of biomass, which can also be used for biofuels and biomaterials production. While estimates of biomass resources vary greatly, realistic assessments should only account for *sustainable* biomass - that is, resources that neither compete with food production nor involve land-use changes with negative impacts on the climate and environment. On this basis, the Intergovernmental Panel on Climate Change (IPCC) estimates a global sustainable biomass energy potential of 100-300 EJ per year, mostly based on agriculture and forestry residues and ligno-cellulosic feedstock. The energy use of biomass can add value to the forestry and agriculture sectors of developing and emerging countries. Recently, biomass production and trading from Latin America, Africa and Asia have increased significantly (i.e. 75 PJ in 2009), although long-distance transportation reduces the benefit of using biomass. In addition, international cooperation is needed to ensure the sustainability of biomass production. The Global Bioenergy Partnership (GBEP) and other organisations are in the process of finalising indicators, as well as certification processes, to ensure the sustainability of biomass production. Biomass co-firing based on residues and wastes has been recognised by the United Nations Framework Convention on Climate Change (UNFCCC) as a technology to mitigate GHG emissions so that countries can sell carbon credits associated with their co-firing projects. Other policies to support co-firing include CO_2 emissions trading schemes (e.g. the EU Emissions Trading System or EU ETS), the removal of fossil-fuel subsidies, incentives for converting power plants into co-fired CHP plants, and mandatory co-firing quota schemes. Supporting policies are in place in EU countries (i.e. Austria, Denmark, Finland, the Netherlands, Sweden and the United Kingdom) and the United States. Emerging economies with large productions of agricultural waste and coal-based electricity (e.g. China and India) are also well-positioned to implement co-firing.

Process and Technology Status

Biomass co-firing consists of burning biomass along with fossil fuels in coal- and gas–fired power plants (ETSAP E01, E02). This brief deals with biomass co-firing in coal power plants, which is by far more widespread and extensively proven than biomass co-firing in gas-fired plants[1]. Co-firing can play an important role in increasing the share of biomass and renewable sources in the global energy mix and reducing greenhouse gas (GHG) emissions (ETSAP 05; IEA 2010). Only a relatively low investment is needed to adapt or retrofit existing conventional coal power plants for biomass co-firing, or to build new power plants specifically designed for co-firing.

Co-firing biomass in coal-fired power plants offers advantages with respect to using biomass in dedicated power plants. Advantages include higher efficiency (i.e. modern coal power plants are more efficient than smaller-scale dedicated biomass power plants), lower sulphur emissions (due to biomass combustion), lower costs (due to the larger size of coal power plants) and no need for continuous biomass supply because the plant can burn coal if biomass is not available. However, the use of two different fuels increases the complexity of power generation from both a technical and regulatory point of view.

Co-firing activity is not easy to track since individual plants may change the quantity and type of biomass used and may use co-firing either on an experimental or commercial basis (Platts, 2011b). In its database, Platts counts almost 230 power plants that use, have used or announced the intention to use, some type of biomass with coal as the main fuel[2]. A previous count (2009) by the IEA Bioenergy Implementing Agreement identified globally some 150 plants using coal or lignite along with biomass[3] (IEA Bioenergy Task 32, 2009a). The majority of these plants are located in northern Europe and in the United States, with some units in Asia

1 This paper covers electricity and heat production from co-firing solid biomass in coal power plants (and combined heat and power plants, CHP). It also includes biomass and lignite co-firing since the technology is fundamentally the same. The paper does not cover co-firing of solid biomass in gas power plants (either directly or after liquefaction or gasification) for which several technologies exist but which is less widespread and tested than co-firing in coal plants.

2 Note that fuels may be burned in the same plant but co-fired for only part of the time while burned separately at other times, for example to make use of seasonal fuels, such as bagasse (cf. MSPA, 2011).

3 It must be noted that a considerable number of these plants use biomass as their primary fuel and coal as a standby or start-up fuel.

and Australia. Most of them are combined heat and power (CHP) plants, and many of them produce only electric power. Their capacity ranges from 50-700 MWe. Most plants are operated by utilities, but industry also plays an important role, especially in sectors, such as pulp and paper or wood processing.

Biomass feedstock includes forestry and agriculture residues (e.g. sugar cane bagasse), animal manure, wastes, such as sawdust or bark from the timber industry, waste wood and dedicated energy crops (e.g. short-rotation coppices). The sources vary greatly between countries, depending on their local natural endowments, their industrial potential and their biomass energy use.

Handling and combustion characteristics of vegetal biomass can be substantially improved through pelletisation and torrefaction. *Pelletisation* is a process to physically densify fine wood particles (e.g. sawdust) into compact, low-moisture and low-eroding capsules by applying pressure and heat. Advanced ("black") pellets can also repel water, thus improving logistics and storage options. *Torrefaction* consists of biomass heating in the absence of oxygen, thus creating a charcoal-like substance with reduced moisture, small particle size, minimal biological degradation and increased energy density. After torrefaction, biomass can be milled and compressed to very dense pellets or briquettes. Torrefaction plants require significant capital costs (and large feedstock availability to compensate for the investment) but are expected to have lower operation costs than pelletisation plants (Kiel 2011). There are currently more than ten demonstration plants. Furthermore, research institutes around the world are working on the improvement and standardisation of biomass pellets in terms of energy density, humidity, environmental properties, durability and the entire production process from the raw material to storable pellets.

As for the regional use of different biomass feedstock, bagasse is used as an alternative fuel along with coal in developing countries and regions with a large sugarcane production, such as Mauritius, La Réunion, Guatemala, Guadeloupe, India, Dominican Republic (Platts, 2011a; ISO 2009), while countries, such as Malaysia and Thailand, have explored the use of rice husks. Other countries, like Brazil, have significant bagasse co-generation capacity (7.3 GW in 2011) but do not combine biomass with fossil fuels (REN21 2011; ISO 2009).

- **Co-firing Technologies –** Co-firing includes three major technologies:
  - **Direct co-firing** is the simplest, cheapest and most common option. Biomass can either be milled jointly with the coal (i.e. typically less than 5% in terms of energy content) or pre-milled and then fed separately into the same boiler. Common or separate burners can be used, with the second option enabling more flexibility with regard to biomass type and quantity.

- **Indirect co-firing** is a less common process in which a gasifier converts the solid biomass into a fuel gas that is then burned with coal in the same boiler. Though more expensive because of the additional technical equipment (i.e. the gasifier), this option allows for a greater variety and higher percentages of biomass to be used. Gas cleaning and filtering is needed to remove gas impurities before burning, and the ashes of the two fuels remain separate.

- **Parallel co-firing** requires a separate biomass boiler that supplies steam to the same steam cycle. This method allows for high biomass percentages and is frequently used in pulp and paper industrial facilities to make use of by-products from paper production, such as bark and waste wood.

Co-firing more than 20% of biomass in terms of energy content is technically feasible today (IEA Bioenergy Task 32, 2009b). Depending on the plant set-up and the chosen co-firing technology, substitution of more than 50% of coal can also be achieved (DENA, 2011; Vattenfall 2011). However, in most cases co-firing levels are below 5%, exceeding 10% on a continuous basis only in about a dozen coal-fired plants worldwide (IEA Clean Coal Centre, 2012). The co-firing mix also depends on the type of boiler available. In general, fluidised bed boilers can substitute higher levels of coal with biomass than pulverised coal-fired or grate-fired boilers (Leckner 2007).[4] However, pulverised fuel combustion is much more widespread and in some specific pulverised coal-fired installations, a 100% conversion from coal to biomass has been demonstrated (IEA Bioenergy Task 32, 2009b). In the Netherlands and the United Kingdom, the full conversion of large coal-fired power plants to 100% biomass has been considered. However, logistical and economic constraints limit the conversion to a few plants with suitable infrastructure (cf. availability and cost of feedstock, see below).

Biomass co-firing is more cost-effective in combined heat and power plants (CHP, ETSAP E04), which produce useful heat in addition to power. CHP is often used in industrial facilities where there is specific demand for both heat and power or in combination with district heating networks. Since CHP plants offer a higher overall efficiency than power plants, they also enhance the economics of biomass co-firing.

4 For a more detailed discussion of the different boiler technologies for biomass, see IEA ETSAP 2010b.

Technology Performance

- **Efficiency of Biomass Co-firing –** Overall, the net electric efficiency of a coal/biomass co-firing plant typically ranges from 35-44% (ETSAP, 2010b; IEA 2012), depending on the plant technology, size and specific biomass feedstock. Direct co-firing results in slightly higher efficiencies (i.e. around 2% points) than indirect and parallel co-firing because of the conversion losses in the biomass gasifiers and boilers (ECN 2012a). The overall efficiency of direct co-firing falls with higher percentages of biomass due to fouling and slagging, associated corrosion, especially in pulverised coal-fired or grate-fired boilers (IEA Bioenergy Task 32, 2009b; IRENA 2012). The overall efficiency of direct co-firing in coal-fired power plants with fluidised bed boilers is less sensitive to higher levels of biomass, although high levels require more sophisticated boiler and fuel handling control systems. Furthermore, fluidised beds can handle biomass with larger particle sizes (<72mm instead of < 6mm) and higher moisture content (10-50% instead of < 25%) than pulverised boilers (IRENA 2012). However, in general co-firing in modern, large and highly-efficient coal power plants results in a biomass conversion efficiency that is significantly higher than what can be achieved in small (<10 MW) and medium-scale (10-50MW) dedicated biomass power plants with efficiencies of 14-18% and 18-33%, respectively (Baxter, 2005; IPCC, 2011; IEA 2012). Apart from the higher efficiency, the economies of scale of large power plants will also lead to lowered costs for the energy provided per unit of biomass fuel used.

- **GHG Emissions and Environmental Impact –** Biomass co-firing offers a comparatively low-cost way to reduce greenhouse gas (GHG) emissions[5]. As the combustion of biomass is considered carbon neutral (i.e. the CO_2 released in the process is withdrawn from the atmosphere by photosynthesis during the plant's growth[6]), co-fired power plants release less net GHG emissions than conventional power plants. The cost of the precluded emissions is relatively low because the incremental investment costs for retrofitting or building new co-fired power plants is modest in comparison with other options to reduce

5 A recent study by the German energy agency DENA cites CO_2 avoidance costs of € 27–54/t CO_2eq in coal-fired plants and € 52–89/t CO_2eq in lignite plants. The difference stems mainly from the fact that lignite is cheaper (DENA, 2011).

6 While the combustion of biomass can be considered carbon neutral, the overall GHG balance of the biomass provision (i.e. pre-combustion supply chain) depends on many factors, such as processing, transport modes and distances, and—in the case of dedicated energy crops—on cultivation/harvesting, and possible land use change effects.

power generation emissions. If combined with carbon capture and storage (CCS) technologies, biomass co-firing results in negative GHG emissions (i.e. net removal of CO_2 from the atmosphere), also referred to as "biogenic carbon sequestration"[7]. Assuming an average level for CO_2 emissions from coal combustion of 95 kg/GJ[8] and a market development according to the IEA "New Policies Scenario" (IEA World Energy Outlook, IEA 2011), it is estimated that the CO_2 emissions in 2035 could be reduced by between 45-450 million tonnes per year if 1-10% of the coal fuel input were replaced by biomass. This estimate assumes that upstream emissions of biomass supply are negligible, although the supply chain also involves GHG emissions.

While biomass co-firing can reduce the net GHG emissions of coal plants, other polluting emissions deserve a specific assessment. Co-firing typically reduces sulphur dioxide, which leads to acid rain, and other harmful emissions as compared to coal, but the extent of such reductions depends strongly on the specific biomass feedstock, plant technology and operation (Al-Mansour and Zuwala J., 2010). For example, using treated wood waste as fuel (e.g. from furniture or demolition) may require filtering of toxic gases, ash decontamination or a special design for the combustion systems to deal with chemicals contained in wood coatings, glues or preservatives. The reduction of biomass particulate emissions may require attention if co-firing occurs in smaller-scale power plants with low-efficiency particulate filters and no de-sulphurisation, which usually traps fine particles in a parallel process.

In terms of water consumption, the impact of biomass co-firing depends on the biomass type and growth conditions. In many cases, co-firing can positively impact water use in coal-fired power plants; for example, if waste is used as the feedstock (IEA, 2010).

7 It should be noted, however, that CCS leads to efficiency losses. For more information on Bio CCS, see e.g. European Biofuels Technology Platform at http://www.biofuelstp.eu/bio-ccs-jtf.html.

8 Actual emission factors for coal combustion vary, depending especially on the type of coal, cf. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Current Costs and Cost Projections

At present, co-firing in state-of-the-art combined heat and power plants is considered the most cost-effective option of producing electricity from biomass. Determining the overall cost for biomass co-firing in coal-fired power and CHP plants requires analysis of several components, particularly the costs related to investment, operation, maintenance and fuel. It must be noted that the actual costs are very sensitive to the specific site and the existing installation (if any), which determine the investment costs, as well as costs of the coal and biomass to be used (Power Generation University, 2011). The fuel cost is the most important factor when considering the additional costs for co-firing.

The investment cost depends on the plant capacity and service (i.e. power generation only or combined heat and power), as well as the type of the biomass fuel to be used, and the quality of the existing boiler (if any). The costs of retrofitting[9] an existing coal-fired power plant to enable biomass co-firing are typically in the range of USD 300-700/kW for co-feed plants (IPCC 2011; IEA 2012; IRENA 2012) with European estimates around £200/kW or €220/kW (Mott McDonald 2011; ECN 2012a). Separate feed plants cost around USD 760-900//kW (IPCC, 2011). These low investment costs compared to dedicated biomass power plants are the consequence of pre-existing large coal-fired power plants and related infrastructure. Investment costs for indirect co-firing are around USD 3,000-4,000/kW, which is about ten times higher than direct co-firing (ECN 2012b). However, this method allows for the use of cheaper waste fuels with impurities.

The operation and maintenance (O&M) costs are likely to be similar to coal-fired power plants (USD 5-10/MWh) since co-firing increases fuel handling costs but reduces de-sulphurisation and ash disposal costs (Mott McDonald 2011). Typical O&M costs average around 2.5-3.5% of capital costs for direct co-firing (IRENA 2012) and around 5% for indirect co-firing (ECN 2012b). In general, it scales up when the biomass-to-coal ratio increases and the quality of the biomass used decreases.

The biomass fuel cost consists of two components: the cost of the feedstock and the cost of transportation, preparation and handling.

Feedstock costs vary greatly with the biomass origin (e.g. dedicated cultivation or agriculture and forestry waste), type and composition (i.e. energy and moisture

9 Includes facilities for fuel handling and preparation, boiler modification, contingency, taxes, fees, etc.

content). A recent IRENA study provides feedstock cost data for a range of locally available biomass resources in the United States, Europe, Brazil and India (IRENA, 2012). These costs range from USD 0-11/MWh for bagasse in Brazil and India to USD 6-22/MWh for agricultural residues in the United States and Europe.

For large-scale co-firing, operators have to turn to inherently more expensive dedicated energy crops (e.g. short rotation coppices) or international biomass trade if the regional infrastructure allows for this option. Particularly over long distances, the transportation costs depend to a large extent on the energy density (i.e. heating value) of the biomass fuel. Biomass pelletisation is a way to significantly increase the heat value per volume of biomass. Over the last four years[10], prices of industrial pellets fluctuated between € 24-30/MWh, which is around € 12/MWh more than the cost of coal (Hawkins Wright, 2011).

Taking both components into account, large-scale biomass co-firing would typically exceed the cost of coal. In Germany, DENA (2011) assumes a premium of € 12/MWh_e on top of coal, with future premiums ranging between € 0-20/MWh_e in 2030, depending on coal prices. However, this price differential can be overcome if the price of CO_2 emission allowances is sufficiently high.

Taking into account the above-mentioned cost components and their variabilities, **the range for the levelised cost of electricity (LCOE) from biomass** co-firing is wide. The IPCC suggests a range from USD 22-67/MWhe at a discount rate of 7%, where the actual price will depend strongly on the fuel cost (assumed range between USD 0-18/MWh), the investment costs (USD 430-900/kW) and the plant capacity factor (70-80%), among other factors (IPCC, 2012). The IEA suggests a range of LCOE between USD 80-120/MWh based on feedstock costs between USD 29-43/MWh (IEA 2012), while IRENA suggests a range between USD 44-130/MWh (IRENA 2012).

10 CIF prices according to PIX Pellet Nordic Index Baltic/North Sea and APX-ENDEX Amsterdam-Rotterdam-Antwerp. Assumed calorific value of 4.8 MWh/t (cf. FOEX Indexes Ltd, 2011).

Sustainability, Potential and Barriers

While co-firing currently seems to be one of the most efficient options to exploit biomass for energy use, its sustainability and potential are closely linked and depend on the overall sustainability of the biomass resources. In 2009, the global coal-fired electricity generation capacity was around 1,580 GW (IEA, 2011),[11] responsible for about 42% of the world's electricity production (IEA ETSAP, 2010a) and emitting 8.56 Gt of CO_2. The substitution of 10% of this coal power capacity would allow for some 150 GW biomass power capacity (i.e. about 2.5 times the current installed biomass power capacity) and reduce CO_2 emissions by some 0.5 Gt per year. Since statistics on the current use of co-firing are limited, an indicative assumption of 1-10% co-firing in some 200 power plants (with an average capacity of 500 MW) leads to 1-10 GW of co-firing capacity and suggests that the currently exploited co-firing potential is in the single-digit percentage range.[12]

The actual technical potential for co-firing will depend heavily on what develops with coal-fired power stations. In several European countries, the share of coal will decline, thus reducing the potential for biomass co-firing. However, globally the use of coal for power generation is projected to increase (e.g. IEA, 2011) – although some studies conversely project a possible decline (e.g. EREC/Greenpeace, 2010). This means that the commercial potential will depend on local biomass costs, the costs of globally traded biomass pellets and local policies to reduce GHG emissions.

In 2010, the use of biomass for power and heat generation reached the level of 62 GW of power capacity and 280 GWth/y of heating capacity worldwide (REN21, 2011). This included the use of solid, liquid and gaseous biomass in dedicated biomass power and CHP plants, as well as co-firing. A substantial increase in biomass co-firing poses the question of the sustainability and availability of the feedstock supply, which could also be used for the production of biofuels and bio-ethylene (ETSAP P10, I13). Depending on assumptions about agricultural and forestry residues, future crop yields, land availability for energy crops, demographic expansion and population diet, estimates of the bio-energy resource potential vary over a wide range (IC 2011). Some studies support the position that, because

11 The IEA uses a global capacity factor of almost 60% for coal.

12 Note that this indicative illustration of the technical co-firing potential disregards factors constraining the actual potential, particularly biomass resource availability, the actual co-firing retrofitting potential of existing coal power plants, which depends on the age of the facility, the basic efficiency, the existing boiler and the load factor (cf. below or Hansson et al. 2010).

of competing demand between food production, energy and industrial uses, no expansion potential exists for energy production from biomass. Others studies see a theoretical potential of up to 1,500 EJ per year (Note that the current global primary energy supply os in the order of 510 EJ/ year). Of course, realistic assessments should only include sustainable biomass resources—that is, biomass and associated land-use that cannot be used for food production and are compatible with sustainable land use from the environmental and climatic point of view. On this basis, the IPCC's special report on renewable energy identified a deployment potential for biomass energy use in the range of 100-300 EJ/year, mostly based on ligno-cellulosic feedstock, residues and biomass that are not in competition with other primary needs. The estimate includes power and heat generation (including co-firing) and production of biofuels (IPCC, 2011). Exploiting a significant part of this potential would require a tremendous effort and need to resolve the duality between heat and power and biofuels.

- **Potential for Developing Countries –** Co-firing offers advantages for emerging and developing countries since the use of waste from forestry and agriculture will increase the economic value of these sectors, which are usually strong components of the economy in these countries (IEA Bioenergy, 2009). Instead of being burned on the fields, as is commonly done, agricultural waste could be used profitably in co-firing power-plants[13]. However, international cooperation is needed to ensure the environmental and social sustainability of biomass exploitation (e.g. guarding against land-grabbing or deforestation, biodiversity loss in connection with large-scale monocultures). Of key importance is the fact that biomass co-firing has been recognised as a mitigation technology by the UNFCCC and that countries can sell carbon credits associated with their co-firing projects. Also important is biomass trading, which is increasing swiftly, driven by high fossil fuel prices and policies to reduce GHG emissions. While almost no woody biomass was traded in 2000, the global 2009 net trade in woody pellets amounted to about 75 PJ (IEA Bioenergy, 2011b). Expectations are that up to 5% of total biomass use in 2020 could be sourced by international trade, with North America, Africa, Brazil and Russia as the major suppliers (WEF, 2011). International trading, however, implies transportation and energy consumption, thus reducing the benefit of the use of biomass.

13 If agricultural and forest residues are extracted, the issues of nutrient and soil organic carbon balances must be addressed. With regard to forest residues, their impact on biodiversity also need consideration.

- **Sustainability Guidelines and Certification –** The Global Bioenergy Partnership (GBEP) has recently completed a set of 24 indicators to measure the sustainability of bioenergy (GBEP, 2011). These indicators cover environmental, social and economic aspects (e.g. soil protection, water resources, biological diversity, land allocation, food prices, energy access, infrastructure, workforce training). Similarly, the World Bioenergy Association (WBA) uses 15 sustainability criteria as the basis for their verification scheme of biomass sustainability. The Bioenergy and Food Security Criteria and Indicators project (BEFSCI) of the United Nations Food and Agriculture Organisation (FAO) has made a compilation of bioenergy sustainability initiatives[14]. Certification schemes can help safeguard against unsustainable practices (e.g. in the energy forestry sector). The IEA Bioenergy Implementing Agreement has produced an overview of bioenergy certification initiatives (IEA Bioenergy, 2011c).

  On the industry side, the European Pellet Council, in collaboration with the Wood Pellet Buyers Initiative, recently launched its "ENplus" certificate to support standardisation for pellets used in Europe, both locally produced and imported. More than 30 producers and 40 traders have so far been certified, with several others in the pipeline (as of 13 December 2011). The scheme is expected to expand and include also sustainability criteria ("ENplus GREEN"; Ryckmans 2011; European Pellet Council, 2011, personal communication). Similar wood pellet certification schemes are being developed in the United States and by the Technical Committee on Solid Biofuels of the International Organisation for Standardisation (ISO).

- **Policies and Incentives to Support Co-firing –** Considering current prices for coal and biomass, co-firing is generally more expensive than solely coal-based power generation or CHP. The competitiveness of biomass co-firing can be improved through measures to make coal-based energy more expensive, particularly carbon pricing through emission cap-and-trade schemes or carbon taxation. Based on current carbon prices, the incremental cost of co-firing cannot be fully recovered by selling emission permits, but the new European Union Emissions Trading System (EU ETS) in 2013 is likely to increase co-firing competitiveness and pellet use in Europe as large emitters (e.g. coal power plant owners) are subjected to auctioning of their CO_2 allowances (Fritsche 2011; VITO et al. 2011). Other measures to increase the profitability of biomass co-firing include the removal of specific fossil-fuel subsidies, incentives for the conversion of power plants into CHP plants, government support to biomass supply infrastructure and dedicated R&D funding for co-firing.

14 See http://www.fao.org/bioenergy/foodsecurity/befsci/62379/en/.

Governments can also establish mandatory use of biomass co-firing by quota obligation schemes. For example, the European Union has established a mandatory renewable energy share for Member States to be achieved by 2020 (RED, Directive 2009/28/EC). In order to fulfill this obligation, EU Member Countries can adopt a range of policies. In Denmark, for example, a quota-like system is in place to encourage utilities to use biomass, the majority from straw and the rest from woody feedstock (FORCE Technology, 2009). In the United Kingdom, biomass co-firing contributes to reaching mandatory renewable energy quotas, with a 2012-2013 target of 1.04 million renewable obligation certificates, equivalent to 1.04 TWh (DECC, 2011). In the Netherlands, policy is moving from a fixed governmental support to utilities on the order of € 60-70/MWh to a mandatory supplier obligation to be introduced by 2015. In Germany, utilities have requested policy support through the German Renewable Energy Act (EEG) to expand co-firing activities (DENA, 2011) since co-firing is not currently competitive. However, the German Government is not considering new legislation for co-firing at this time (Deutscher Bundestag, 2011).

In the United States, Renewable Energy Portfolio Standards exist in several states and co-firing is increasingly attractive to utilities. In Australia, the lack of specific incentives is seen as the main reason behind what is perceived as a delay in implementing co-firing technology in comparison with Europe (RIRDC, 2011).

In China, in spite of massive coal power deployment and large biomass resources (i.e. crops, forestry and woody residues amount to an equivalent of 400 million tonnes of coal per year), co-firing is not widespread because of the limited experience with biomass power generation (Wang 2011) and the exclusion of co-firing from the incentives (e.g. generation allowances) granted to other biomass-based power options. (Minchener, 2008). Other emerging economies that produce large amounts of agricultural residues and rely heavily on coal power (e.g. India) are also well-positioned to implement co-firing.

Policies should seek the most efficient use of the given biomass potential by encouraging co-firing in CHP plants where district heating systems are available (e.g. in northern Europe) and in connection with industrial facilities. The benefits from burning waste, which would otherwise constitute a disposal challenge, should also be considered.

Technical barriers to co-firing include the local availability of large amounts of quality biomass, as well as the cost of collection, handling, preparation and transportation, in comparison with the relatively low cost of coal. From a technical point of view, the risk of slagging, fouling, erosion and corrosion associated with the use of biomass can be countered by choosing appropriate co-firing technologies and feedstock. For example, most direct co-firing issues arise when there is no dedicated infrastructure and the biomass share is too high and/or of poor quality (Maciejewska et al., 2006).

References

1. AEBIOM (2011), Statistical Report, European Biomass Association, Brussels, August 2011.
2. Al-Mansour F., Zuwala J. (2010), An evaluation of biomass co-firing in Europe, in Biomass and Bioenergy, Volume 34, Issue 5, May 2010, pp. 620-629.
3. APX-ENDEX (2011), APX-ENDEX Successfully Launches the World's First Exchange for Biomass Renewable (Press Release), Amsterdam/Brussels/London, 3 November 2011, Available at: http://www.apxendex.com/index.php?id=24&tx_ttnews%5Btt_news%5D=545&tx_ttnews%5BbackPid%5D=94&cHash=5fa96bc69e (Accessed 12 Dec. 2011).
4. Baxter L., Koppejan J. (2004), Biomass-coal Co-combustion: Opportunity for Affordable Renewable Energy, EuroHeat & Power, January 2004.
5. DECC (2011), Calculating the Level of the Renewables Obligation 2012/13, UK Department of Energy and Climate Change, Office for Renewable Energy Deployment, London, Available at: http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/renewable-energy/2884-calc-level-of-renewables-obligation-12-13.pdf (Accessed 30 September 2011).
6. DENA (2011), Die Mitverbrennung holzartiger Biomasse in Kohlekraftwerken. Ein Beitrag zur Energiewende und Klimaschutz?, DENA, Berlin, 2011.
7. Deutscher Bundestag (2011), Mitverbrennung von holzartiger Biomasse in Kohlekraftwerken, Antwort der Bundesregierung, Drucksache 17/8037.,
8. EC (2010), Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. COM(2010)11; Brussels.
9. ECN (2012a), Use of sustainable biomass to produce electricity, heat and transport fuels in EU27. A model-based analysis of biomass use for 2020 and 2030. Deliverable D5.3, ECN-E—12-021, March 2012.
10. ECN (2012b), Co-firing low cost fuels using indirect gasification. The economics of indirect gasification. Presented at Clearwater Clean Coal Conference, Florida, USA, 3-7 June 2012.
11. EUBIONET III (2011), Solutions for biomass fuel market barriers and raw material availability, Summary of the EUBIONET III project results - VTT-M-06463 – Results-oriented report, October 2011.
12. European Pellet Council (2011), Available at: http://www.pelletcouncil.eu (Accessed 12 December 2011).
13. EREC/Greenpeace (2010), World Energy [R]evolution - A Sustainable World Energy Outlook, June 2010.
14. FOEX (2011), PIX Indexes Pellet Nordic, CIF, Index History, FOEX Indexes Ltd, http://www.foex.fi/uploads/bioenergy/PIX_Nordic_Pellet_History.pdf and http://www.foex.fi/index.php?page=pix-rcp (Accessed 12 Dec. 2011).

15. FORCE Technology (2009), Pellet market country report – Denmark, FORCE Technology, Kongens Lyngby, July 2009.
16. Fritsche, Uwe (2010), The Blue Angel for wood chips and pellets: a voluntary standard; presented at the Joint Workshop on Extending the RED Sustainability Requirements to Solid (and Gaseous) Bioenergy; Brussels, October 12, 2011, http://www.oeko.de/service/bio/dateien/en/fritsche_blue_angel1.pdf.
17. Hawkins Wright (2011), Forest Energy Monitor, Issue 15, September/October 2011.
18. GBEP (2011), The GBEP Sustainability Indicators for Bioenergy; Rome http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/Report_21_December.pdf.
19. IC (2011), Imperial College Centre for Energy Policy and Technology/UK Energy Research Centre (2011), Energy from biomass: the size of the global resource. An assessment of the evidence that biomass can make a major contribution to future global energy supply; London http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2098.
20. IEA (2007), IEA Energy Technology Essentials: Biomass for Power Generation and CHP. IEA, Paris, 2007.
21. IEA (2010), Energy Technology Perspectives 2010, IEA, Paris, 2010.
22. IEA (2011), World Energy Outlook 2011, IEA, Paris, 2011.
23. IEA (2012), Bioenergy for Heat and Power, Technology Roadmap, IEA, Paris, June 2012.
24. IEA Bioenergy (2009a), Bioenergy – a Sustainable and Reliable Energy Source, 2009.
25. IEA Bioenergy Task 32 (2009a), Database of Biomass Co-firing Initiatives, Available at: http://www.ieabcc.nl/database/cofiring.html (Accessed 25 Nov. 2011).
26. IEA Bioenergy Task 32 (2009b), Technical status of biomass co-firing (Deliverable 4), 2009.
27. IEA Bioenergy (2011b), Summary and conclusions from IEA Bioenergy Task 40 country reports on international bioenergy trade, Utrecht, April 2011.
28. IEA Bioenergy (2011c), Update: Initiatives in the field of biomass and bioenergy certification schemes, April 2010, Available at: http://www.bioenergytrade.org/downloads/overviewcertificationsystemsfinalapril2010.pdf (Accessed 12 December 2012).
29. IEA ETSAP (2010a), Technology Brief E01 – April 2010.
30. IEA ETSAP (2010b), Technology Brief E05 – May 2010.
31. IEA Clean Coal Centre (2012), information from personal email exchange, January 2012.
32. IPCC (2011), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation; Edenhofer, Ottmar et al. (eds.); IPCC Working Group III http://srren.ipcc-wg3.de/report/srren-full-report.

33. IRENA (2012), Biomass for Power Generation, Renewable Energy Technologies: Cost Analysis Series, Volume 1: Power Sector, Issue 1/5, June 2012.
34. Kiel (2011) Prospects of Torrefaction to Optimize Bioenergy Value Chains, ECN, Energy Delta Convention 2011, Groningen, 22 November 2011.
35. Platts (2011a), UDI World Electric Power Plants Data Base (WEPP), Platts Washington, DC, December 2011.
36. Platts (2011b), WEPP Data base description and research methodology - UDI world electric power plants data base, Platts Washington, 17 June 2011.
37. Maciejewska A. et al. S.D. (2006), Co-firing of biomass with coal: constraints and role of biomass pre-treatment, Institute for Energy, 2006.
38. Minchener (2008), The development of co-firing power generation market opportunities to enhance the EU biomass sector through international cooperation with China, final report, IEA Environmental Projects Limited and Tsinghua University, 2008.
39. Mott MacDonald (2011), Biomass conversion of coal plant. Commissioned by the Committee on Climate Change, 11 October 2011.
40. MSPA (2011), Mauritius Sugar Producers' Association, Available at: http://www.mspa.mu/index.php?rubrique=17 (Accessed 20 December 2011).
41. Power Generation University (2011), Co-Firing of Biomass in the US: Strategy and Opportunities http://www.powergenu.com/courses.aspx, (Accessed 18 December 2011).
42. REN21 (2011), Renewables 2011 Global Status Report, REN21 Secretariat, Paris, 2011.
43. RIRDC (2011), Facilitating the Adoption of Biomass Co-firing for Power Generation, RIRDC Publication No. 11/068, Australian Government, Rural Industries Research and Development Corporation, Available at https://rirdc.infoservices.com.au/downloads/11-068 (Accessed 20 December 2011).
44. Ryckmans, Yves (2011), Wood Pellet Buyers Initiative: Sustainability of wood pellets; presented at the Joint Workshop on Extending the RED Sustainability Requirements to Solid (and Gaseous) Bioenergy; Brussels, October 12, 2011. http://www.oeko.de/service/bio/dateien/en/ryckmans_sus_bio.pdf.
45. Suthum P. (2007), Co-firing biomass with coal for power generation, Fourth Biomass Asia Workshop, 20-22 November 2007.
46. Vattenfall (2011), Testergebnisse des Versuchsprogramms mit 4.300 Tonnen veredelten Holzpellets - Heizkraftwerk Reuter West von Mai bis Juli 2011; Berlin http://www.vattenfall.de/de/file/content/2011-10-12_Pr_sentation_Holzpellets_Reuter_West_18970857.pdf.
47. VITO/Oeko-Institut/TU Vienna/Utrecht University/ETA Florence/REC (2011), Benchmarking biomass sustainability criteria for energy purposes; study carried out for EC DG ENER under contract ENER/C1/495-2009/SI2.572581; Mol.

48. Wang, X. Tan, H. et al. (2011), Experimental investigation on biomass co-firing in a 300 MW pulverized coal-fired utility furnace in China, Proceedings of the Combustion Institute, vol. 33, i.2, pp. 2725-2733.

Further Information Sources[15]

49. Literature overview: Munir, S. (2010), A review on biomass–coal co-combustion: current state of knowledge, Energy and Resources Research Institute, School of Process, Environmental and Materials Engineering, University of Leeds, September 2010.
50. Co-firing technology: The handbook of biomass combustion and co-firing, Sjaak Van Loo, Jaap Koppejan (editors), Earthscan, London, Sterling, 2008.
51. A Compilation of Bioenergy Sustainability Initiatives, Bioenergy and Food Security Criteria and Indicators (BEFSCI) project: http://www.fao.org/bioenergy/foodsecurity/befsci/62379/en/.
52. Bioenergy Decision Support Tool (FAO, UNEP): http://www.bioenergydecisiontool.org.
53. Demonstration of large scale Biomass Co-firing and supply chain integration, http://www.debco.eu.
54. Experiences in Europe and List of Biomass Co-firing Plants, European Biomass Industry Association: http://www.eubia.org/338.0.html.
55. IEA Clean Coal Centre: http://www.iea-coal.org.uk, http://www.coalonline.org/site/coalonline/content/browser/81569/Cofiring-coal-with-other-fuels.
56. PELLETS@LAS, Database providing up-to-date pellet market information for Europe: http://www.pelletsatlas.info.
57. Standardisation and information on biomass fuels and ashes: http://www.phydades.info, http://www.biodat.eu.

15 Addition information sources not included in the references section.

Summary key data and Figures for Biomass Co-firing

Table 1 – Summary Table: Key Data and Figures for Biomass Co-firing

Technical performance	Typical current international values and ranges			
Energy input[2]	Wood chips (+coal)	Wood (+coal)	Pellets (+coal)	Treated pellets (+coal)
Output	Electric Power, or combined heat and power (CHP) Combined Heat and Power			
Water content (%)	35-50	35-50	< 10	< 5
Density (kg/m^3)	314-408	490-638	650	750
Energy density (MWh/m^3)	0.3-0.6	0.5-0.9	3.2	4.3

Technology variant	Direct co-firing	Indirect co-firing	Parallel co-firing
Energy efficiency	35-42% / 44-85% with CHP	33-42% / 44-85% with CHP	33-42% / 44-85% with CHP
Lifetime	30+	30+	30+
Capacity factor, %	From 20-100%, but typically between 60-80%	From 20-100%, but typically between 60-80%	From 20-100%, but typically between 60-80%
Typical plant size,	10 - > 1000 MW	10 - > 1000 MW	- > 1000 MW
Installed capacity	>100 plants	5-10	< 5
GHG Emissions (emitted/avoided)	Lignite co-firing: 950-1100 gCO_{2av}/KWh_e for local biomass, 800-950 gCO_{2av}/KWh_{el} for imported biomass Coal co-firing: 900-1000 gCO_{2av}/KWh_{el} for local biomass, 720-880 gCO_{2av}/KWh_{el} for imported biomass		
Other pollutants	On average, 15% NO_x emissions reductions with 7% co-firing Other pollutants dependent on biomass feedstock		
Regional implementation	Mostly North America/ Europe	Mostly North America/ Europe	Mostly North America/ Europe
Market share	Low	Low	Low

Costs	Typical current international values (2010 USD)		
Technology variant	Direct	Indirect	Parallel[3]
Investment cost, USD/kW	430-550	3,000-4,000	1,600 - 2,500
O&M cost, % of investment per year	2.5-3.5% of capital costs	5% of capital costs	For steam cycle, ~ 4% of capital costs
Biomass fuel energy cost - waste, €/MWh	Variable (na)	Variable (na)	Variable (na)
Biomass fuel energy cost – crops, €/MWh	24-30	24-30	24-30
Levelised cost of electricity, USD cents/kWh	2.2-6.7	5-13	7-15

Data projections	Typical projected international values and ranges		
Technology variant	Direct	Indirect	Parallel
Efficiency (2020/2030/2050)[4], %	Depends on introduction fluidised beds	35/38/na	33/35/na
Lifetime, years	30+	30+	30+
Emissions/pollutants (emitted/avoided)	Depending on logistics and biomass feedstock		
Investment cost (2020/2030/2050), USD/kW	n/a	3100/ 2750/na	3700/3300/na
Production cost (2020/2030/2050), USD/MWh	n/a	100/90/na	140/130/na
Global/regional potential	High (na)	High (na)	High (na)
Market share, %	Depends on competition for biomass feedstock		

16 Based on data from DENA (2011).
17 Based on cost for separate boiler (IPCC 2011).
18 Based on ETSAP Technology Brief on Biomass for Heat and Power, May 2010.

Disclaimer

The designations employed and the presentation of materials herein do not imply the expression of any opinion whatsoever on the part of the Secretariat of the International Renewable Energy Agency concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The term "country" as used in this material also refers, as appropriate, to territories or areas.

The preparation of the paper was led by Philippe Lempp (GIZ).

Comments are welcome and should be addressed to Ruud Kempener (RKempener@irena.org), Giorgio Simbolotti (giorgio.simbolotti@enea.it) and Giancarlo Tosato (gct@etsap.org)