Biomass Production and Logistics

TECHNICAL HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** Primary sources of biomass cover energy crops and forest growth (including dedicated plantations and natural forestry), residues from agriculture and forestry activities and organic wastes from households and industries. The biomass production and logistic chain includes production (harvesting, collection), pretreatment and densification, crucial to increase the efficiency of transport and use (storage, chipping, drying, pelleting, torrefaction, pyrolysis and hydro-thermal upgrading), transport (by truck, train, ship, pipelines of bales, chips, pellets, briquettes, firewood logs), as well as conversion to liquid fuels (ethanol, biodiesel, etc.), gaseous energy carriers (syngas, biogas, hydrogen), and electricity and final uses. Moisture and ash contents are two important characteristics for the biomass energy content. The selection of the optimal harvest-to-delivery logistics depends on the type of biomass feedstock (bulk density, energy content, seasonality of availability, moisture content), local conditions and the targeted use. In the coming years, wood pellets and torrefied pellets are expected to play an important role in the bioenergy market. The use of ligno-cellulosic feedstock is a promising avenue, mostly based on agricultural and forest residues, or species which growth requires less water, fertilizers and land-use (e.g. marginal and degraded land), and do not compete with food production.

■ **PERFORMANCE AND COSTS –** Total cost of supplying solid biomass feedstock is highly sensitive to local conditions including opportunity land cost and logistics, and supply-demand balance. Overall cost is expected to reduce by up to 25% between 2010 and 2020 thanks to economies of scale, improved harvesting and process technologies. While long-term bioenergy prices may depend somewhat on fossil fuel prices, short-term biomass prices are driven by the production cost and the cost of the raw material, which represents up to 40% of the production costs. Transportation and preprocessing represent up to 43% each of total cost, and storage up to 9%. In Europe, wood pellets prices range USD 7.5-13/GJ, wood chips range USD 3-9/GJ; firewood USD 4-18/GJ.

■ **POTENTIAL AND BARRIERS –** Biomass is an appealing source of energy in the current climate and energy context. It could supply a much higher share of the energy needs in the future compared to now, what will require important investment in new infrastructure for both biomass transformation and transportation. Global bio-energy potential ranges from 100 to 500 EJ/yr by 2050, depending on assumptions (food production; eating habits; farming practices; etc.).Wood pellets are the dominant solid biofuel commodity on the international market. Europe is currently the major market for woody pellets imported from Canada (British Columbia) and the South-eastern United States. New supplying regions may include Malaysia, Indonesia, Brazil, and stable African countries; new demanding regions may include Japan, Korea, and China. Key barriers for the use of biomass for energy purposes include raw material availability, lack of handling and port infrastructure, lack of quality standards, import/export tariffs, technical certification to ensure sustainability (biodiversity, carbon stocks, water drainage, life-cycle greenhouse gas emissions).

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PROCESS AND TECHNOLOGY STATUS

The biomass production and logistic chain includes several components (Figure 1), from the primary sources of biomass to final bioenergy uses in e.g. biorefineries, coal-biomass co-fired power plants, dedicated biomass power plants, industrial heat production, building heating, biogas production. The components of this chain can be grouped in five categories:

- **Production** (harvesting, collection);
- **Pretreatment** (storage, chipping, drying, pelleting, torrefaction);
- **Transport** (by truck, train and ship);
- **Conversion** to liquid fuels (ethanol, biodiesel, etc.), gaseous energy carriers (syngas, biogas, hydrogen), and electricity;
- **Final uses.**

This Technology Brief covers the first three categories, while biomass conversion into liquids and gaseous fuels as well as the final uses of biomass are described in other Technology Briefs (e.g. Biomass for Heat and Power, ETSAP E05; Production of Liquid Biofuels, ETSAP P10; Production of Biogas, ETSAP P11). The brief focuses on modern biomass technologies. Traditional uses of biomass (e.g. open fires mostly used in developing countries) are not considered in this brief because there is a general consensus that these uses should gradually be replaced by universal access to modern energy technologies, with higher energy efficiency and lower environmental impact.

■ **Primary Sources of Biomass -** Primary sources of biomass can be broadly classified in three categories:

- Energy crops and forest growth (including dedicated plantations and natural forestry);
- Residues from agriculture and forestry activities;
- Organic wastes from households and industries.

According to the European Standards (European Committee for Standardization, 2013), solid biofuels include: woody biomass from trees, bushes and shrubs; herbaceous biomass from plants that have a non-woody stem and die back at the end of the growing season such as straw and energy grass (e.g. miscanthus, reed canary grass, etc.); fruit biomass from parts of plants such as olive stones, cherry pits, grape waste, nut shells etc.; and blends and mixtures. Solid biofuels do not include animal-based biomass (e.g. manure, meat and bone meal) and aquatic biomass such as algae.

Grain crops, sugar crops and oil seeds (e.g. maize, sugarcane, cassava, rapeseed, soybean, palm oil, jatropha, etc.) that are currently used for energy production based on existing technologies are usually referred to as "**first-generation biomass**", while ligno-cellulosic feedstock such as cereal straw, forest residues, herbaceous or woody crop species (e.g. miscanthus, switchgrass, reed canary grass, poplar, willow, eucalyptus) are usually referred to as "**second-generation feedstock".**

Ligno-cellulosic feedstock may require new technologies, not commercially available yet, to be converted into usable fuels (e.g. conversion of cellulose into sucrose biomass for bio-ethanol). However, it is also widely recognized that the second-generation biomass feedstock for energy use are more sustainable than first-generation feedstock, because they are mostly based on agricultural and forest residues, or species which growth requires less water, fertilizers and land-use (e.g. marginal and degraded land), and do not compete with food production.

Tables 1 to 3 provide physical and energy characteristics of different types of biomass used for energy purpose, at different stages of the logistic chain.

Moisture and ash contents are two important characteristics for the biomass energy content, and play an important role in the biomass supply chain. The non-combustible part of biomass is left as ash after burning. The higher the ash content, the lower the energy value. Moisture content of biomass deeply affects the energy density of biomass. While green wood (100% moisture content on a dry basis) has an energy value (LHV) of approximately 8.2 MJ/kg, air-dry wood (15% moisture) has an energy value of 16.0 MJ/kg, and oven-dry wood could reach 18.7 MJ/kg (Rosillo-Calle et al., 2008). The difference between high heating value (HHV) and low heating value (LHV) also varies widely with moisture content.

■ **Pre-treatment of Solid Biomass –** Pre-treatment of biomass refers to handling and transformation of solid biomass to reduce the costs and increase the efficiency of transport and use. The main pre-treatment target is to increase the energy density of the feedstock. Once biomass is harvested and collected, (the greater the yield, the more efficient harvesting and collection, and the lower the cost), it is transported to a temporary storage site, where different pre-treatments can apply before transportation to bio-refineries, power plants or other final users.

Baling *and* ***Sizing*** are first densification processes, which may also occur at the collection site. Baling is particularly important for straw in order to reduce transport and storage space, given the low energy density of straw (baling of cereal straw is a well-established practice, while industrial handling of stalk and leaf residues from maize and sugar cane harvesting is a more recent practice). Sizing processes such as chipping, grinding, shreeding are also used to facilitate the biomass handling.

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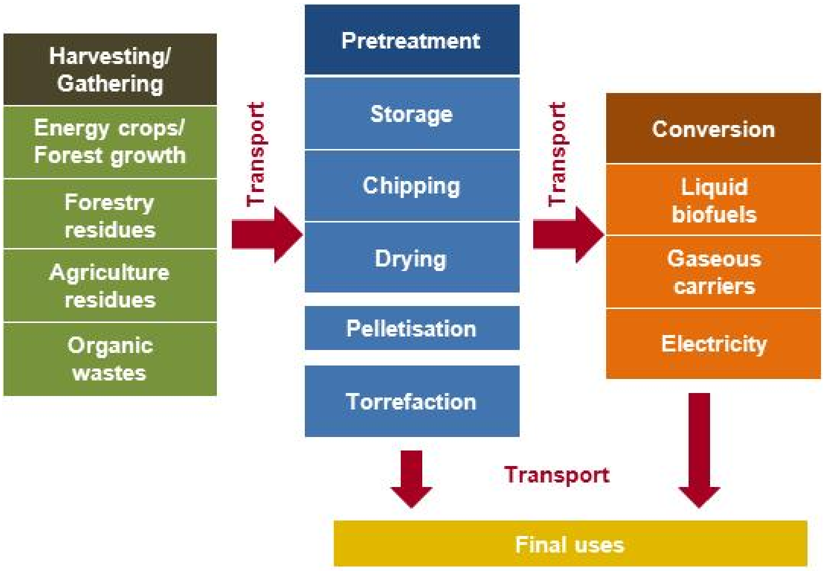

Figure 1 - Biomass Production and Logistic Chain

Losses of dry matter may usually occur during harvesting, transport and storage processes, either physical losses during harvesting and transportation (e.g. dropping off a truck), or chemical degradation losses during storage of wet biomass. Usually, losses can be lowered by reducing the moisture content of biomass and the presence of oxygen in the storage sites.

Drying is a crucial process to reduce the transportation costs, increase the combustion efficiency, but also to avoid fungal growth which lead to decomposition and loss of matter, especially in wood chips given their size and moisture level. Alternatively, biomass can be chipped as late as possible in the logistic chain. Types of dryers include *rotary drum dryers* (biomass rotates around a drum and is in contact with hot air), *fluidised bed dryers* (a gas flow crosses a bed made of biomass particles and particles like sand) and *steam-based re-compressive dryers*.

Table 1 - Characteristics of Agriculture Residues and Dedicated Energy Crops (AEBIOM 2008 and IRENA 2012)

Feedstock	Dry mass yield (a) (t/ha-year)	Lower heating value (MJ/kg)	Energy produced (GJ/ha)	Water content at harvest (%)	Ash content (%)
Agriculture residues					
Straw	2-4	15-18.1 (b)	35-70	14.5	5.0
Herbaceous crops					
Miscanthus	8-32	17.5-18.1	140-560	15.0	3.7
Switchgrass	9-18	16.8-18.6	n/a	15.0	6.0
Hemp	10-18	16.8	170-300	n/a	n/a
Woody crops					
Willow	8-15	16.7-18.5	280-315	53.0	2.0
Poplar	9-16	18.7	170-300	49.0	1.5
Giant read	15-35	16.3	245-570	50.0	5.0
Reed canary grass	6-12	16.3	100-130	13.0	4.0
Black locust	5-10	18.5-19.5	100-200	35.0	n/a
Wood	3-5	18.70	74.8	50.0	1-1.5

a) Yields of non-dedicated crops (sugar cane, sugar beet, palm oil, etc.) are provided in ETSAP P10
b) Corn stalks/stover 17-18 MJ/kgDM; sugarcane bagasse 15-18 MJ/kgDM; wheat straw 15-18 MJ/kgDM

Table 2 - Physical Description and Classification of Traded Solid Biomass Feedstock (Alakangas 2010, Kofman 2010)	
Form	Description
Bales	Compressed, shaped and bound solid biomass (0.1-4m^3 squares or cylinders), with high moisture level. Field drying is an option.
Chips	Chipped woody biomass with a defined particle size (5 to 100 mm) produced by mechanical treatment, with usually high moisture before drying and relatively low energy density. More difficult to handle than pellets; require large volume fuel storage and regular deliveries.
Pellets	Densified solid biofuel made from pulverized woody biomass with/out additives, usually shaped into cylindrical form (diameter less than 25 mm), random length of typically 5 to 40 mm with broken ends. Low moisture. Easy to handle. Raw material can be woody, herbaceous or fruit biomass, of blends.
Briquettes	Densified solid biofuel made with/out additives, shaped into cubic or cylindrical units, produced by compressing pulverized woody biomass. Briquettes are similar to wood pellets, but physically larger. Low moisture. They offer an alternative to firewood logs (controlled fuel value). Raw material is woody, herbaceous or fruit biomass, of blends.
Firewood logs	Cut and split oven-ready fuelwood used in household wood burning appliances like stoves, fireplaces and central heating systems. Firewood logs usually have a uniform length, typically in the range of 150 to 1000 mm.
Hogfuel	Fuelwood in form of pieces of varying size/shape, produced by crushing with blunt tools (rollers, hammers, flails).

Table 3 - Characteristics of Biomass Feedstock (IEA 2012 and Koppejan et al. 2012)

Feedstock	Moisture content (%)	Bulk density (kg/m³)	Low Heating Value (GJ_{LHV}/t)	Energy density (GJ_{LHV}/m³)
Baled straw	15 (air dried)	140	15	2
Organic waste	60	500	7	4
Solid wood	20 (air dried)	550	15	8
Wood chips	20 (air dried)	200	15	3
Sawdust	10	160	17	3
Wood pellets	10	660 (550-750)	17 (15-18)	11 (7.5-11.0)
Torrefied wood pellets	5	750 (750-850)	21 (20-24)	16 (15.0-18.7)
Pyrolysis oil	25	1100	17	19
Coal (anthracite)	*10*	*870*	*35*	*31*

Pelletisation (or briquetting[1]) contributes the densification of biomass feedstock. Pelletisation and briquetting are commercially available and relatively simple technologies. The production of wood pellets involves feedstock (e.g. sawdust) drying, screening to remove unwanted materials (e.g. stones), hammer-milling, pressing (usually at temperature of more than 100°C), cooling, and packaging. The current installed pelletisation capacity and the capacity utilization (%) in selected countries are provided in Figures 2.

Torrefaction consists of biomass heating in the absence of oxygen up to 200-300°C, breaking its fibrous structure, and removing vapors and volatiles to give biomass coal-like physical properties (European Climate Foundation, 2010; Koppejan et al., 2012). Different torrefaction reactor technologies are available, usually able to handle feedstock with a specific size (from sawdust to larger size). Most used are rotating drum, screw reactors, Herreshoff oven/multiple hearth furnaces, torbed reactors, microwave reactors, belt dryers, fixed beds. After torrefaction, woody biomass is usually pelletised. Torrefied pellets have several advantages compared to traditional wood pellets: a) can be obtained from any kind of fibrous feedstock, and facilitate the exploitation of cheap, local feedstock; b) have higher calorific value and bulk density; c) are hydrophobic; d) allow easy grinding; e) offer coal-like combustion characteristics and can easily be co-fired in coal power plants at higher share than wood pellets or chips; f) generate less ash than woody pellets; g) reduce transportation, handling and storage cost; and h) increase combustion efficiency. Torrefied pellets offer higher bulk density and 25-30% higher energy density than conventional woody pellets. Several pilot-scale projects for production of torrefied pellets are in operation and commercial-scale plants are under construction.

A rapid increase of worldwide investment in torrefaction capacity is expected in the coming years (e.g. Stramproy Green project in the Netherlands; Renogen project in Belgium, Idema project in Spain, New Biomass Energy project in the United States[2]).

[1] Briquettes are similar to pellets, but with a bigger size

[2] See Deutmeyer et al., 2012 for details on these projects

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While the overall economic advantage of the torrefaction is still under discussion, in most efficient applications, the cost of energy used for torrefaction is offset by reduced transportation, storage and combustion costs. The possible use of torrefied feedstock in a number of applications (e.g. co-fired power plants, cement kilns, coke and steel industry, dedicated biomass burners) has resulted in a recent increase of interest in torrefaction technologies.

Pyrolysis and hydro-thermal upgrading is a thermo-chemical biomass pre-treatment in which biomass is heated up to temperatures between 400°C and 600°C in the absence of oxygen to produce pyrolysis oil (also referred to as bio-oil), solid charcoal, and by-product gas. Pyrolysis oil has about twice the energy density of wood pellets, making it suited to long-distance transport. At present, two companies have large pyrolysis oil plants, i.e. Ensyn and Dynamotive, both in Canada (Goh and Junginger, 2013).

■ **Solid Biomass Storage -** Storage of biomass feedstock is often necessary due to the seasonal production, drying and pre-treatment processes, and the need to ensure appropriate and continuous supply.). While storage contributes the biomass air drying, if stored in large piles, some biomass feedstock (e.g. straw, wood chips) present a high risk of fire due to bacterial action, and regular stirring may help reduce this risk. Long-term and large storage facilities are needed because of seasonal production, while large storage volumes are needed for users of large amounts of biomass (e.g. bio-refineries, power plants). For example, it is estimated that a bio-refinery may typically store only up to 10 days of biomass feedstock supply (Miao, 2012).

■ **Transportation of Solid Biomass -** Transportation of solid biomass includes either short- (for collection) and long-distance movements. The relatively low energy density of biomass (in volume and in mass) compared with fossil fuels translates into costly transportation per unit of energy content. The biomass transportation cost may be so high that for bio-refineries it is more convenient to locate the plant close to the biomass feedstock collection site than close to the end-use market. As a consequence, biomass densification before long-distance transportation is of key importance. The choice of transportation mode depends on several factors including cost, form and bulk density of biomass, as well as transportation distance, existing infrastructure, and seasonality. Load and unload of biomass are also to be taken into account as they represent a non-negligible share of the overall transportation cost.

Transportation by trucks is generally applied for relatively short distances (<100 km), when flexibility is required because multiple small production sites have to be accessed, or when train and ship infrastructure are absent.

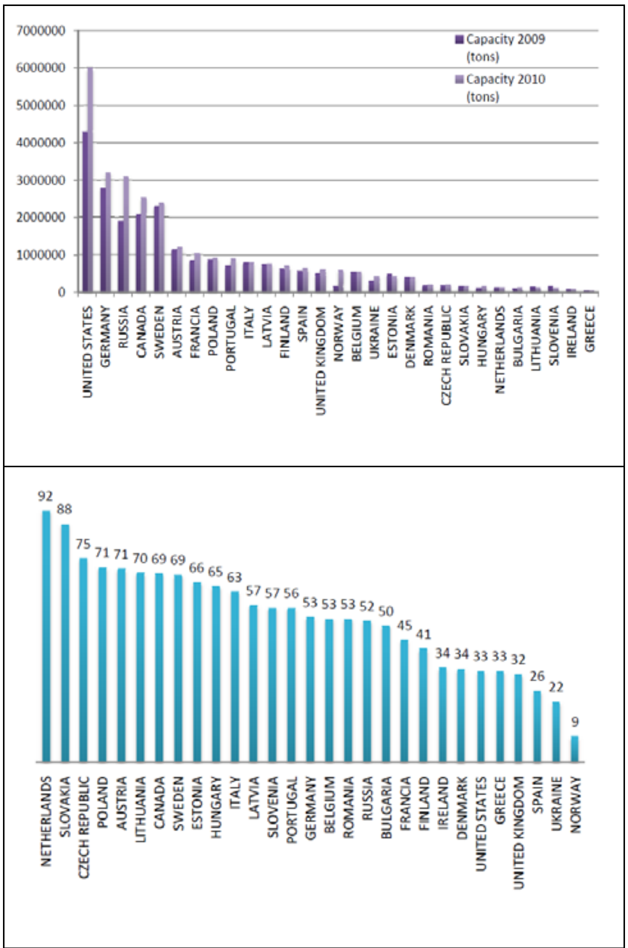

Figure 2 - Wood pellet production capacity (top) and capacity (%) utilization (bottom) - Cocchi et al. (2011)

Transportation by trains is applied for longer overland distances and may compete with ship transport for middle distances. **Transportation by ships** (dry bulk carriers or tankers for liquid biofuels) applies to long distances and large amounts of biomass. It is the cheapest and least energy-consuming transportation mode. Europe is currently the major market for woody pellets imported from Canada (British Columbia) and the South-eastern United States (Figure 3).

Pipeline transportation based on a slurry of wood chips may in principle offer an alternative for large quantities of biomass feedstock. However, it involves high capital investment and some technical challenges such as maintaining feedstock quality and stability in the presence of the fluid carrier, and providing a large amount of water resources.

■ **Typical Biomass Logistics –** The selection of the optimal harvest-to-delivery logistics depends on a number of factors.

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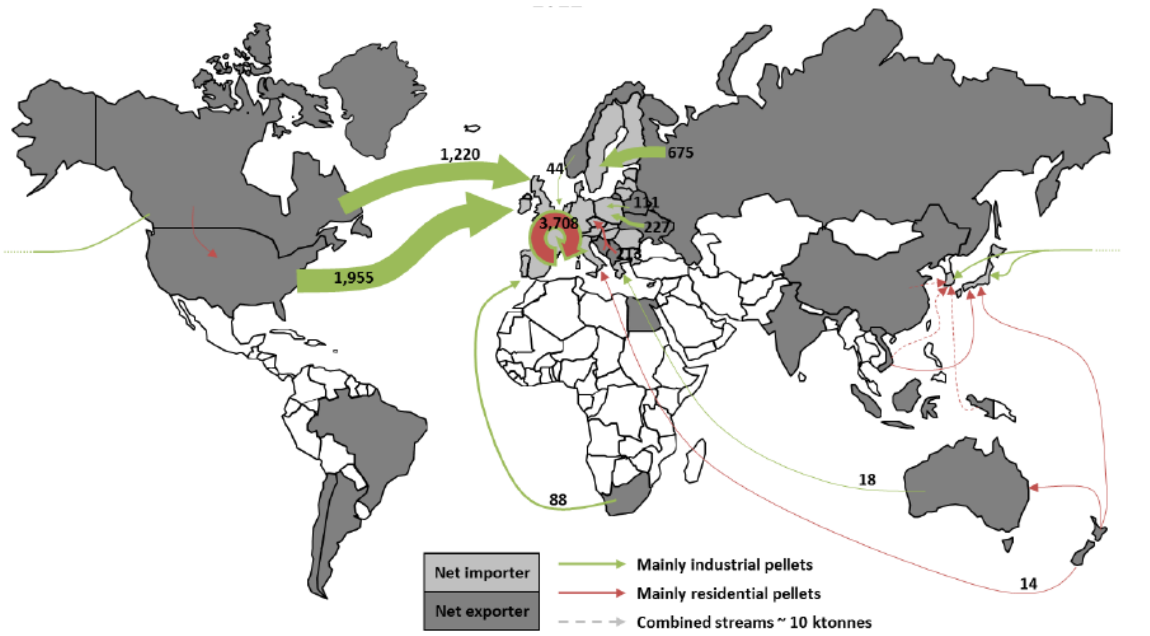

Figure 3 - Global Wood Pellets Trading Flows in 2012 (Goh and Junginger, 2013)

Specific choices are usually associated with each type of biomass feedstock, local conditions and the final use (Miao et al., 2012). Some examples are discussed as follows.

Given their characteristics, dry herbaceous energy crops such as miscanthus, switchgrass, or reed canary grass require usually large equipment for harvesting, pre-treatment, storage and transportation. While baling may facilitate both storage and transportation, the overall cost-efficiency of the logistic activity may be affected by seasonal availability and yield uncertainty, which may lead to suboptimal utilization of the equipment, workforce and storage space. Therefore, densification is important, but often represents a significant portion of the supply costs (20% to 40% of the total biomass-to-biofuel cost), and the energy consumption for grinding dry feedstock can reach 1 to 3% of their inherent heating value.

The capacity of bioenergy plants may also impact the efficiency of logistics. Using woody chips to supply small power plants in a <20-km transportation range may be more cost-effective than using bales, pellets or briquettes, which are instead more convenient for supplying medium or large power plants, with wider transportation ranges.

The logistics of short-rotation woody feedstock such as willow or poplar can use the harvest and transportation equipment used for forestry biomass. Baling or chipping are more popular in North America, while bundling is more widely used in Europe. Coppices can also be densified to pellets at farms or satellite and centralized pellet mills.

The logistic choices for energy crops depend on crops composition. Varieties with high sugar content need to be processed quickly, while those with high fiber and low sugar content can be processed and handled similar to grass or woody biomass.

The collection of crop residues can occur at the same time as the primary product (grain, oil seed, fruit) or separately, with less losses. Similar to grass crops, densification of residues is key to reduce the transportation and storage costs.

Transport of liquid biofuels (bioethanol, biodiesel) is usually done by trucks, rail and ship (BBI Biofuels Canada, 2011; EIA, 2012). Using pipelines for bioethanol transport may involve problems that are associated with the corrosive nature of ethanol and its compatibility with pipeline components. Ethanol can also dissolve both residues and water and therefore may lose the required specifications when transported in pipelines that are also used for fossil fuels. However, bio-ethanol transportation by pipeline has been successfully used in the United States (Kinder Morgan line from Tampa to Orlando) after a special pipeline cleaning and bio-ethanol treatment with anticorrosion additives to prevent corrosion of the steel pipes. While bio-ethanol transportation by pipeline currently accounts for less than 2% of overall bio-ethanol flow in

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Brazil (a major bio-ethanol producing country), new projects to build some1300 km pipeline systems in the next years are expected to increase this share and reduce the transport costs. Low blends of biodiesel (also a strong solvent) are shipped by existing pipelines in the US with no product degradation, though trace of biodiesel in the pipeline may affect the quality of jet fuels if transported in the same pipeline. In cold regions, heating systems may be necessary at pipeline origin and delivery points to handle biodiesel.

PERFORMANCE AND COSTS

In the coming years, *wood pellets* and *torrefied pellets* are expected to play an important role in the bioenergy market. Details on their production are provided in Table 4. It should be noted that the consumption of electricity in combined torrefaction/pelletisation plants can be reduced as grinding is less energy intensive for torrefied material, while a hammermill is needed in case of wood pellet production. However, more energy is necessary to densify the torrefied material (from 50 to 150 kWh/t) due to the higher temperatures required in the process. The torrefaction process also requires much higher raw-material input, i.e. 1.2t dry-input or 2.5t wet-input per 1.0t dry-output, compared with a 2t wet-input for 1.0t dry-output for wood pellets.

Performance and costs breakdown of sawdust-based pellets production steps are shown in Table 5. In comparison, using wood chips instead of sawdust, the investment cost is higher since additional grinding is needed before drying, with an additional energy consumption. Wood chips however have higher bulk density compared to sawdust and enable saving in raw-material storage. Energy consumption for drying usually is around 1200 kWh/t of evaporated water.

The total cost of supplying solid biomass feedstock for energy use can be expressed as the addition of the **production**, **pre-treatment** and **transportation** costs. All these costs are highly sensitive to local conditions including opportunity land cost and logistics, and supply-demand balance (see for example Table 6). The choice of the best energy crop to grow in a certain region also depends on local conditions, (climate, soil, logistics). As a consequence, the role of bioenergy in future energy scenarios is expected to be driven by marginal costs rather than by the supply potential (Lysen et al., 2008). While local conditions in production regions are key factors for biomass competitiveness, at present a limited number of studies deal with the variability of bioenergy supply and costs by regions. Knowledge in this field can be improved by coupling energy and agriculture models to build supply-cost curves at global, regional and local levels.

■ **Current and Projected Costs** – It should be noted that while long-term bioenergy prices may depend somewhat on fossil fuel prices (high fossil fuels prices will facilitate the investment in bioenergy), short-term biomass prices are driven by the production cost and the cost of the raw material (Alakangas, 2011), which represents a high share of the production costs (e.g. woody pellets, see Table 7).

In Europe, wood pellets prices range USD 7.5-10/GJ for the residential market, and USD 8-13/GJ for the industrial market; wood briquettes range USD 12-22/GJ and USD8-13/GJ for residential and industrial markets, respectively; wood chips range USD 4-8.5/GJ and USD 3-9/GJ; firewood for residential market are between USD 4 and 18/GJ; sawmill by-products are in the rangeUSD 3-5/GJ (Alakangas, 2011). Prices of woody biomass compared to heating oil in 2011 and 2013 for several EU countries are shown in Figure 4.

As far as the future cost is concerned, according to the European Climate Foundation (2010), the overall cost reduction potential between 2010 and 2020 is expected to be up to 25% (Figure 5). This would be due to economies of scale, improved harvesting and process technologies (European Climate Foundation, 2010).

■ **Biomass Transportation Costs -** Biomass transportation costs can be divided into local transportation costs (i.e. collection and transport to close storage and processing facilities, local delivery), and long-distance transportation costs. Biomass carriers and transportation technologies (trucks, ships, etc.) are similar to those used for oil and gas logistics, with similar technical-economic characteristics (see ETSAP P03). Specific estimates are provided in Table 8.

It should be noted that international shipping usually accounts for a small part of the final biomass cost and that long-distance biomass transportation costs, especially shipping costs, will remain modest at least in the next decade, and dependent on global fleet cost trends and volatility (Goh and Junginger, 2013). In contrast, local transportation by trucks from field to storage and processing facilities accounts for a significant share of the total cost as these are dedicated transportation modes, with no return freight and large spatial spreading.

A summary of performance, costs and potential for solid biomass is provided in Table 10 (Summary Table).

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Table 4 - Examples of Performance and Costs of Pellets Production (Koppejan et al., 2012 and Ehrig et al., 2013)		
	Wood pellets	Torrefied pellets
Example 1 (Koppejan et al., 2012)		
Feedstock intake (Mt, 50% moisture)	255,000	255,000
Output capacity (Mt)	123,800	100,000
Product LHV (GJ/Mt)	17.5	21.7
Product bulk density (kg/m3)	620	800
Product energy density (GJ/m3)	10.7	17.4
Electricity consumption (kWh/t)	171	263
wood yard	20	20
pre-dryer	45	33
hammer mills	50	-
torrefaction	-	60
pellet mills	56	150
Investment cost (MUSD)	19.5	29
wood yard	5.0	5.0
pre-dryer	4.5	3.6
hammer mills	2.0	-
torrefaction reactors	-	13
pellet mills	4.0	3.1
silos	1.0	-
civil works	3.0	4.3
Example 2: Ehrig et al. (2013)		
Production capacity (t/y)	40,000 (upscaled to 120,000)	40,000 (upscaled to 120,000)
Technology	Belt dryer, hammermill, pellet ring die	Belt dryer, rotating drum reactor, heat generator, hammermill, pellet ring die
Internal heat recovery (MW) (torrefaction gas)		2.7 (8.1) depending on torrefaction degree
Input/output mass ratio	1.01/1	1.2/1
Net calorific value of final product	4.9 MWh/t (17.7 GJ/t)	5.4 MWh/t (19.6 GJ/t)
Bulk density (kg/m³)	650	705
Moisture content **(%)**	6	< 2
Investment Costs (million USD)	4.86 (11.93)	14.82 (36.27) +/-20%
Operation & Maintenance	1.8%/y of investment costs	4%/y of investment costs
Other costs (insurance)	3%/y of investment costs	3%/y of investment costs
Required staff	1.25 persons/shift (3 shifts/d)	1.5 persons/shift (5 shifts/d)

Table 5 - Performance and Costs Breakdown of Processes for Pellet Production Based on Sawdust Feedstock (40,000 t/yr capacity and 91% utilization uactor) - Thek & Obernberger 2009, and Sokhansanj & Fenton 2006

	Investment (kUSD)	Annualized inv. (USD/t pellets-yr)	Maintenance (kUSD/yr)	Maintenance (kUSD/t pellets)	Life-time (yr)	Energy consumption (GJ/t pellets)
Drying	1235	3.1	64.5	1.6	10	0.086
Grinding	268	0.7	13.9	0.4	15	0.067
Pelletisation	607	1.6	31.7	0.8	10	0.184
Cooling	42	0.1	2.2	0.0	15	0.007
Storage	1408	2.9	59.5	1.4	20	0.000
Other	1307	3.0	53.2	1.3	15	0.066
Total	4866	11.4	225.0	5.6	-	0.410

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Table 6 - Estimated Energy Crops Potential in 2050 for four IPCC-SRES Scenarios and Various Cutoff Costs (assuming abandoned agriculture land and marginal land - Hoogwijk et al., 2008)

(EJ/y)	A1				A2				B1				B2			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Canada	0	11	14	18	0	8	9	12	0	11	12	14	0	10	11	13
USA	0	18	34	53	0	7	19	33	0	25	33	36	0	28	39	49
Central America	0	7	13	17	0	2	3	4	0	4	8	11	0	2	3	5
South America	0	12	74	87	0	5	15	24	0	28	61	63	0	6	33	43
Northern Africa	0	1	2	5	0	1	1	4	0	1	2	3	0	1	1	2
Western Africa	7	26	28	50	8	15	15	23	1	13	14	27	1	4	5	6
Eastern Africa	8	24	24	41	4	6	6	16	3	14	14	22	1	2	2	5
Southern Africa	0	13	17	43	0	0	1	10	0	12	13	29	0	0	0	2
OECD Europe	0	3	12	14	0	6	12	14	0	3	9	9	0	7	15	16
East Europe	0	7	9	9	0	6	6	8	0	8	8	8	0	8	8	9
FSU	0	79	85	127	1	42	47	68	0	67	69	88	0	60	62	78
Middle East	0	0	3	13	0	0	1	8	0	0	2	4	0	0	1	3
South Asia	0	12	15	27	1	8	10	14	0	6	8	14	0	1	3	6
East Asia	0	16	64	107	0	0	6	23	0	50	61	77	0	0	21	46
South East Asia	1	9	10	10	0	7	7	7	0	3	3	3	0	2	4	4
Oceania	0	33	35	55	2	17	18	34	10	28	29	35	6	24	25	30
Japan	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
Global	16	271	438	675	15	129	177	302	14	272	344	443	8	155	234	316

(1) <USD 1/GJ (2) < USD 2/GJ (3) < USD 4/GJ (4) Geographical potential (EJ/y)

Table 7 - Share of Costs of Process Activities in Wood Pellet Production (Cornelissen 2013, and Sokhansanj & Fenton 2006)

Activity	Share of total production costs of wood pellets (before long-distance transportation)
Harvest and collection	25 to 40% (lower for loafing, higher for bales)
Local transportation	15 to 42%
Preprocessing	30 to 43%
Storage	1 to 9%

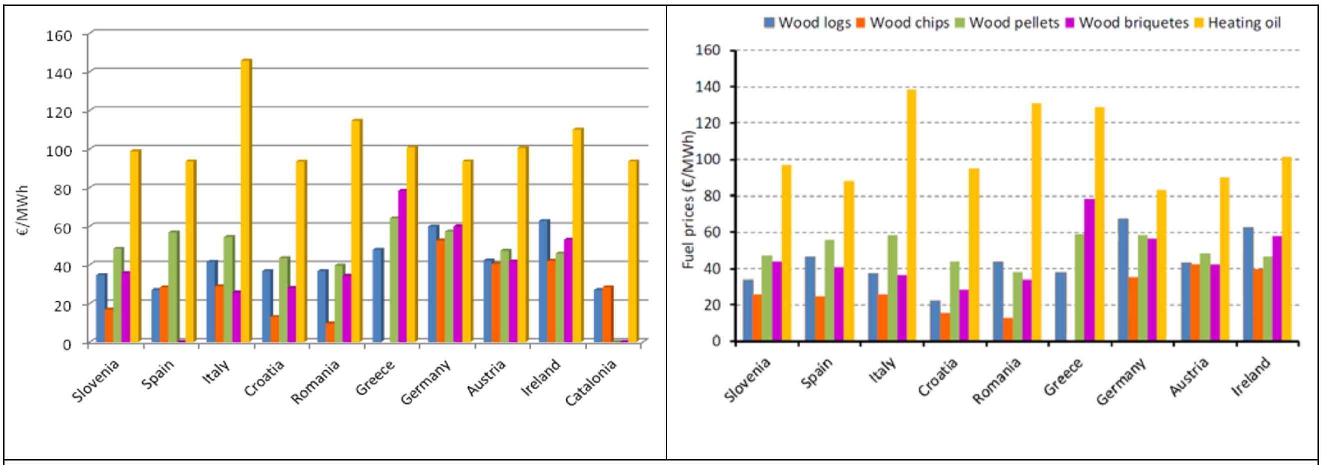

Figure 4 - Prices of wood fuels compared to heating oil in 2011 (top) and 2013 (bottom) in several EU countries – Moisture content: logs: 20%; chips: 20%; pellets: 10%; briquettes: 10% - (Krajnc & Prislan 2011-2013)

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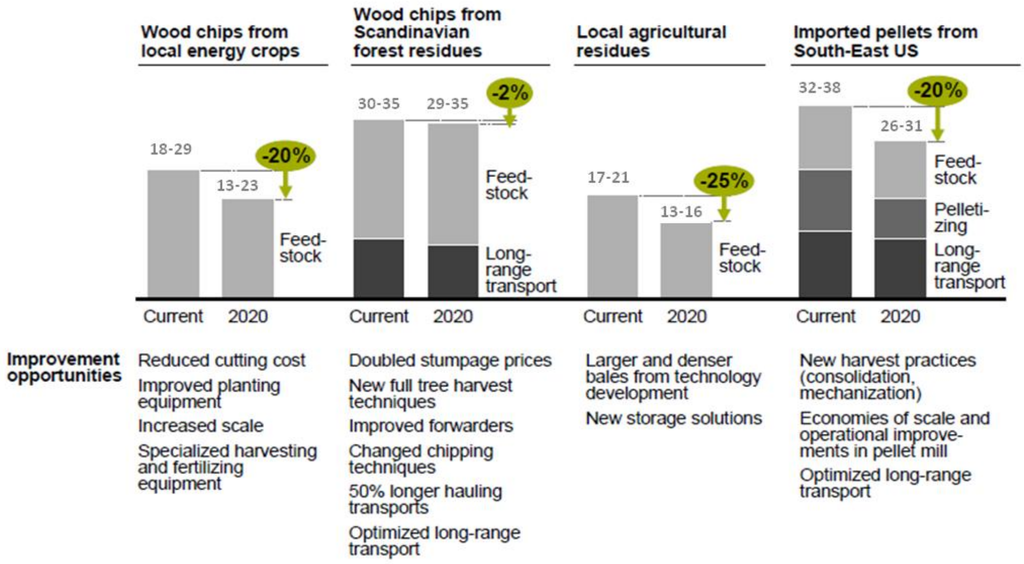

Figure 5 - Current and Future Costs (USD/MWh) of Biomass Fuels in Selected Supply Chains (European Climate Foundation, 2010)

Table 8 - Biomass Transporation Costs
(AEBIOM 2009; Cornelissen 2013; Goh & Junginger 2013; Miao 2012; NREL 2011; Sokhansanj & Fenton 2006)

Mode	Distance and Characteristics	Costs (all inclusive)
Ship	Within Europe	USD 0.001 – 0.013/dry t - km
	North America to Europe - Panamax vessels (60-80 kt)	USD 56-90/t pellets
	Russia to Europe (4 to 5k t)	Up to USD 32/t
Train	Within Europe	USD 0.021 – 0.023/dry t - km
	Scandinavia to continental Europe, mix ship/train	USD 34-38/t woodchips
Truck	Local (26t truck, up to 35 km)	USD 0.42/t-km
	Local (20 to 100 km)	USD 6-21/t pellets-chips
	Within Europe (up to 200 km)	USD 15-23/ wet t
	Within US	USD 13/t

Biomass Transportation Energy Consumption (MJ /GJ-km) (Labriet *et al.*, 2009)

	Solid biomass*	Bioethanol	Biodiesel
Ship	0.0038	0.0055	0.0038
Train	0.0142	0.0079	0.0057
Truck	0.0330	0.0260	0.0190

Biomass Transportation Costs without Energy (kUSD/PJ-km) (Labriet *et al.*, 2009)

		Solid biomass*	Bioethanol	Biodiesel
Ship	1500 km	0.66-2.41	0.32-0.45**	0.23-0.32**
	10000 km	0.16-0.66	0.17-0.28**	0.12-0.20**
Train	500 km	1.05-4.45	2.80	2.00
	1000 km	0.60-3.03	1.91	1.37
	1500 km	0.46-2.56	1.61	1.16
	2000 km	0.38-2.32	1.47	1.05
Truck	50 km	5.98-20.20	4.76	3.41
	200 km	3.69-9.33	4.16	2.98

* Low costs for pellets, high costs for chips for truck transport and bales for ship transport.
** Dedicated transport costs are higher than non-dedicated transport costs (+40% for short distance, +63% for long distance)

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POTENTIAL AND BARRIERS

Biomass is an appealing source of energy in the current climate and energy context. Bioenergy can contribute energy supply and security objectives, with very low (or even negative) lifecycle greenhouse gas emissions. As far as climate change is concerned, in energy scenarios to keep the global temperature increase within 2°C and halve 2050 energy-related CO2 emissions compared to 2009, biomass is projected to provide up to 24% of the global 2050 primary energy supply. About half this energy would be consumed for electricity and heat generation, and half for production of liquid biofuels. According to the IEA Energy Technology Perspectives study (IEA-ETP, 2012), biomass would supply around 7.5% of world electricity generation in 2050 compared to the current 1.5%. However, an increased use of bioenergy will require important investment in new infrastructure for both biomass transformation and transportation.

The global bio-energy potential, in particular the future bioenergy potential, has been assessed bay a number of studies based on different assumptions and leading to significantly different results, a selection of which is provided in Table 10 (Summary Table).

The expected 2050 biomass potential ranges from 100 to 500 EJ/yr by 2050, with 40-170 EJ/yr from residues, 60-100 EJ/yr from forestry surplus and 120-250 EJ from energy crops, (Chum et al., 2011). Key factors that impact the bioenergy potential include food production; eating habits; farming practices (irrigation and fertilizers use); animals growth techniques (pastoral or landless); type and size of land available for bioenergy (arable, grassland, fallow, set-aside, marginal/degraded land); type, yield and energy content of biomass, and climate change altering soil conditions, precipitations, etc. Most such factors are hardly predictable at both regional and global level. Bioenergy potential may also depend on CO_2 fertilization (Haberl et al., 2011), with an increased yield in diverse world's regions from 1 to 28% compared with the business-as-usual scenario.

At present, wood pellets are the dominant solid biofuel commodity on the international market, while trade of wood waste and wood chips for energy use are significantly smaller. Europe is the key region for international solid biofuel trade, accounting for around 66% of the global 2010 net trading (Lamers et al., 2012). In the short term, the international market will continue to be dominated by pellets, and major producers will be regions with large amounts of biomass and suited infrastructure (e.g. Canada, Southern United States).

New resources and producing regions may gradually be added including Malaysia, Indonesia, Brazil, and stable African countries. Major consumers in the short and mid-term are expected to be Western Europe, North America, but also Japan, Korea, and China (Cocchi et al., 2011; IEA, 2012). In 2020, between 16 Mt and 33 Mt of wood pellets could be imported in the EU, in business-as-usual and high-trade scenarios, respectively (Cocchi et al., 2011). After 2020, trading of high-tech biomass (pyrolysis oil, torrefied wood pellets) and ligno-cellulosic feedstock is likely to grow rapidly and to supply bioenergy power and/or heat plants in regions with limited feedstock resources. Trading routes are likely to include Eastern Europe to Central Europe, Latin America to the United States, the European Union and Japan, Australia to China, with an increasing role of other Asian and African countries as producers (IEA, 2012).

Key barriers for the use of biomass for energy purposes include (IEA, 2012) raw material availability, lack of handling and port infrastructure, lack of quality standards, import/export tariffs, technical certification to ensure sustainability (biodiversity, carbon stocks, water drainage, life-cycle greenhouse gas emissions). While several standards are already in-place or under developments, much more needs to be done to deal with all these challenges. The overall sustainability of extensive use of bioenergy still remains under discussion especially as for life-cycle greenhouse gas emissions and land-use impact. The European Commission in the Renewable Energy Directive has proposed sustainability criteria and default emission factors (Table 9). It has also proposed to limit the amount of food crop-based biofuels to count for the achievement of the EU's 10% target for renewable energy in the transport sector by 2020. Local air quality and pollution (particulate, nitrogen oxides) associated with biomass combustion must also be considered.

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Table 9 – Biomass Default Emission Factors (EC, 2010)	
Primary Solid and Gaseous Biomass Products	**gCO_{2eq}/MJ**
Wheat straw	2
Bagasse bales	20
Miscanthus bales	7
Wood chips from forest residues (European temperate continental forest)	1
Wood chips from forest residues (tropical and subtropical forest)	25
Wood chips from short rotation forestry (European temperate continental forest)	4
Wood chips short rotation forestry (tropical/sub-tropical forest, e.g. eucalyptus)	28
Wood briquettes/pellets from forest residues (EU temperate continental forest) - wood as process fuel	2
Wood briquettes/pellets from forest residues (tropical or subtropical forest) – nat. gas as process fuel	20
Wood briquettes/ pellets from forest residues (tropical or subtropical forest) – wood as process fuel	17
Wood briquettes/pellets from forest residues (EU temperate continental forest) – nat. gas as process fuel	35
Wood briquettes/pellets from short rotation forestry (EU temperate continental forest) – wood as process fuel	4
Wood briquettes/pellets from short rotation forestry (EU temperate continental forest) – nat. gas as process fuel	22
Wood briquettes/pellets from short rotation forestry (tropical/sub-tropical forest) – wood as process fuel	22
Wood briquettes/pellets from short rotation forestry (tropical/sub-tropical forest) – nat. gas as process fuel	40
Indirect land-use change emissions from biofuels	**gCO_{2eq}/MJ**
Cereals and other starch rich crops	12
Sugars	13
Oil crops	55
Other feedstock	0

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Table 10 – Summary Table - Key Data and Figures for Biomass Production and Logistics

Global Bioenergy Potential in 2050 (EJ/y)			
Reference	Dedicated energy crops	Agriculture residues	Forestry
Berndes et al. (2003)	50-240	-	66-113
Beringer et al. (2011)	26-116 / 52–174	-	-
Chum *et al.* (2011)	120-250	40-170**	60-100
Doornbosch and Steenblik (2007)	109	35	91
Fischer and Schrattenholzer (2001)	150-200	35	83*-117*
Haberl *et al.* (2010)	44-133	49	19-35
Hoogwijk *et al.* (2003, 2005)	311-657	5-27	-
IEA (2007)	0-857	-	29-151
Lysen and van Egmond (2008)	120-330	40-170**	60*-100*
Seidenberger *et al.* (2008)	6-80	79	-
Smeets *et al.* (2007a, 2007b)	215-1272	49-69	8*-70*
* Excl. forestry residues ** Incl. organic waste			

Production costs of biomass feedstocks				
		USD/GJ	USD/t	Source
USA	Forest residues	1.3-2.6	15-30	IRENA (2012)
USA	Woodwaste (sawmills, pulp and paper)	0.5-2.5	10-50	IRENA (2012)
USA/EU	Agricultural residues (corn stover and straw)	1.7-4.9	20-58	IRENA (2012), Cornelissen (2013)
USA/EU	Energy crops (poplar, willow, switchgrass)	4.5-6.9	39-60	IRENA (2012), Cornelissen (2013), Sokhansanj and Fenton (2006)
USA	Pellets	6.0-7.1 (1)	100-119 (1)	IRENA (2012)
EU	Woodchips from local energy crops	5.2-8.2	60-94	EU Climate Foundation (2010)
EU	Woodchips from Scandinavian forest residues	5.6-6.7	64-77	EU Climate Foundation (2010)
EU	Woodchips from Scandinavian forest residues	8.6-10.1 (2)	98-115 (2)	EU Climate Foundation (2010)
EU	Local agriculture residues	4.8-6.0	55-68	EU Climate Foundation (2010)
EU	Pellets from USA	9.3-10.8 (3)	157-182 (3)	IRENA (2012)
Brazil	Bagasse	1.3-2.3	11-13	IRENA (2012)
Brazil	Woodchip	9.3	71	IRENA (2012)
India	Bagasse	1.4-2.5	12-14	IRENA (2012)
Average	Miscanthus chips	1.4-2.8 (dry)	26-50 (dry)	AEBIOM (2009)
Average	Miscanthus briquettes	2.3-4.1	38-65 (9%)	AEBIOM (2009)
Average	Log wood	3.5-4.5	53-68 (20%)	AEBIOM (2009), Cornelissen (2013)
Average	Wood chips	2.0-3.3	30-49 (30%)	AEBIOM (2009)
Average	Wood pellets from wet material (incl.drying)	5.8-7.8	99-133	Alakangas (2011)
Average	Wood pellets from dry material	4.0-6.3	69-107	Alakangas (2011)

(1) Includes feedstock costs (USD3.0-3.7/GJ, USD50-63/t) and pelletising (USD3.0-3.4/GJ, USD50-56/t)
(2) Transportation cost is added to the cost of Woodchips from Scandinavian forest residues (USD3.0-3.4/GJ, USD34-38/t)
(3) Transportation cost is added to the cost of pellets in USA (USD3.4-3.7/GJ, USD56-63/t)

Performance and Costs of Pellet Production and Torrefaction (excl. harvest, collection, local transport)							
		Pelletisation					Torrefaction
		Range	Sawdust	Dry wood shave	Wood chips	Log wood	
Investment	kUSD/t pellet	0.07-0.25 (a)	0.119	0.07	0.145	0.251	0.280
Maintenance	kUSD/t pellet-yr			5% invest cost			7% invest cost
Energy use	GJ/t pellet	0.32-0.70	0.41	0.32	0.52	0.70	0.95
Mass Efficiency	-	1	1	1	1	1	0.83

(a) lower values for dry wood shavings, higher values for green log wood

Sources: Cornelissen (2013); Ehrig (2009); Koppejan et al. (2012); Thek and Obernberger (2009)

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