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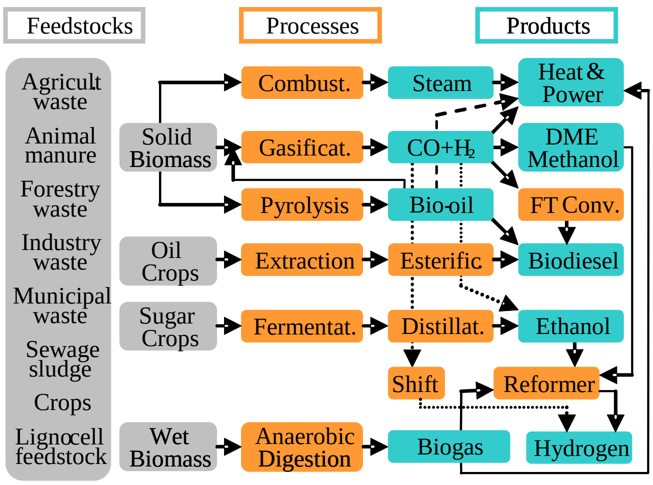
Biomass for Power Generation and CHP *

- **PROCESSES** – Biomass combustion is a carbon-free process because the resulting CO_2 was previously captured by the plants being combusted. At present, biomass **co-firing** in modern coal power plants with efficiencies up to 45% is the most cost-effective biomass use for power generation. Due to feedstock availability issues, dedicated biomass plants for **combined heat & power (CHP)**, are typically of smaller size and lower electrical efficiency compared to coal plants (30%-34% using dry biomass, and around 22% for municipal solid waste). In cogeneration mode the total efficiency may reach 85%-90%. Biomass **integrated gasification** in gas-turbine plants (BIG/GT) is not yet commercial, but integrated gasification combined cycles (IGCC) using black-liquor (a by-product from the pulp & paper industry) are already in use. **Anaerobic digestion** to produce biogas is expanding in small, off-grid applications. **Bio-refineries** may open the door to combined, cost-effective production of bio-chemicals, electricity and biofuels.
- **TYPICAL COSTS –** Because of the variety of feedstocks and processes, costs of bio-power vary widely. Co-firing in coal power plants requires limited incremental investment ($50-$250/kW) and the electricity cost may be competitive (US$0.02/kWh) if local feedstock is available at low cost (no transportation). For biomass typical cost of $3-$3.5/GJ, the electricity cost may exceed $0.03-$0.05/kWh. Due to their small size, dedicated biomass power plants are more expensive ($1500-$3000/kW) than coal plants. Electricity costs in cogeneration mode range from $0.04 to $0.09/kWh. Electricity cost from new gasification plants is around $0.10-$0.13/kWh, but with significant reduction potential in the future.
- **STATUS** –Abundant resources and favourable policies are enabling bio-power to expand in Northern Europe (mostly co-generation from wood residues), in the United States and in countries producing sugar cane bagasse (e.g. Brazil). Proliferation of small projects, including digesters for off-grid applications, is recorded in both OECD and emerging economies. Global biomass electricity capacity is in the range of 47 GW, with 2–3 GW added in 2005. Associated investment accounted for 7% of total investment in renewable energy capacity in 2005 ($38 billion excluding large hydro).
- **POTENTIAL & BARRIERS –** In the short term, co-firing remains the most cost-effective use of biomass for power generation, along with small-scale, off-grid use. In the mid-long term, BIG/GT plants and bio-refineries could expand significantly. IEA projections suggest that the biomass share in electricity production may increase from the current 1.3% to some 3%-5% by 2050 (IEA ETP, 2006), depending on assumptions. This is a small contribution compared to the estimated total biomass potential (10%-20% of primary energy supply by 2050), but biomass are also used for heat generation and to produce fuels for transport. Main barriers remain costs; conversion efficiency; transportation cost; feedstock availability (competition with industry and biofuels for feedstock, and with food and fiber production for arable land); lack of supply logistics; risks associated with intensive farming (fertilizers, chemicals, biodiversity).

FEEDSTOCK & PROCESSES – Biomass resources include agricultural residues; animal manure; wood wastes from forestry and industry; residues from food and paper industries; municipal green wastes; sewage sludge; dedicated energy crops such as short-rotation (3-15 years) coppice (eucalyptus, poplar, willow), grasses (Miscanthus), sugar crops (sugar cane, beet, sorghum), starch crops (corn, wheat) and oil crops (soy, sunflower, oilseed rape, iatropha, palm oil). Organic wastes and residues have been the major biomass sources so far, but energy crops are gaining importance and market share. With re-planting, biomass combustion is a carbon-neutral process as the CO_2 emitted has previously been absorbed by the plants from the atmosphere. Residues, wastes, bagasse are primarily used for heat & power generation. Sugar, starch and oil crops are primarily used for fuel production.



Biomass Conversion Paths

* Biomass are also be used to produce fuels for transport (see ETE02) and for heating & cooking.

Cheap, high-quality biomass (e.g., wood waste) for power generation may become scarce as it is also used for heat production and in the pulp & paper industry. New resources based on energy crops have larger potential but are more expensive. Technologies and cost of power and heat generation from biomass depend on feedstock quality, availability and transportation cost, power plant size, conversion into biogas (if any). If sufficient biomass is available, bio-power and CHP plants are a clean and reliable power source suitable for base-load service.

■ **Co-firing –** Biomass co-firing in modern, large-scale coal power plants is efficient, cost-effective and requires moderate additional investment. In general, combustion efficiency of biomass can be 10 percentage points lower than for coal at the same installation, but co-firing efficiency in large-scale coal plants (35%-45%) is higher than the efficiency of biomass-dedicated plants. In the case of co-combustion of up to 5%-10% of biomass (in energy terms) only minor changes in the handling equipment are needed and the boiler is not noticeably derated. For biomass exceeding 10% or if biomass and coal are burned separately, then changes in mills, burners and dryers are needed. In addition, coal ashes that are used to produce construction materials should not be contaminated with tar and alkali metals-rich ash from biomass. Many co-firing technology options have been demonstrated in several countries (Northern Europe, United States and Australia) in some 150 installations using different feedstock (wood biomass, residues and crops). Using low-cost local biomass, the incremental investment may have a short payback period (2 years), but low-quality biomass such as herbaceous crops and wet wood may produce tar and cause slagging and fouling that affects plant reliability and raises costs.

■ **Combustion in dedicated power and CHP plants –** Biomass can be burned to produce electricity and CHP via a steam turbine in dedicated power plants. The typical size of these plants is ten times smaller (from 1 to100 MW) than coal-fired plants because of the scarce availability of local feedstock and the high transportation cost. A few large-scale such plants are in operation. The small size roughly doubles the investment cost per kW and results in lower electrical efficiency compared to coal plants. Plant efficiency is around 30% depending on plant size. This technology is used to dispose of large amounts of residues and wastes (e.g bagasse). Using high-quality wood chips in modern CHP plants with maximum steam temperature of 540°C, electrical efficiency can reach 33%-34% (LHV), and up to 40% if operated in electricity-only mode. Fossil energy consumed for bio-power production using forestry and agriculture products can be as low as 2%-5% of the final energy produced. Based on life-cycle assessment, net carbon emissions per unit of electricity are below 10% of the emissions from fossil fuel-based electricity. When using MSW, corrosion problems limit the steam temperature and reduce electrical efficiency to around 22%. New CHP plant designs using MSW are expected to reach 28%-30% electrical efficiency, and above 85%-90% overall efficiency in CHP mode if good matching is achieved between heat production and demand. Incineration of MSW is a mature technology. Emissions of pollutants and dioxin can be effectively controlled, but in many countries, incinerators face public acceptance issues and are seen as competing with waste recycling. Municipal solid waste (MSW) also offers net reduction of CO_2 emissions. MSW can generate some 600 kWh of electricity per tonne and emit net 220-440 kg CO_2 from the combustion of the fossil-derived materials (20-40% of MSW). The CO_2 emitted to generate 600 kWh from coal would be some 590 kg. Methane emissions from MSW in modern landfills would be between 50-100 kg/t (equivalent to 1150-2300 kg CO_2), 50% of which is collected and 50% is released in the atmosphere. Thus, electricity production from MSW offers a net emission saving between 725 and 1520 kg CO_2/t MSW. The saving is even higher for CHP generation.

■ **Gasification**,– Biomass conversion into biogas can be either from fast thermo-chemical processes (e.g., pyrolysis[1]) which can produce biogas and other fuels, with only 2%-4% of ash, or from slow anaerobic fermentation - which converts only a fraction (50%-60%) of feedstock but produces soil conditioners as a byproduct. The biogas can be used in combustion engines (10 kW to 10 MW) with efficiency of some 30%-35%; in gas turbines at higher efficiencies or in highly-efficient combined cycles. Biomass integrated gasification gas turbines (BIG/GT) are not yet in commercial use, but their economics is expected to improve. The first integrated gasification combined cycle (IGCC) running on 100% biomass (straw) has been successfully operated in Sweden. Technical issues appear to have been overcome. IGCC plants are already economically competitive in CHP mode using black-liquor from the pulp and paper industry as a feedstock. Other developments have brought Stirling engines[2] and organic Rankine cycles[3] (ORC) closer to the market whereas integrated gasification fuel cell plants (IGFC) will need significantly more R&D to enter.

[1]Pyrolysis is high temperatures (300-700°C) material decomposition. Products are solid (charcoal), liquid (oil) or gaseous. Slow pyrolysis produces solid products. Modern fast (flash) pyrolysis at moderate temperature provides up to 80wt% bio-oil. High temperature is required for gas production.
[2] Stirling engines are highly efficient, external combustion engines that run pistons on gas expansion following temperature changes. Often associated with use of biogas and natural or residual heat sources, they are being demonstrated for CHP applications.
[3] In the organic Rankine cycles (ORC) an industrial oil is used as a process fluid instead of steam in a closed thermal cycle.

■ **Anaerobic digestion, landfill gas** - In the absence of air, organic matter such as animal manures, organic wastes and green energy crops (e.g. grass) can be converted by bacteria-induced fermentation into biogas (a 40%-75% methane-rich gas with CO_2 and a small amount of hydrogen sulphide and ammonia). Anaerobic digestion is also the basic process for landfill gas production from municipal green waste. It has significant potential, but it is characterised by relatively small plant size. Anaerobic digestion is increasingly used in small-size, rural and off-grid applications at the domestic and farm-scale. The rising cost of waste disposal may improve its economic attractiveness. In modern landfills, methane production ranges between 50 and 100 kg per tonne of MSW. In general, some 50% of such gas can be recovered and used for power and heat generation. After purification and upgrading, biogas can be used in heat plants, stationary engines, fed into the natural gas grid, or used as a transport fuel (compressed natural gas). Large-size plants using MSW, agricultural wastes and industrial organic wastes (large-scale co-digestion) need some 8000-9000 tonne MSW per year per MW of installed capacity. Some 200 such plants are in operation or under construction world wide using more than 5 million tones of MSW.

■ **Bio-refineries and hydrogen** – Bio-refineries can theoretically produce a variety of products such as biopolymers, liquid bio-fuels, biogas, electricity or hydrogen. Using proper feedstock and exploiting production synergies, bio-refineries could gain economic appeal. The pulp and paper industry as well as the food industry have processing plants already produce several products for different markets but energy carriers are not usually one of them. Hydrogen can be obtained from biomass in a number of ways, the most direct being reforming of bio-methane and bio-ethanol. Processes are well known but efficiency and cost of biomass-to-hydrogen conversion need to be improved.

TYPICAL COSTS - Because of widely varying feedstocks and conversion processes, it is difficult to identify typical costs for biomass energy. The most economical approach is to use local biomass to avoid costly, energy-consuming transportation. Pelletisation can facilitate transportation but not all biomass readily forms pellets. New logistic routes have been developed to export pellets from Canada and Russia to Europe. The incremental investment cost of biomass/coal co-fired power plants range from $50 to $250/kW. Where feedstock is available at little or no cost, co-firing can reduce the electricity generation cost to as low as $0.02/kWh. If biomass is available at costs between $3.0-$3.5/GJ, then the electricity generation cost is higher than for typical coal-based electricity ($0.03-$0.05/kWh). This is however the most competitive near-term option for using biomass in power generation. The cost of electricity from dedicated solid biomass plants depends on technology, feedstock quality and cost, regional location, and size of the plant. Large-size plants require biomass transportation over long distances. Small size means higher investment cost per kW and lower electrical efficiency relative to coal plants. The capital cost of power plants with biomass gasification in the United States is about $2000-$3000/kW and generation cost is in the order of $0.09/kWh. Such plants may be cost-effective in CHP mode if connected to district heating schemes. The cost of biomass combustion steam cycle and CHP plants can be lower, with $1000/kW as the cost target. In Europe, the investment cost of biomass plants varies considerably from $1000 to $5000/kW, depending on plant technology, level of maturity and plant size (Table 1). Assuming a delivered biomass price of $3/GJ, the generation costs from biomass gasification plants, even at higher efficiencies, are expected to be some $0.10-$0.13/kWh, more than twice the cost of fossil-fuel power plants. These costs may be significantly reduced by technology learning and then represent a low-cost option for renewable electricity.

STATUS - Biomass currently provides about 10% of the world's primary energy supplies most being used in developing countries as fuel wood or charcoal for heating and cooking. Biomass use for power and CHP generation is steadily expanding in Europe, mainly in Austria, Germany, the United Kingdom, Denmark, Finland and Sweden, where bioelectricity is mostly produced from wood residues and MGW in co-generation plants. Favoured by resource abundance and national policies, the European Nordic countries not only produce bio-power but also export equipment and services for biomass power generation. According to REN21 *Global Status Report 2006*, global biomass power capacity added in 2005 amounted to 2–3 GW, bringing total capacity to about 44 GW. In 2004 Germany, Hungary, the Netherlands, Poland, and Spain registered annual capacity increases of 50%–100% or more. In Australia, Austria, Belgium, Denmark, Italy, South Korea, New Zealand and Sweden, growth was in the range of 10%–30%. The biomass power industry is also active in the United States where some 85% of total wood process wastes (excluding forest residues) are used for power generation. Countries that are major producers of sugar cane are often major producers of (or are developing) bio-electricity from bagasse power plants. A proliferation of small projects, including power plants and biogas digesters, is recorded in both IEA and emerging economies. Progress with rural use of biomass energy is difficult to track. It is especially hard to distinguish between modern and traditional biomass use, which still dominates in rural areas of developing countries (REN 21). China, Brazil, Latin American, Thailand, Cambodia and India are turning increasingly to biomass power plants and gasifiers alongside solar PV, small hydro and wind power. Some 70 MW of small-scale biomass gasification systems for off-grid power generation and 3.8 million household-scale biogas plants are installed in India. China reported 17 million existing biogas users in 2005. Use of biomass stoves is growing in Africa (Morocco, Uganda, Malawi, Ethiopia). Heat and power generation from biomass accounted for 7% of an estimated $38 billion invested in new renewable energy capacity worldwide in 2005 (excluding large hydro).

POTENTIAL – In the short term, co-firing is expected to remain the most efficient use of biomass for power generation. As electricity from coal represents 40% of worldwide electricity, each percentage point replaced by biomass results in some 8 GW of installed biomass capacity giving about 60 Mt of CO_2 avoided per year. This is more than the feasible reduction using small-size, biomass-dedicated power plants with lower efficiency. Co-firing in coal plants can also reduce ash, dust, NOx and SO_2 emissions. Blending with non-toxic, selected waste materials could enlarge the feedstock base and enhance co-firing potential. In the mid-long term, technologies with high potential include BIG/GT, bio-refineries and small-scale anaerobic digesters. According to *Energy Technology Perspectives* (IEA, 2006), global electricity production from biomass is projected to increase from its current share of 1.3% to some 3%-5% by 2050, depending on scenario assumptions. In absolute terms, the net increase would be 5-8 times the current production, with a significant contribution to CO_2 emission reduction but small in comparison with global biomass potential that also includes heat and biofuel production. Today's global industrial biomass energy use is about 9 EJ/year. Estimates of global potential for industrial biomass production by 2050 vary considerably. Estimates of 100-200 EJ per year (roughly 10%-20% of 2050 primary energy supply) are based on the assumption of no water shortage and increased food agriculture yields in the coming decades, partly due to genetically modified crops. In this case, large amounts (20%-50%) of arable land would be available for biomass production. Some 50 EJ per year could be provided by ligno-cellulosic feedstock and used to produce biofuels via advanced processes (enzymatic hydrolysis). Current estimates however are very uncertain. The use of marginal, non-arable land could also play an important role. Currently the best agricultural crop yields of biomass approach 10-15 dry tonnes/ha per year so that some 11 000 ha can produce biomass for a 30 MW power station, enough to supply electricity to some 30 000 houses.

BARRIERS – Main barriers to widespread use of biomass for power generation are cost, low conversion efficiency and feedstock availability. Most important are the lack of internalisation of external costs in power generation and effective policies to improve energy security and reduce CO_2 emissions. In the long term, bio-power potential will depend on technology advances and on competition for feedstock use, and with food and fibre production for arable land use. Competition may not be an issue until 2020 if industrial-scale production and international standards facilitate biomass international trade. While long-distance transportation reduces economic and environmental attractiveness of biomass, conversion into "bio-oil" (e.g., by pyrolysis) could facilitate international trade. Risks associated with widespread use of biomass also relate to intensive farming use of fertilizers and chemicals and biodiversity conservation. Controls and certification that biomass feedstock is produced in a sustainable way are needed to secure continued access to public forest and lands, and to improve public acceptance of forest management activities. Nutrients should be returned to forests and land through ash from biomass combustion, thus alleviating nutrient loss and need for fertilisers. While over-exploitation of biomass resources in developing countries should be avoided, biomass can be important for using marginal land and bringing socio-economic benefits in these regions.

Table 1 – Typical Data and Figures for Power Generation from Biomass

Data Confidence – Power generation from biomass includes a number of processes and feedstocks. Data refer to typical technologies but wide ranges exist, depending on process, feedstock, transport and local conditions.

Technologies	Efficiency % (LHV)	Typical size MWe	Typical Costs [1] **Capital**, $/kW	**Electricity**, $/kWh
Co-firing	35-40	10-50	1100-1300	0.05
Dedicated steam cycles	30-35	5-25	3000-5000	0.11
IGCC	30-40	10-30	2500-5500	0.11-0.13
Gasification+engine CHP [2]	25-30	0.2-1	3000-4000	0.11
Stirling engine CHP	11-20	<0.1	5000-7000	0.13
Further Information	www.iea.org; www.ieabioenergy.com; International Bio-Energy Partnership (www.fao.org); *Energy Technology Perspectives* (IEA, 2006); *World Energy Outlook* (IEA, 2006) REN21 – Global Status Report 2005 and Update 2006 (www.ren21.net)			

1) Biomass cost $3/GJ; Discount rate 10%
2) Heat value $5/GJ;