8 BIOMASS FOR POWER GENERATION

	2010	2013	2014	2010-2014 (% change)
New capacity additions (GW)	7.7	5.5	3.0+	-61%
Cumulative installed capacity (GW)	68	86	89+	31%
Typical total installed cost range: OECD (2014 USD/kW)	1 880 – 6 820	1 880 – 6 820	1 880 – 6 820	n.a.
Typical total installed cost range: non-OECD (2014 USD/kW)	400 - 2000	400 - 2000	400 - 2000	n.a.
Global LCOE range (2014 USD/kWh)	0.03 – 0.14	0.03 – 0.14	0.03 – 0.14	n.a.

Notes: 2014 deployment data are estimates. n.a. = data not available or not enough data to provide a robust estimate.

Highlights

- A range of biomass power generation technologies are mature and biomass is a competitive power generation option wherever low-cost agricultural or forestry waste is available. In addition, new technologies are emerging that show significant potential for further cost reduction.

- Biomass-fired power generation technologies range from mature solutions to emerging technologies that have not yet been deployed on a large scale. The total installed costs of biomass power generation technologies reflect this diversity, varying between USD 1 880 and USD 6 820/kW in the OECD. Costs are significantly lower in developing countries where cheaper, less efficient technologies are more typical and costs range from USD 400 to USD 2 000/kW.

- Secure, long-term supplies of low-cost, sustainably sourced feedstocks is critical to the economics of biomass power plants. Feedstock costs can be zero for some wastes, including those produced onsite at industrial installations, such as black liquor at pulp and paper mills or bagasse at sugar mills. Sometimes their use actually saves disposal costs.

- Biomass can provide dispatchable baseload electricity at very competitive costs. The regional or country weighted LCOE ranged from a low of USD 0.04/kWh in India and USD 0.05/kWh in China to USD 0.085/kWh in Europe and North America over the last ten years. Individual projects typically generate electricity that costs between USD 0.03 and USD 0.14/kW. But higher values exist, up to USD 0.25/kWh, particularly for waste incineration projects in the OECD where the primary purpose of the process is not electricity generation, but waste disposal.

Introduction

A range of technologies are currently available to transform biomass into electricity. Many of these biomass power generation technologies – including direct combustion in stoker boilers, low-percentage co-firing, anaerobic digestion, municipal solid waste incineration, landfill gas and combined heat and power – are mature, commercially viable technologies with long track records. These technologies can provide low-cost, reliable electricity where low-cost feedstocks are available and they have relatively modest future cost reduction potentials.

A set of less mature technologies, such as atmospheric biomass gasification and pyrolysis, are still in the initial commercial deployment phase. Technologies such as integrated gasification combined cycle, bio-refineries and bio-hydrogen are in the demonstration or research and development (R&D) phases. These technologies have correspondingly greater cost reduction potentials, but play a much smaller role in today's power generation system.

Cumulative worldwide installed capacity at the end of 2013 was around 86 GW (Figure 8.1) and is anticipated to reach 130 GW by the end of 2025 (GlobalData, 2014). Around one-third of the installed capacity is located in Europe, 29% in the Asia Pacific region and almost 20% in North America (GlobalData, 2014).

The potential for biomass cost reductions remains highly heterogeneous as a result of the different stages of development of the various technologies. Cost reduction potentials are relatively small for established technologies; however, the long-term potential for cost reductions for less mature technologies remains good, taking into consideration the estimated future installation and the annual growth rate of cumulative installed capacity of 13% per year between 2000 and 2013.

The process of biomass power generation is dependent on three main components:

- Biomass feedstocks: Feedstock for biomass generation varies from region to region and different feedstocks have different properties that impact their use for power generation.
- Biomass conversion: Conversion is a process through which feedstocks are transformed into energy used to generate heat and/or electricity (e.g. gasification, pyrolysis, digestion into biogas and combustion).
- Power generation technologies: An extensive range of commercially viable power generation technologies are available that can use the useful energy generated by biomass as a fuel input.

The current analysis focuses on the costs of the conversion and power generation technologies, and touches on the available feedstock costs. One of the most important determinants of the economic success of biomass projects is the availability of a secure and sustainable fuel supply (i.e. feedstocks) for conversion.

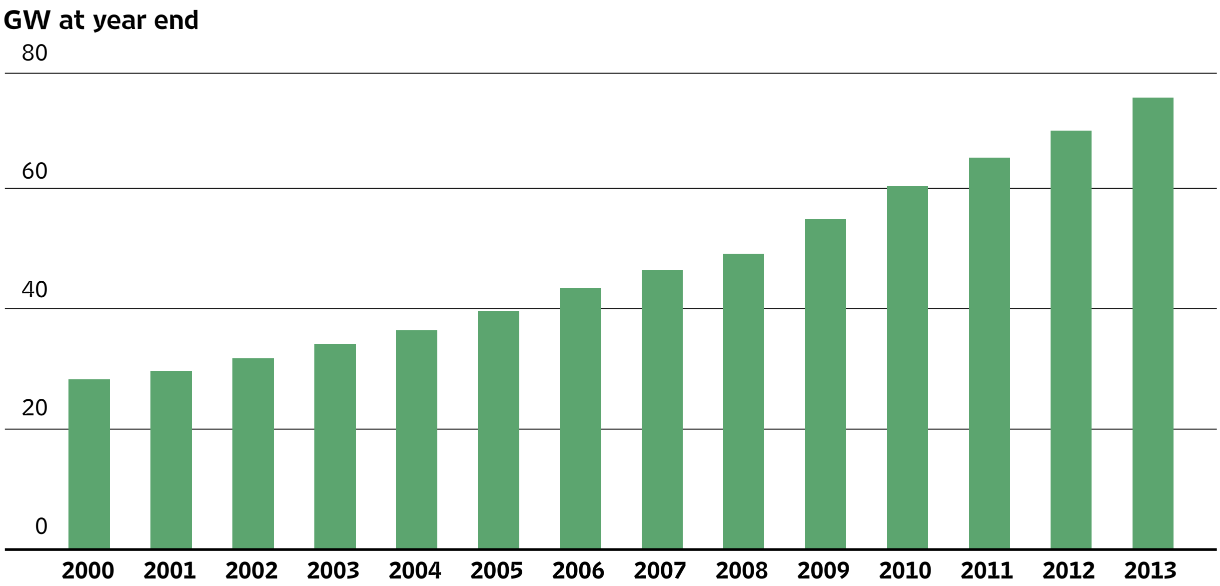
Given the critical importance of biomass to virtually all future scenarios for a low-cost transition to a sustainable energy sector, the current very poor understanding of the country-level, regional and global supply curves for sustainable biomass feedstocks represents a significant risk to the world's ability to avoid dangerous climate change effects at a reasonable cost.

Biomass feedstocks

Biomass is defined as organic material of recently living plants, such as trees, grasses and agricultural crops. As shown in Table 8.1, biomass feedstocks are very diverse and their chemical compositions vary from species to species. There are combustion technologies that run on a variety of biomass feedstocks, but some specific technologies can only operate on a limited selection, or relatively homogeneous set, of feedstocks, which can add complexity to the planning and economic viability of biomass-based power plants.

Biomass power plants require sustainably sourced, low-cost, adequate and predictable biomass feedstock supplies. The range of costs for feedstocks is highly variable, from zero for wastes produced as a result of industrial processes – and even negative prices for waste that would

Figure 8.1: Global cumulative installed capacity, 2000-2013



Source: Global Data, 2014

otherwise have incurred disposal costs (e.g. black liquor at pulp and paper mills) – to potentially high prices for dedicated energy crops if productivity is low and transport costs are high. More modest costs are incurred for agricultural and forestry residues that can be collected and transported over short distances, or are available at processing plants as a by-product. Transport costs add a significant amount to the costs of feedstocks if the distances become large, as a result of the low-energy density of biomass. As a result, the trade in biomass, such as wood chips and pellets, is particularly sensitive to transportation costs and is unlikely to ever represent a large share of biomass use. Transforming wet biomass into higher-density forms (e.g. through torrefaction or conversion into biofuels) will help reduce transportation costs per unit of energy, but the transformation costs must be taken into account.

Feedstock costs typically account for between 20% and 50% of the final cost of electricity based on biomass technologies. Agricultural residues, such as straw and sugarcane bagasse, tend to be the least expensive feedstocks, as they are a harvest or processing byproduct, but they are correlated with the price of the primary commodity from which they are derived and they have registered increased costs over the past five years. Biomass power generation plants incur the risk of being adversely affected by volatile commodity prices unless they have secure supplies (e.g. vertically integrated agricultural processing industries that also produce their own power) or have contracted long-term for supplies.

Collection and transport costs dominate the costs of feedstocks derived from forest residues. The density of forestry residues in a given area determines the placement of biomass power plants and their economic size. This is because at a certain point the additional feedstock transport costs will offset the economies of scale of a larger plant that requires feedstock from a larger radius. The effect of this limitation is that economies of scale for biomass power plants are typically limited and a larger number of geographically dispersed biomass plants can be more economic than one large one.

Prices for biomass sourced and consumed locally are difficult to obtain, which renders it almost impossible to realise comparisons over time. A notable exception is India, which tracks the evolution of the price of bagasse through an index. Feedstock prices are dependent on the energy content of the fuel, moisture content and other chemical properties that affect the costs of utilisation at the power plant and the efficiency of generation. The range of costs can be quite wide and very site-specific (Table 8.1). Spot prices for wood chips on North American markets ranged between USD 5.5 and USD 6.6/GJ in July 2014, while forward prices for wood chips in Europe for the third and fourth

Table 8.1: Biomass feedstock characteristics and costs in the United States

		Typical moisture content	Heat value MJ/kg (LHV)	Price (2014 USD/GJ)
Forest residues	**Pine residues**	30 - 40%	17.5 - 20.8	1.2 - 1.5
	Hardwood residues	30 - 40%	17.5 - 20.7	0.9 - 1.4
Wood waste		5 - 15%	19.9	1.1 - 3.2
Agricultural residues		20 - 35%	15.1 - 18.1	1.4 - 3.5
Energy crops	**Poplar**	10 - 30%	17.7	1.5 - 3.6
	Switchgrass and other	20%	16.8 - 18.6	2.4 - 3.4
	Miscanthus	15%	17.8 - 18.1	2.8 - 8.2
	Bagasse	10 - 30%	17.7 - 17.9	2.2
	Sorghum	20%	14.3 - 18.3	2.3 - 2.9
	Willow	10 - 30%	16.7 - 18.4	3.1 - 3.4

Sources: Frank W. Norris Foundation, 2014; and United States DOE, 2011

quarters ranged between USD 8.2 and USD 8.4/GJ (Argus Media Biomass Markets, 2014).

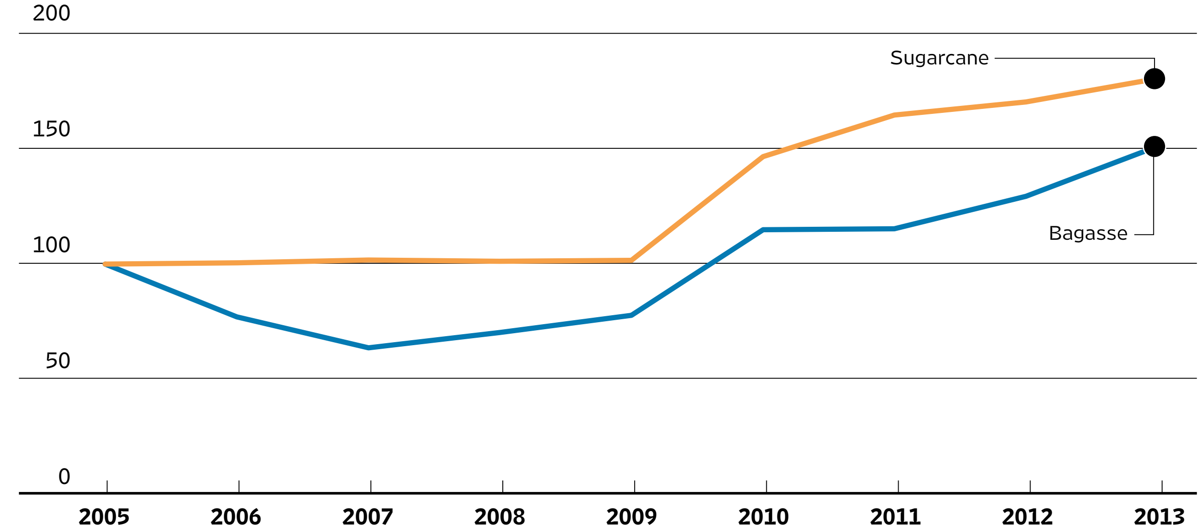
Some prices for feedstocks in developing countries are available, but the information is relatively limited. In the case of Brazil, the price of bagasse varies significantly depending on the harvest period and appears to be volatile. The price of bagasse was between USD 43 and USD 52/tonne in 2014 – significantly higher than the USD 11-13/tonne price in 2009 (PCH Portal, 2014; and Business Standard, 2014). Despite the increase in the price of bagasse in the last five years, there was a substantial growth in annual bagasse generation capacity, at an average of more than 1 300 MW installed per year from 2009 to 2013 (Global Data, 2014). The price increase since 2009 may have had an important impact on the economics of bagasse-based power plants, most likely motivating potential developers to consider other feedstocks, such as eucalyptus (Bhatia et al., 2013). Despite this, bagasse-based generation in 2012 accounted for around 80% of all electricity generation from biomass in Brazil (Bhatia et al. 2013).

In India, the Office of the Economic Adviser within the Ministry of Commerce and Industry compiles bagasse and sugarcane price data, which are then transformed into an index. Prices were estimated to have increased from USD 19/tonne in 2005 to around USD 26/tonne (USD 1.5/GJ) of bagasse in 2014 (PCH Portal, 2014; and Business Standard, 2014), and they have followed the price trend of sugarcane (Figure 8.2).

Biomass capacity deployment in India appears to be dependent on the price and availability of bagasse; annual new capacity additions were around 600 MW on average between 2009 and 2013. According to the Ministry of New and Renewable Energy, almost 55% of biomass installed capacity used bagasse in 2012.

The analysis in this report for OECD countries examines feedstock costs of between USD 10/tonne for low-cost residues to above USD 180/tonne for internationally traded pellets (Tables 8.1 and Argus, 2014). This compares to forward prices and spot prices for pellets at ARA (Amsterdam, Rotterdam, Antwerp) that ranged between USD 180 and USD 184/tonne during May-July 2014 (Argus Media Biomass Market, 2014). Environmental policies in the European Union have fostered an international wood pellet market in which the United States and Canada play a significant role in supplying pellets to Europe (NREL, 2013).

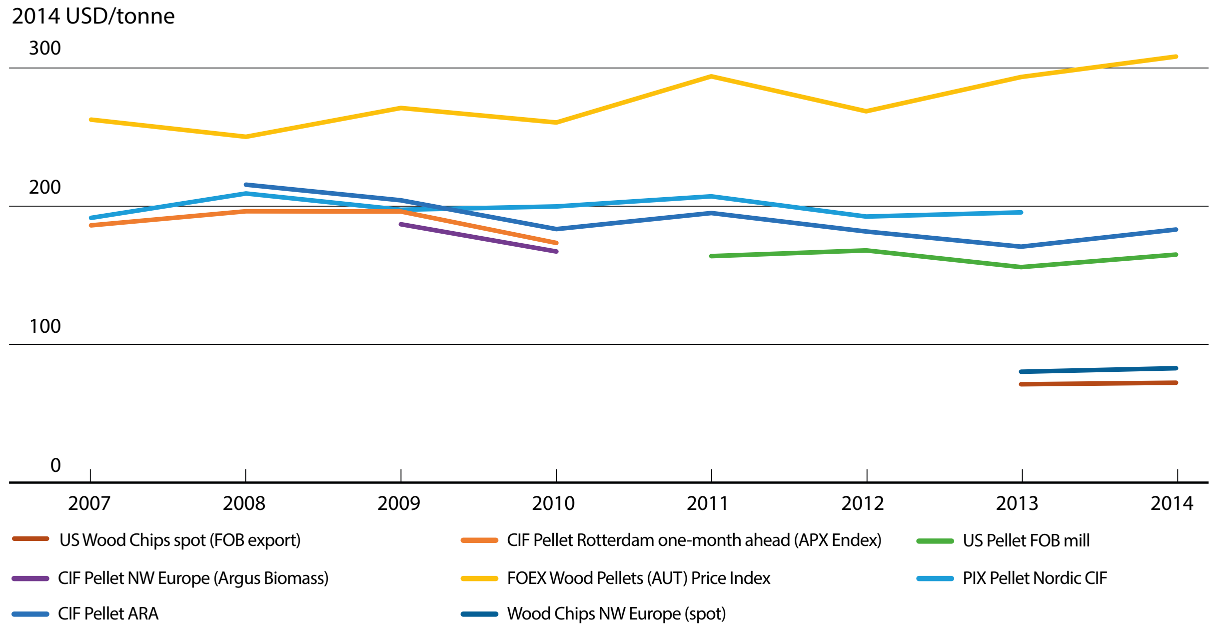
Figure 8.2: Evolution of the price of sugarcane and bagasse in India, 2005-2013



Note: 2005 baseline = 100

Source: Office of the Economic Adviser, Ministry of Commerce and Industry, 2014

Figure 8.3: Biomass pellet prices for large-scale consumers in Austria, the Netherlands, Scandinavia and the United States



Note: CIF = cost insurance and freight. FOB = free on board.

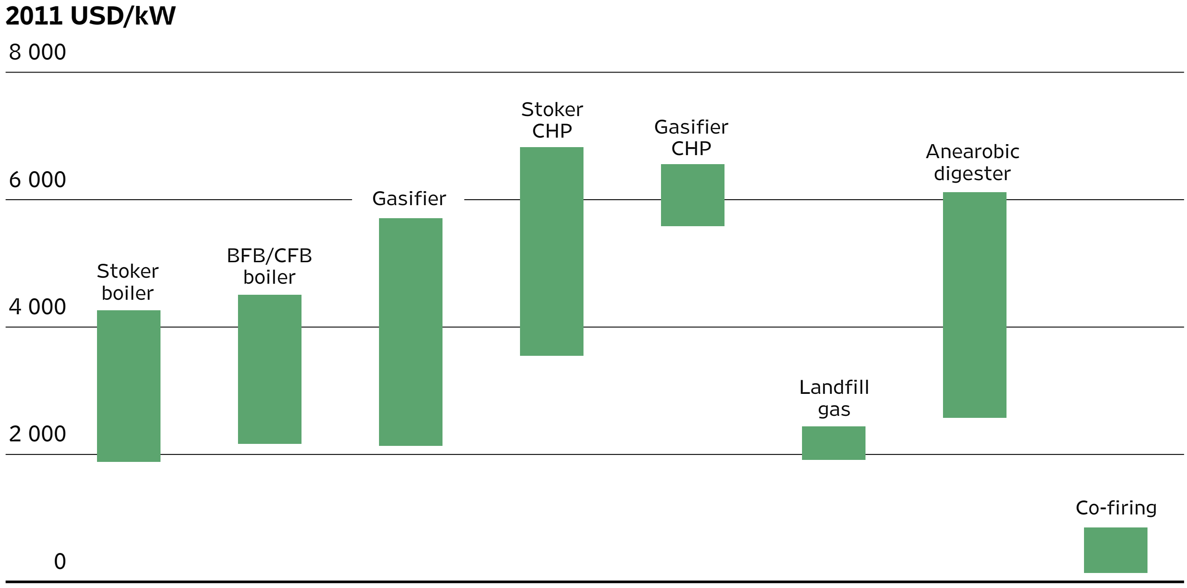
Sources: Own calculations based on Sikkema et al., 2010, Foex Indexes, 2014, Argus Media 2013 & 2014 and IEA, 2014.

Figure 8.3 presents the evolution of pellet prices and wood chips in selected European and North American markets. Pellet prices at ARA have decreased by almost 15% since 2008. Pellet prices for Scandinavian markets have seen a smooth evolution since 2007 having registered a 2% increase since 2007. Pellet prices in the United States were 10% lower than ARA prices making the United States a competitive exporter for European markets. The same difference can be observed for wood chips as well. Inland markets such as Austria are penalised by transport costs which account for a significant proportion of the final prices. In 2013, Austrian prices were around 50% higher than the ARA price.

Biomass-fired power generation capital costs

Technology options largely determine the cost and efficiency of biomass power generation

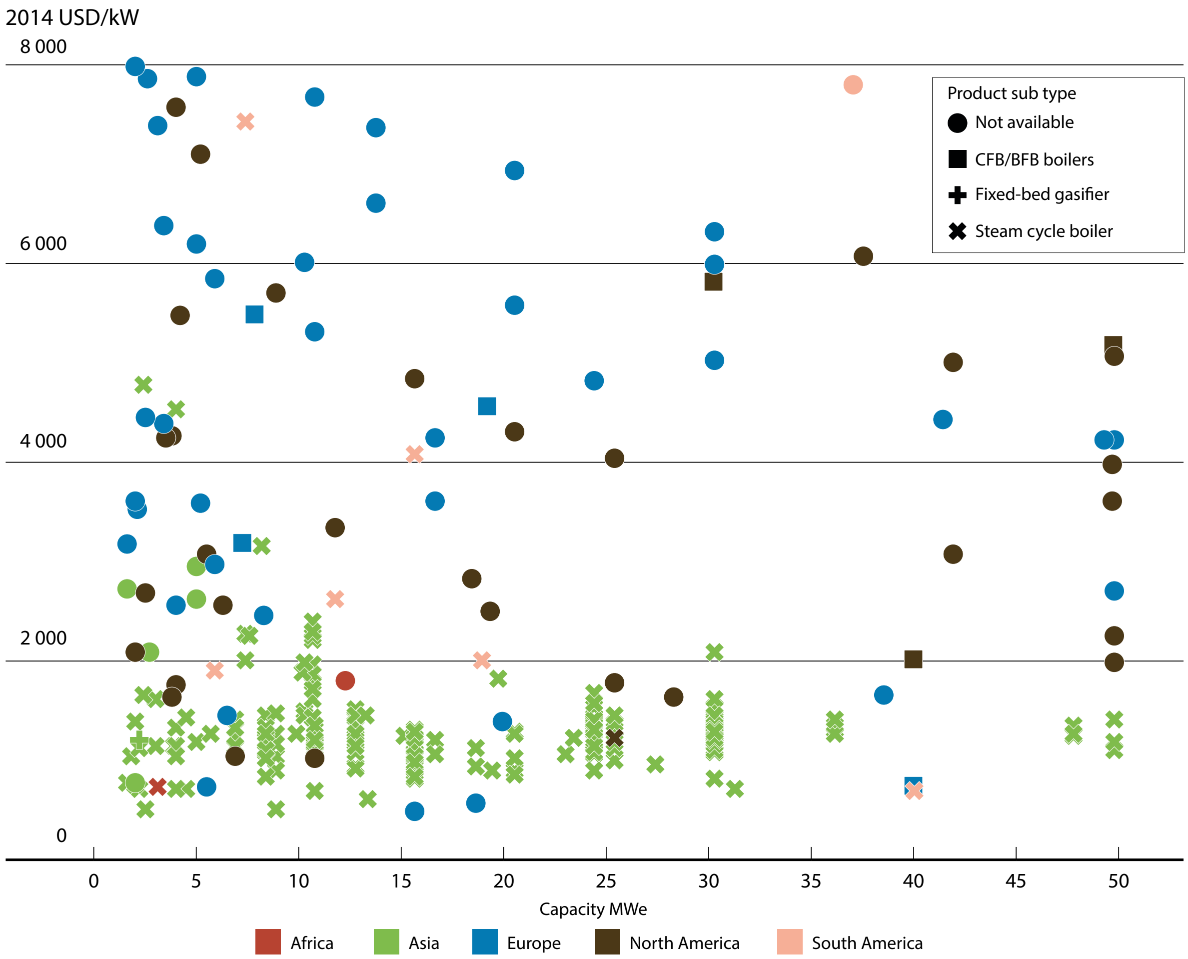
Figure 8.4: Typical total installed capital costs of biomass-fired electricity generation technologies in OECD countries



Note: BFB = bubbling fluidised bed; CFB = circulating fluidised bed

Source: IRENA Renewable Cost Database, 2014

Figure 8.5: Total installed costs of biomass power generation technologies



Source: IRENA Renewable Cost Database and GlobalData, 2014.

equipment, although equipment costs for individual technologies can vary significantly, depending on the region, feedstock type and availability, and how much feedstock preparation or conversion happens on site.

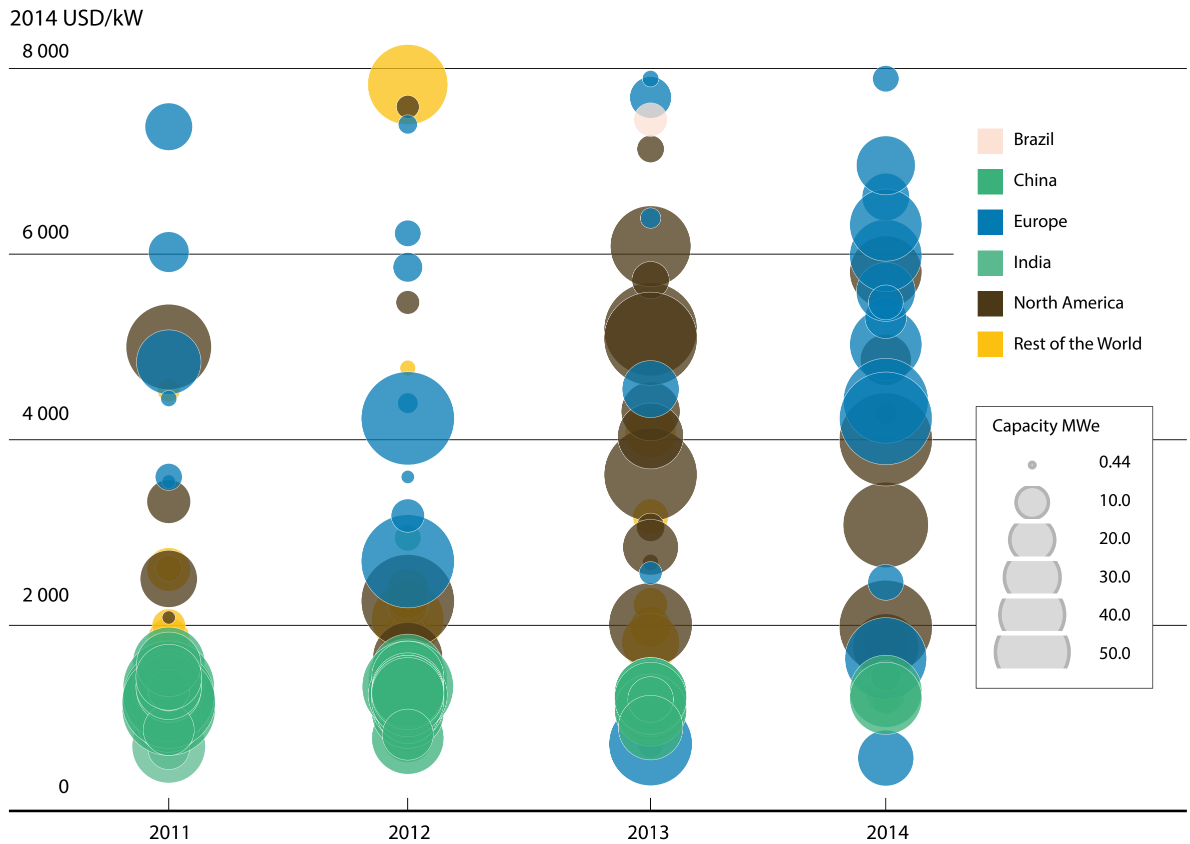
Planning, engineering and construction costs, fuel handling and preparation machinery, and other equipment (e.g. prime mover and fuel conversion system) represent the major categories of the total investment costs – or capital expenditure (CAPEX) – of a biomass power plant. Additional costs are derived from grid connection and infrastructure (e.g. roads). Figure 8.4 presents the range of capital costs for selected technologies in OECD countries. Combined heat and power (CHP) biomass installations have higher capital costs, but the higher overall efficiency (around 80% to 85%) and the ability to produce heat and/or steam for industrial processes or for space and water heating through district heating networks can significantly improve the economics.

Biomass power plants in developing countries can have significantly lower investment costs than the cost ranges for OECD projects, due to lower local content costs and the cheaper equipment allowed by less stringent environmental regulations. For example, the range of capital costs for a set of 124 manure and wastewater systems associated with electricity generation was between USD 500/kW and USD 5000/kW in developing countries.

Figure 8.5 and Figure 8.6 highlight the relatively low cost of biomass combustion technologies for projects in Asia and South America. Although small-scale projects can have higher capital costs, the majority of larger projects have installed capital expenses in the range of USD 450 to USD 2 000/kW. The data to which IRENA has access is dominated by steam cycle boiler systems, although in many cases the technology is not disclosed.

Individual projects can have very different cost components, infrastructure being particularly project-sensitive. A set of 12 projects from Africa and India had infrastructure costs of between 1% and 58% of total investment costs. Equipment costs can account for 8% to 86%, while grid connection

Figure 8.6: Total installed costs of biomass-fired power generation projects, 2011 to 2014



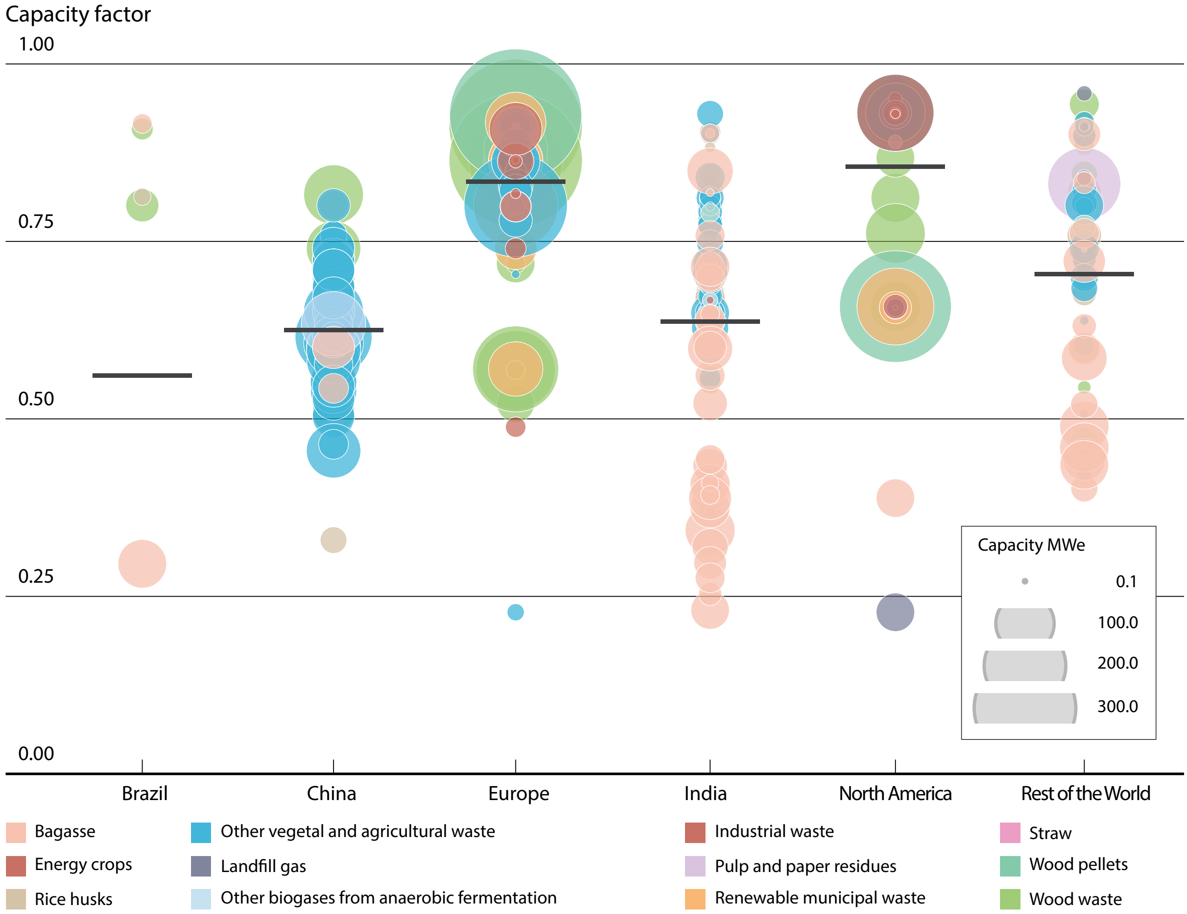
Source: IRENA Renewable Cost Database

Table 8.2: Fixed and variable operations and maintenance costs for biomass power

	Fixed O&M (% of CAPEX/YEAR)	Variable O&M (2014 USD/MWh)
Stoker/BFB/CFB boilers	3.2	4-4.93
Gasifier	3-6	4
Anaerobic digester	2.1-3.2 2.3-7	4.4
Landfill gas	11-20	n.a.

Sources: United States DOA, 2007; United States EPA, 2009; and Mott Macdonald, 2011

Figure 8.7: Project capacity factors and weighted averages of biomass-fired electricity generation systems by country and region



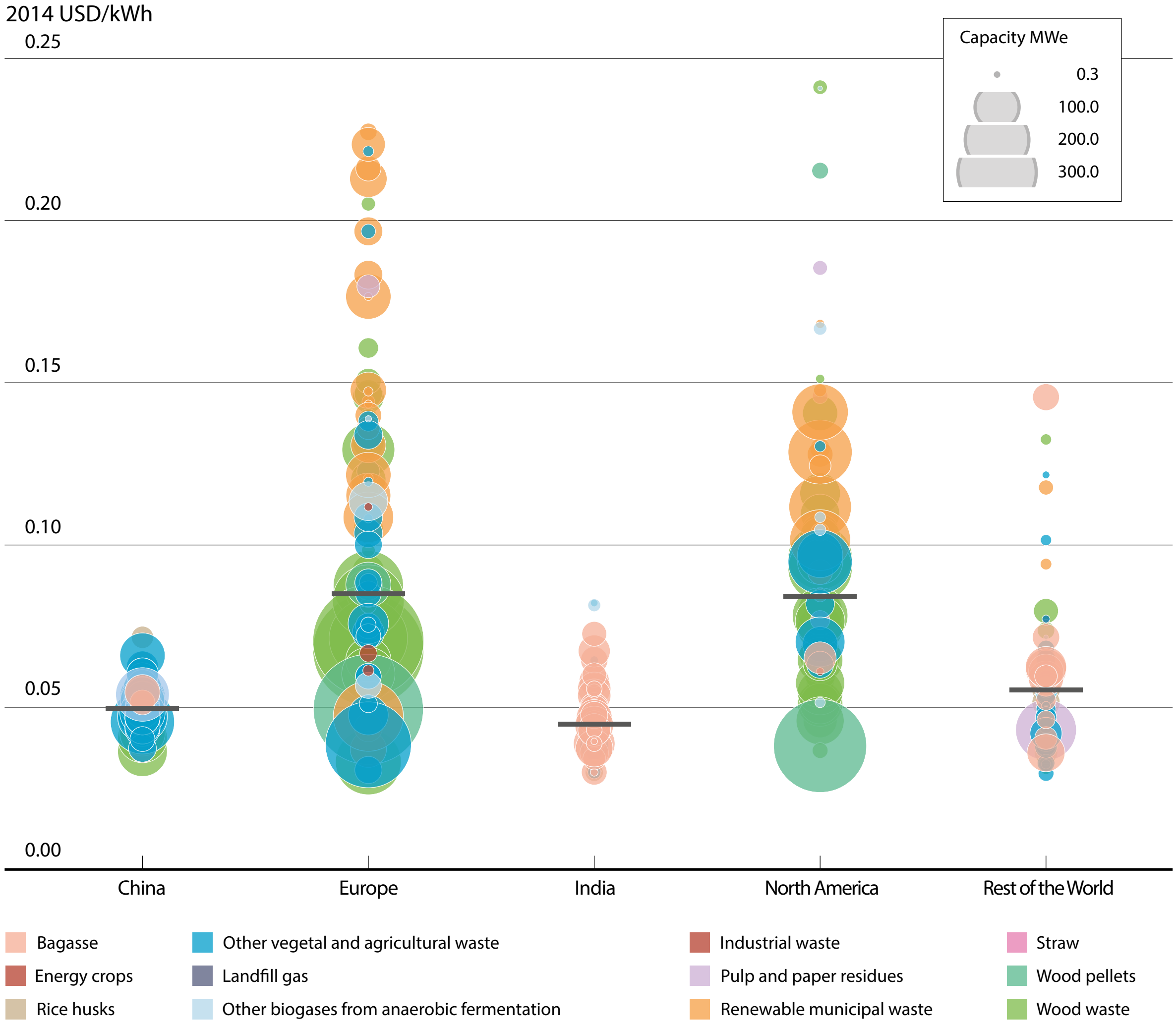
Source: IRENA Renewable Cost Database

can be as high as 41% of total investment costs (IRENA, 2013).

Biomass-fired power generation operations and maintenance costs

Fixed operations and maintenance (O&M) costs for biomass power plants typically range from 2% to 6% of the initial CAPEX per year, while variable O&M costs are typically relatively low at 0.005/kWh (Table 8.2). Fixed O&M costs include labour, scheduled maintenance, routine component/equipment replacement (for boilers, gasifiers, feedstock handling equipment, etc.), insurance, etc. The fixed O&M costs of larger plants are lower per kilowatt (kW) due to economies of scale, especially for labour. Variable O&M costs are determined by the output of the system and are usually expressed as USD/kWh. Non-biomass fuel costs, such as ash disposal, unplanned maintenance, equipment replacement and incremental servicing costs are

Figure 8.8: Levelised electricity cost ranges and weighted averages of biomass-fired electricity generation by feedstock and country/region, 2000 to 2014



Source: IRENA Renewable Cost Database

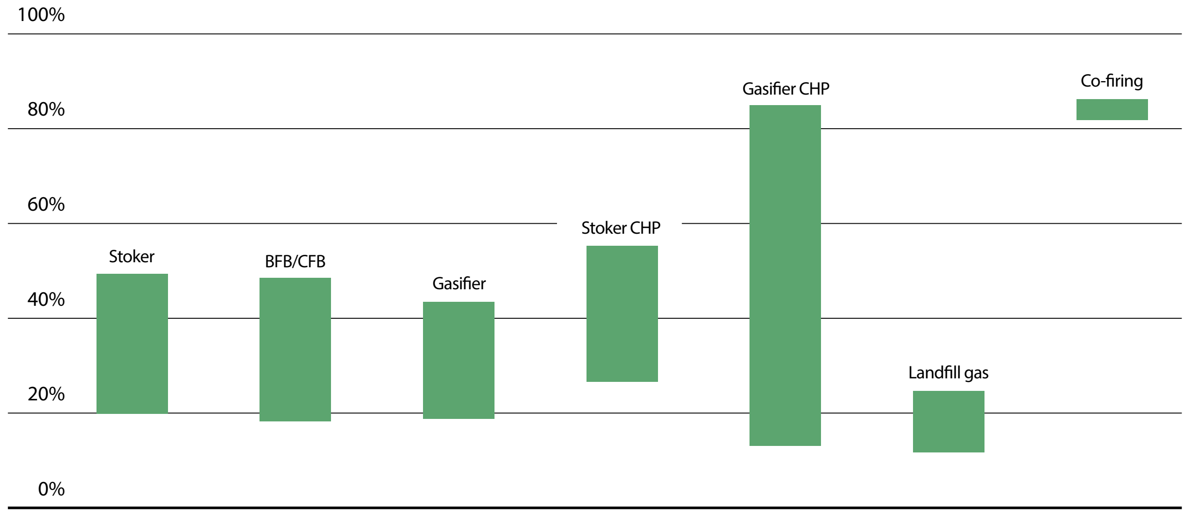
the main components of variable O&M costs. Unfortunately, the available data often merge fixed and variable O&M costs into one number, thus rendering a breakdown between fixed and variable O&M costs impossible.

Biomass-fired power generation capacity factors and efficiency

Technically, it is possible for biomass-fired electricity plants to achieve capacity factors of 85% to 95%. In practice, most plants do not regularly operate at these levels. Feedstocks may be a constraint on capacity factors in cases where systems relying on agricultural residues may not have year-round access to low-cost feedstock and buying alternative feedstocks might make plant operation uneconomical. This is illustrated in Figure 8.7, where the lower capacity factors for projects in India represent the impact of a large number of bagasse-fired projects that will operate only during and after the harvesting period until they exhaust the available feedstock supply. In contrast, the higher capacity factors observed in Europe and North America are a consequence of these plants relying on steady supplies of wood pellets and wood waste provided by a functional, buyer-driven international market for such feedstocks (NREL, 2013, Argus Biomass Markets, 2014), as well as waste-to-energy plants and those using forestry or pulp and paper residues.

The assumed net electrical efficiency (after accounting for feedstock handling) of the prime mover (generator) averages around 30%, but varies from a low of 25% to a high of around 36%. In developing countries, cheaper technologies

FIGURE 8.9: THE SHARE OF FEEDSTOCK COSTS IN THE LEVELISED COST OF ELECTRICITY OF BIOMASS-FIRED ELECTRICITY GENERATION BY TECHNOLOGY



and sometimes poor maintenance result in lower overall efficiencies that can be around 25%, but many technologies are available with higher efficiencies, with 31% for wood gasifiers to a high of 36% for modern well-maintained stoker, circulating fluidised bed (CFB), bubbling fluidised bed (BFB) and anaerobic digestion systems (Mott MacDonald, 2011). Biomass integrated gasification combined cycle (BIGCC) systems are able to achieve higher efficiencies, but require much higher capital investments. To date, the hoped for development of BIGCC systems has not materialised.

THE LEVELISED COST OF ELECTRICITY FROM BIOMASS-FIRED POWER GENERATION

The wide range of biomass-fired power generation technologies and feedstock costs translates into a broad range of observed LCOE of biomass-fired electricity. Figure 8.8 summarises the estimated range of costs for biomass power generation technologies in a range of countries and regions where the IRENA Renewable Cost Database has good coverage. Assuming a cost of capital of 7.5% to 10%, and feedstock costs between USD 1 and USD 9/GJ, the weighted average LCOE of biomass-fired electricity generation is around USD 0.04/kWh in India and USD 0.05/kWh in China. The weighted average LCOE in North America and Europe is higher, reflecting more sophisticated technology with more stringent emissions controls and higher feedstock costs. The weighted average of projects in Europe and North America was around USD 0.085/kWh. Where capital costs are relatively low, and low-cost feedstocks are available, bioenergy can provide competitively priced, dispatchable electricity generation with an LCOE as low as around USD 0.04/kWh.[32] The most competitive projects make use of agricultural or forestry residues already available at industrial processing sites where marginal feedstock costs are minimal or even zero. Where industrial process steam or heat loads are also required, the ability to integrate CHP systems can reduce the LCOE of electricity to as low as USD 0.03/kWh.

Low-cost opportunities to develop bioenergy-fired power plants present themselves at sites where low-cost feedstocks and handling facilities are available to keep feedstock and capital costs low. Where this is not the case, or where these feedstocks need to be supplemented by additional feedstocks (e.g. outside seasonal harvesting periods), then competitive supply chains for feedstocks are essential for making biomass-fired power generation economically sound.

This is the pattern seen outside Europe and North America, where biomass costs for most projects can range from negligible for agricultural or forestry processing residues, up to USD 2.25/GJ. They may sometimes exceed these values and rise to as much as USD 4/GJ where additional feedstocks are purchased to achieve higher capacity factors. These projects, using simple and cheap combustion

[32] *However, many of these low-cost technologies will not meet stringent air quality standards.*

technologies can have very competitive LCOEs (Figure 8.8). As an example, auctions in Brazil organised in August 2013 saw developers win contracts for 647 MW to be delivered in 2018 at average prices of USD 0.056/kWh (BNEF, 2013). However, even higher-cost projects in certain developing countries, will be attractive because they provide security of supply where brownouts and blackouts can be particularly problematic for the efficiency of industrial processes.

Many of the higher cost projects instituted in Europe and North America are using municipal solid waste as a feedstock. It is important to note that the primary objective of these projects is not power generation, but to dispose of waste. Capital costs are often higher as greater sorting of heterogeneous feedstocks is required, as well as expensive technologies to ensure local pollutant emissions are reduced to acceptable levels. Excluding these projects, which are typically not the largest projects, reduces the weighted average LCOE in Europe and North America by around USD 0.01/kWh and narrows the gap with the LCOE of non-OECD regions.

Figure 8.9 highlights the importance of the feedstock costs in OECD countries, where feedstock costs range from USD 1/GJ for residues to USD 10/GJ or more for pellets. Feedstock costs account for 20% to 50% of the LCOE power-generation-only options (co-firing is a particular case and is excluded.) Gasifier-based CHP presents wider ranges for the weight of the feedstock in the final LCOE – between 14% for locally sourced, low-cost feedstocks up to 85% for some imported feedstocks, such as pellets.