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BIOPOWERSWITCH!


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A BIOMASS BLUEPRINT TO MEET 15% OF OECD ELECTRICITY DEMAND BY 2020


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A Biomass Blueprint to Meet 15% of OECD Electricity Demand by 2020

Prepared for WWF International and Aebiom by
Imperial College London,
Centre for Energy Policy and Technology

and **E4tech (UK) Ltd**

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Foreword

MINISTER ROLNICTWA
I ROZWOJU WSI
Wojciech Olejniczak

The use of renewable energy resources is an action for economic development, which will bring benefits in the coming decades. It is a consequence of striving towards sustainable economic development, stimulated by a growing concern about the impacts of global warming. Fossil fuels are becoming less available and in many regions the fuel resources are estimated to run out within a few decades.

In recent years the Parliament and Government of the Republic of Poland adopted numerous documents which are essential for enhancing the use of renewable energy. For Poland it means the acceleration of the energy management transformation process and increasing the contribution of power based on renewable energy sources, including biomass. Today, Poland's power supplies are based mainly on coal.

Increasing energy prices result in deteriorating conditions for the whole economy, including agriculture. A very important element of "professional" power industry, based on renewable energy resources, is overcoming the organisational, technical and technological barriers, which today make biomass less competitive than fossil fuels. Such possibilities already exist on the local markets, where biomass is easily accessible and is not connected with high transportation costs. Increases in renewable energy production will not only result in an improvement in the areas of environment protection and energy safety, but will also provide a great chance for agriculture.

In Poland, due to the large area of arable land, it is possible to transform some parts of it into bioenergy plantations. This will enable the restructuring of Polish rural areas and agriculture by developing lands which today are permanently fallowed or used extensively. Management of the food market surplus and ensuring stable incomes from agricultural production for energy needs is a great chance – not only for the Polish rural areas.

Wojciech Olejniczak

Minister of Agriculture
and Rural Development,
Poland

Introduction

Every day, we burn fossil fuels – coal, oil, and gas – that have taken half a million years to form. While the full impacts of the resulting carbon dioxide gas emissions will only become truly apparent in the decades to come, we are already feeling the 'heat'. If we really want to prevent catastrophic climate change, we will have to make radical alterations to the ways in which we generate energy. One major solution lies in the modern use of the oldest fuel known to man: wood.

WWF and the European biomass association (AEBIOM) have together produced the *Biopower Switch!* study to show that biomass from forestry and farming has the potential to become a major source for sustainable power generation. Written by international energy researchers from the Imperial College London and E4tech Consulting, this report demonstrates that biomass can supply 15% of electricity demand in OECD countries by 2020 – equivalent to power well over 100 million homes.

By utilising modern and efficient technologies, biomass offers a source of sustainable energy that can gradually replace coal and other fossil fuels. Biomass is a carbon-neutral power source in that CO_2 absorbed by the raw material while growing offsets that generated during combustion. Achieving a 15% biopower share will bring environmental benefits such as delivering cuts in CO_2 emissions of up to 1,800 million tonnes annually. It will also support rural development, by creating up to 400,000 jobs.

Biopower Switch! indicates that there needs be no land-use conflict between biomass use for energy and the production of crops for food and fibre in industrialised countries. The development of biomass resources and the conservation of biodiversity and local environments can go hand in hand. The main constraints are commercial and policy barriers, rather than technical ones.

Strong and clear policy signals will be required to drive a modern biopower industry along the pathway to a low-carbon energy future. To achieve this, WWF and AEBIOM are calling for firm commitments towards increasing the share of renewable energy at national and international levels. The European Union, specifically, must show its global leadership by setting a target to supply 25% of its primary energy demand from renewable energy sources by 2020.

Governments should also redirect their agricultural subsidies to support the development of a stable biomass fuel supply by allowing perennial woody and grass energy crops to benefit from incentive schemes and at realistic scales. This needs to be accompanied by the development and enforcement of best practice guidelines for for biomass production to maximise positive social and environmental impacts and minimise any negative effects. Bioenergy is a key technology to fight climate change and deliver economic and social benefits. Governments must act now to promote its world-wide development.

Giulio Volpi
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WWF International

Jean Marc Jossart
AEBIOM,
European Biomass Association

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Executive Summary

1. Background

This study evaluates the potential for sustainable power production from biomass and its contribution to the reduction of CO_2 emissions in the medium term (2020), with a focus on OECD countries. In particular, the study:

- Reviews the current status of bioelectricity and its costs.
- Derives an indicative potential for biomass power by 2020.
- Discusses criteria and best practices for sustainable bioelectricity production.
- Discusses policy measures for successful biomass energy development.

The study has been carried out by the Centre for Energy Policy and Technology at Imperial College London and by E4tech Ltd. The information provided by the study is used by WWF and AEBIOM to inform policy-makers and industrial players about the potential for bioelectricity.

2. The biomass resource

The raw material for bioenergy comes from three main sources:

- Residues – from crops, animal husbandry, logging, and co-products from industrial wood processing such as sawmills.
- Dedicated ‘energy plantations’ – from agricultural or forestry-based activities such as annual crops and short-rotation tree plantations.
- Woody biomass – wood fuels from multi-purpose forests.

These resources are abundant and can realistically supply one to three quarters of world energy demand. Globally, about 50 % of the potentially available residues are associated with forestry and wood-processing industries, about 40 % are agricultural residues (mainly straw, rice husks, and sugarcane and cotton residues), and 10 % animal manure.

3. Technology and economics

The technology for harnessing power and heat from biomass fuels is already available. Electricity generation from biomass fuels currently uses the same basic technology used in power plants that burn solid fossil fuels. However, new technologies are being developed to improve power production efficiency from biomass. The potential also exists for local sources of electricity production from biomass by using small-scale gasification plants or systems involving fermentation of biomass.

By factoring in the pollution-related environmental and social costs generated by fossil and nuclear fuels, bioelectricity becomes a competitive energy source. The cost of biomass fuel supply depends on the cost of producing or recovering the 'feedstock' – raw materials – and those incurred during its transport and pre-processing prior to use in a power plant. Costs vary widely, from extremely cheap for existing residues that simply require disposal, to relatively expensive for production and use of dedicated energy plantations.

Ultimately, the cost of bioelectricity will depend on the economics of feedstock supply, power generation technology, the scale of operation, and the extent to which fossil fuel power plants can be adapted for biomass fuels. Combined heat and power (CHP or cogeneration) results in a more efficient use of biomass and could contribute significantly to the economic viability of electricity from biomass.

4. The 15 % biomass blueprint

This report draws up a blueprint for achieving 15 % of electricity production from biomass use in industrialised countries by 2020 – countries where bioelectricity currently represents on average about 1 % of production capacity.

Based on the conservative assumptions that power demand in OECD countries will double by 2020, the 15 % target is feasible and realistic. It requires exploitation of a quarter of the potential collectable agricultural, forestry and livestock residues in countries and the dedication of 5 % of their crop, forest and woodland area to the growing of woody biomass for energy. With stronger energy savings and efficiency policies, the power share of biomass could even reach 30 %.

Industrialised countries between them have over 1,500 million hectares of crop, forest and woodland, of which some 460 million hectares are crop land. Achieving the 15 % target could require an average of 1.25 million hectares of crop land per year to be converted to energy plantations. This represents just over 2 % of the total land area in industrialised countries. This report shows that there needs be no land-use conflict between biomass use for energy and the production of crops for food and fibre in industrialised countries.

5. The benefits

Biomass is a carbon-neutral power source in that CO_2 absorbed by the raw material while growing offsets that generated during combustion. Achieving the 15 % biopower target will deliver cuts in CO_2 emissions of between 538 and 1 739 million tonnes annually. At present CO_2 emissions in industrialised countries total some 11 467 million tonnes – a figure projected to rise to more than 14 298 million tonnes by 2020.

Unlocking the potential of the 15 % biomass blueprint is expected to create more than 400,000 jobs in industrialised countries by 2020. This estimate is based on research that has shown that two direct and indirect jobs are created for every megawatt of bioenergy installed. Another advantage is that employment could be generated where there is often the greatest need, in rural areas. Here, the production of biomass fuels offers a new income stream for cash-strapped farmers. In countries with economies in transition, where agriculture already employs a significant percentage of the national workforce, biomass production can strengthen job security.

6. The environment

The development of biomass resources and the conservation of biodiversity and local environments can go hand in hand. The biomass production has several environmental advantages, including: substituting fossil fuel use with a CO_2-neutral alternative; reducing emissions of other atmospheric pollutants, such as sulphur; protecting soil and watersheds; increasing or maintaining biodiversity: and reducing fire risk in forestry.

These benefits provide a powerful argument for accelerating the introduction of biomass energy in virtually all industrialised countries. However, because the production of biomass feedstock differs between growing sites, the development of 'one size fits all' policies should be avoided.

To maximise likely benefits and minimise potential impacts, the following guidelines should be followed:

- Biopower schemes need to be subject to rigorous and transparent environmental impact assessments.
- Good agricultural and forestry practices must be adopted, suitable for local conditions.
- There should be no conversion of natural forests or High Conservation Value habitats involved in raw material production or supply.
- Biomass growing practices must protect and enhance soil fertility.
- Water use should be assessed throughout the production and conversion chain, with particular emphasis on avoiding damage to watersheds.
- On the production side, best available conversion technologies should be used to minimise emissions.
- Ash quality from conversion processes should be monitored and where possible nutrient-rich ash should be recycled back to the land.

7. Measures required

Woody biomass has the potential to become a major source of sustainable and safe power over the next two decades. The main constraints are commercial and policy barriers, rather than technical ones. Hence, strong and clear policy signals will be required to drive a modern bioelectricity industry along the pathway to a low-carbon energy future.

To achieve this, governments must:

- Make renewable energy and energy efficiency the basis of greenhouse-gas mitigation strategies and swiftly implement the Kyoto Protocol under the UN Climate Change Convention.
- Take the lead in the development of bioelectricity by setting ambitious and specific targets for the post 2010 period.
- Redirect agricultural subsidies towards development of a stable biomass fuel supply by allowing perennial woody and grass energy crops to benefit from incentive schemes and at realistic scales.
- Stimulate biomass energy demand through preferential tariffs or quotas for biomass power, capital grants for project development, and public procurement for labelled green power.

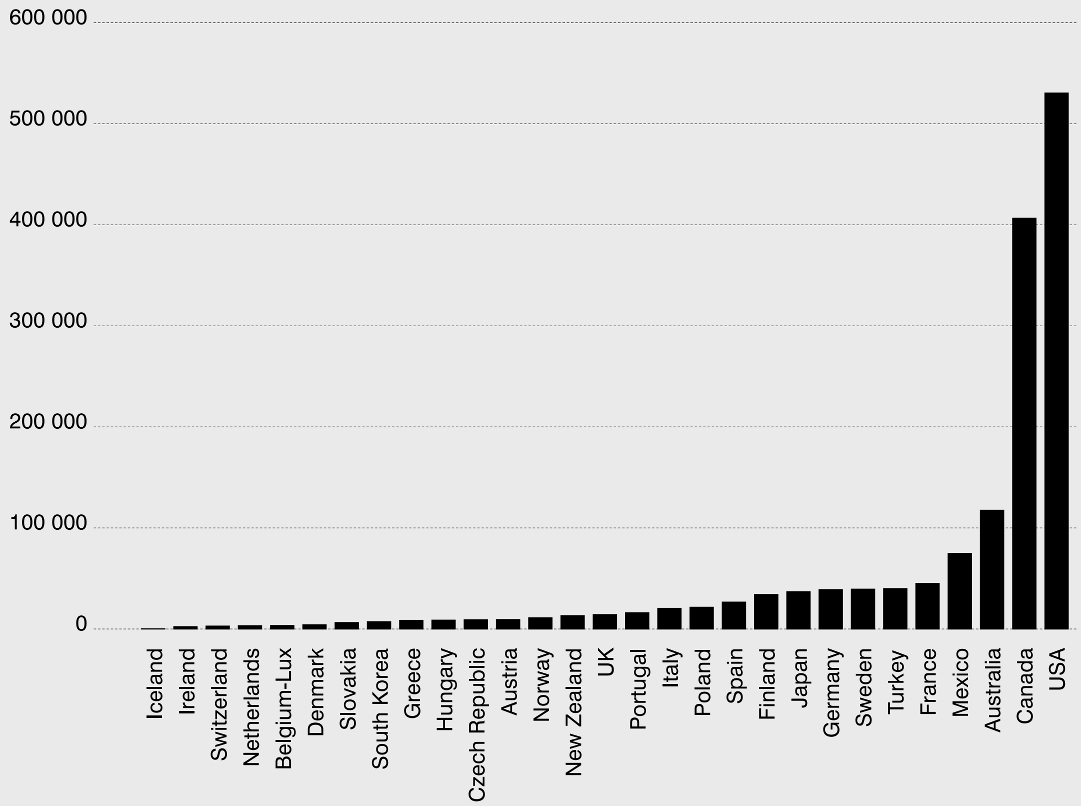
- Establish energy strategies that include local and regional planning guidelines to stimulate the development of biomass generation. This should be based on the determination of raw material supplies at regional or landscape levels.

- Develop public task forces to stimulate biomass power, involving agriculture, forestry, environment, trade and industry, transport, and finance ministries.

- Promote site-specific best practice guidelines for biomass production, including ways of ensuring effective implementation and monitoring.

Figure 1: Potential bioelectricity production in OECD countries by 2020

Bioelectricity Production (GWh)



1. Background

1.1 Defining bioelectricity

The development of renewable energy sources, including biomass, is fundamental to a sustainable energy future. Biomass could play a significant role as a renewable energy source, and there are a number of reasons that make it an attractive option:

- It can provide a (very) low-carbon source of electricity.
- The use of modern biomass conversion technologies can keep emissions affecting air quality to (very) low levels.
- Suitably managed energy plantations can lead to environmental benefits such as the rehabilitation of degraded lands and the protection of watersheds.
- Its widespread, diverse and renewable nature can contribute to energy security and diversity.
- Its production for energy use can contribute to rural regeneration and development[1].

However, biomass energy is characterised by a variety of resources and possible conversion routes, which complicates the understanding of its implications. In particular, a number of issues need clarification in order to understand the potential of biomass as a sustainable energy source: resource and land availability, feedstock supply logistics, fuel chain costs and environmental impacts. Also, the agricultural and forestry dimensions are fundamental to the potential of biomass as a sustainable energy source. In particular, questions such as the quantity of residues the can be used, the types of energy plantations and where and how they should be grown, and the development of suitable feedstock supply infrastructures need careful consideration.

1) Rural development can be defined as improving economic growth in rural areas through the strengthening of the agricultural and forestry sectors and the preservation of the rural environment and heritage.

The aim of this study is to discuss the potential for sustainable biomass supply for power production and its contribution to the reduction of CO_2 emissions in the medium term (2020), with a focus on OECD countries. In particular, the study:

- Reviews the current status of bioelectricity and its costs
- Produces an indicative potential for biomass power by 2020
- Discusses criteria and best practices for sustainable bioelectricity production
- Discusses policy measures for successful biomass energy development

Biomass can be used to provide a variety of energy vectors: heat, electricity and transport fuels. This report focuses on the use of biomass as a source of electricity or combined heat and power. Heat and power uses could in the short to medium-term represent the most beneficial use of biomass energy. However, biomass-based transport fuels remain an interesting option, and policies should be designed as to allow the best environmental and economic use of biomass resources.

The study has been carried out by the Centre for Energy Policy and Technology at Imperial College London and by E4tech Ltd.

1.1. Defining biomass energy

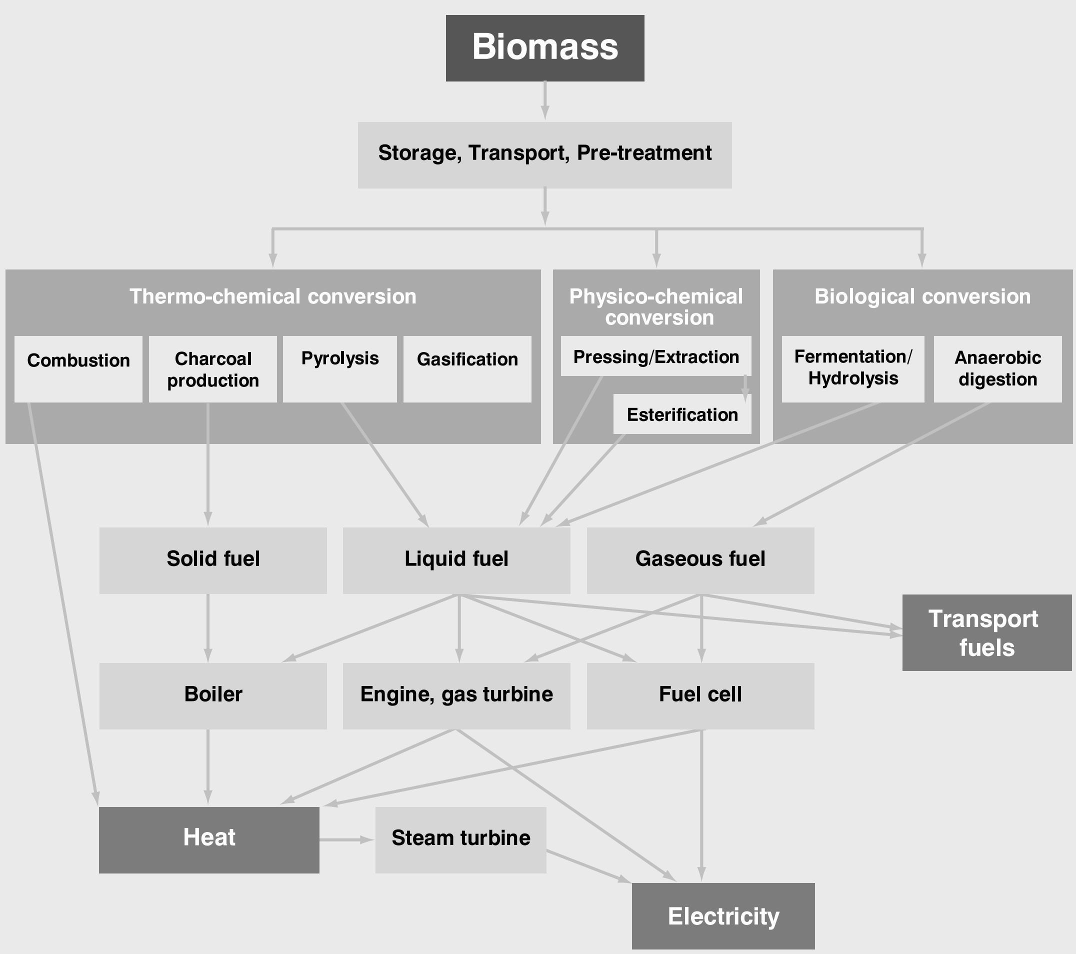
Biomass consists of all organic matter of vegetable and animal origin. It is the oldest fuel known to mankind; wood has been used to keep warm and cook food since the dawn of civilisation. It is wood that fuelled the early days of the industrial revolution, but was supplanted by higher energy density, easily handled and cheap fossil fuels such as coal and oil. However, there is increasing renewed interest in biomass which can be used as a modern fuel for the efficient and clean production of heat and electricity and for the production of clean transport fuels.

Bioelectricity, excluding municipal solid waste to electricity, today represents a very small fraction of world electricity production, about 30 GW representing about 1 % of installed capacity, but has a very strong potential for growth. Its growth will be driven by the need to increase the use of renewable energy sources for electricity production to ensure sustainable production of electricity.

In some cases industrial, commercial and municipal solid waste (MSW) is treated as a biomass resource, though a large part of its composition is inorganic in nature e.g. metals, plastics, glass, etc. This report does not consider MSW or organic wastes arising from industrial or commercial activities. Exceptions are residues from crop growth and forestry felling activities that arise in the fields. Although, industrial and commercial wastes and MSW represent a large potential source of organic material, paper and putrescible materials comprise over 50 % of municipal waste in all EU Member States, these may be best dealt with through recycling and composting because of their low calorific value and the potential value of the derived products. For example, composts from organic wastes are a valuable resource with regard to returning organic matter to agricultural soil.

Figure 2 provides a schematic representation of biomass fuel chains.

Figure 2: Biomass fuel chains



1.2 Sustainability criteria

In order for biomass to fulfil expectations as a sustainable source of electricity, it must satisfy a number of economic, environmental and social criteria including:

- Biomass must be derived from renewable sources.
- Bioelectricity costs must be kept low to ensure economic efficiency.
- Non-renewable energy inputs to bioelectricity chains must be kept low to ensure low carbon emissions.
- Best available logistics and conversion technologies must be used to reduce emissions affecting air quality.
- Sustainable forestry and agricultural management practices must be followed to avoid negative impacts on soil and water and to foster biodiversity.
- Biomass to electricity schemes must be designed to benefit rural development and gain broad acceptance by the general public.

The broad criteria listed above mask the huge range in technology options and site-specific factors implicit in biomass production for energy, where the sustainability of bioelectricity depends on the sustainability of each stage in the fuel chain. Therefore, national and even regional policies must be sufficiently robust to ensure sustainability but flexible enough to allow entrepreneurs to develop efficient fuel production and conversion chains and to encourage investments and improvements in productivity and conversion efficiency.

In evaluating bioelectricity chains, as with other renewable electricity chains, it is clear that simple cost-benefit analysis does not capture a range of ‘external’ costs and benefits that arise from the supply of energy services. National and regional regulation should be designed to capture such externalities and ensure their consideration in decision-making related to energy provision.

2. Status of bioelectricity in OECD countries

2.1 Biomass resources

Biomass is available in a variety of forms and is generally classified according to its source (animal or plant) or according to its phase (solid, liquid or gaseous). Generally, biomass energy can be derived from the following sources: dedicated plantations; residues from primary biomass production; and by-products and wastes from a variety of processes. There is a wide range of biomass resources and some examples are provided in Table 1.

In OECD countries, most biomass use for electricity today is based on residues from the forestry and wood processing industry. Agricultural resides, such as straw, are used in much smaller quantities. There are very few examples of the use of dedicated energy crops, such as short rotation coppice, for electricity.

2.2 Biomass end-uses and conversion technologies

Biomass can be burned directly or converted to intermediate solid, liquid or gaseous fuels to generate heat and electricity. All organic materials can potentially be converted into useful forms of energy but the advantage of modern biomass-to-electricity systems is that these conversion systems can cope with a range of lignocellulose-rich materials. This is in contrast to liquid biofuel production chains that are primarily dependent on sugar, starch or oil-rich crops, typically annuals. The options for biomass conversion to electricity are described below.

Table 1: Examples of biomass resources

Biomass resource categories	Examples
Dedicated plantations	Short rotation forestry and crops such as eucalyptus and willow. Perennial annual crops such as miscanthus. Arable crops such as canola (rapeseed) and sugarcane.
Residues from primary biomass production	Wood from forestry thinning and felling residues. Straw from a variety of cereal crops. Other residues from food and industrial crops such as sugarcane, tea, coffee, rubber trees and oil and coconut palms.
By-products and wastes from a variety of processes	Sawmill waste, manure, sewage sludge and organic fractions of municipal solid waste, used vegetable cooking oil

Biomass direct combustion

Biomass can be burned in modern boilers to generate heat, electricity or combined heat and power (CHP). Most biomass electricity generation is based on the Rankine (steam turbine) cycle. Biomass combustion systems are in commercial use around the world, using different boiler technologies that can burn a wide range of biomass fuels. The most common boiler types are: pile burners, stoker fired boilers, suspension fired boilers and fluidised bed boilers. The latter are rapidly becoming the preferred technology for plants $>10\ MW_e$ because of their clean and efficient combustion characteristics. Plants are typically below $100\ MW_e$, which is significantly smaller compared with conventional large-scale fossil, e.g. coal, plants that are generally $>500\ MW_e$.

Around 1,000 wood-fired plants are in operation in the US and over 100 fluid bed boilers are operating or planned for operation. Most European examples of biomass-fuelled stoker-fired, suspension and fluidised bed boilers are situated in Austria, the Netherlands, Denmark, Sweden and Finland. Most plants use wood fuel or agricultural residues, though there are many examples of plants operating on a variety of other fuels – including poultry litter. Co-combustion of biomass and fossil fuels such as coal is also an option that is employed in some countries such as the US, Australia, Finland and Germany.

Biomass gasification

Gasification is the conversion by partial oxidation at elevated temperature of a carbonaceous feedstock into a gaseous fuel with a heating value ranging from about one-tenth to half that of natural gas, depending on the gasification process used. The product gas can be used to generate heat and electricity by direct firing in engines, turbines and boilers after suitable clean up. Alternatively, the product gas can be reformed to produce fuels such as methanol and hydrogen, which could then be used in fuel cells, for example. Gasification-based systems may present advantages compared to combustion in terms of economies of scale and clean and efficient operation.

Hundreds of small-scale fixed bed gasifiers are in operation around the world, in particular in developing countries. Recent gasification activities, mainly in industrialised countries, have focused on fluidised bed systems, including circulating fluidised bed systems. Larger systems coupling combined cycle gas and steam turbines to gasifiers (biomass integrated gasification combined cycle, BIG/CC) are at the demonstration stage. BIG/CC systems could lead to electrical efficiencies of about 50 %. Current costs are high but significant cost reductions could be obtained through economies of scale and replication.

Biomass pyrolysis

Pyrolysis is the thermal degradation of biomass in the absence of oxygen, whereby the volatile components of a solid carbonaceous feedstock are vaporised by heating, leaving a residue consisting of char and ash. Biomass pyrolysis always produces a product gas, vapour that can be collected as a liquid and a solid residue. The liquid fuel can be transported and stored, and allows for de-coupling of the fuel production and energy generation stages. It can be used to generate heat and electricity by combustion in boilers, engines and turbines. Products other than liquid fuels can be obtained from pyrolysis, such as charcoal, product gas and speciality chemicals.

Anaerobic digestion

Anaerobic digestion is a biological process that converts solid or liquid biomass to a gas in the absence of oxygen. The gas consists mainly of methane and carbon dioxide and contains various trace elements. Anaerobic digestion is used in the treatment of wet wastes of industrial, agricultural and domestic origin. The derived gas is increasingly used for the production of heat and electricity. The solid and liquid residues from the anaerobic digestion process can be used as compost and fertilisers. Farm-based facilities are common, in particular in countries such as China and India, at household or village-scale, for cooking, heating and lighting. Over 600 plants treating farm wastes (often co-digesting wastes from a variety of sources) are in operation in North America and Europe. There are also scattered examples of biogas use as a transport fuel in vehicle fleets.

Table 2 summarises biomass technology options and corresponding end-uses, together with an indication of the status of these technologies.

Table 2: Biomass technology options, corresponding end-uses and status

Conversion technology	Resource type	Examples of fuels	Product	End-use	Technology status
Combustion	Mainly solid biomass	Wood logs, chips and pellets, agricultural residues, chicken litter	Heat	Heat, Electricity (steam turbine, Stirling engine, reciprocating steam engine)	Commercial (boilers and steam turbines)
Gasification	Mainly solid biomass	Wood chips and pellets, agricultural residues	Product gas	Heat (boiler), Electricity (engine, gas turbine, fuel cell, combined cycles), Transport fuels (methanol, hydrogen)	Demonstration/ Early commercial
Pyrolysis	Mainly solid biomass	Wood chips and pellets, agricultural residues	Pyrolysis oil + by-products (product gas, char)	Heat (boiler), Electricity (engine, turbine)	Demonstration
Anaerobic digestion	Wet biomass	Manure, sewage sludge	Biogas + by-products	Heat (boiler), Electricity (engine, gas turbine, fuel cell), Transport fuel	Commercial

2.3 Current production of bioelectricity

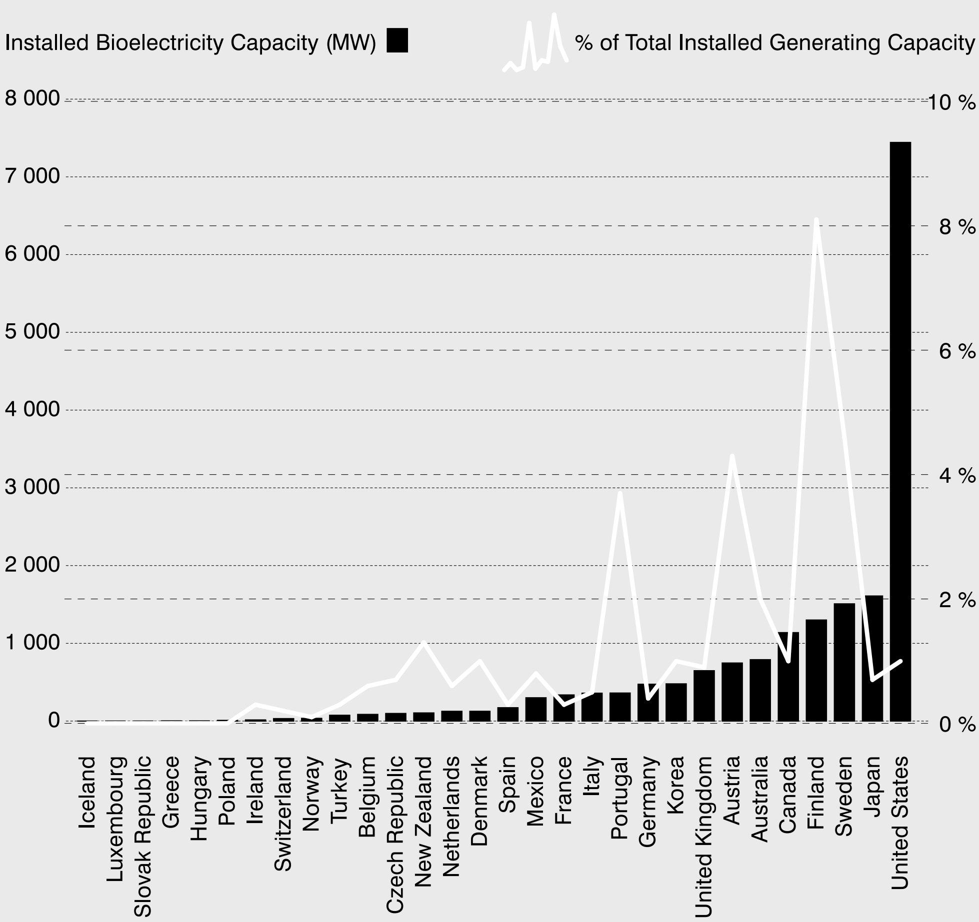
About 18.4 GW of bioelectricity capacity is installed in OECD countries (2000), representing about 1 % of OECD electrical capacity (1997) (Source: IEA). This is distributed across three regions of the OECD as you can see at the Table 3.

FIgure 3 shows how this capacity is distributed at the country level and which countries have the largest proportion of biomass-fuelled electricity capacity. The USA dominates the scene in absolute terms with approximately 7.4 GW installed capacity, but Finland shows the largest national share of biomass fuelled generating capacity at about 8 %. (For more detail relating to Table 3, see Appendix).

Table 3: Distribution of biomass generating capacity across three OECD regions | Source: IEA 2002

Region	Biomass generating capacity (2000)	Percentage of installed capacity (1997)
OECD Europe	6,509 MW	1.0 %
of which EU 15	6,259 MW	1.4 %
OECD North America	8,881 MW	1.0 %
OECD Pacific	2,983 MW	1.0 %

Figure 3: Installed bioelectricity generating capacity in OECD countries



Most bioelectricity production in OECD countries is associated today with forestry and wood processing industry activities. Most plants are of the combined heat and power type, based on a variety of combustion technologies, where the heat produced is generally used for industrial process heat or district heating. Some countries, such as Finland, have considerable experience with co-firing biomass with fossil fuels and waste.

Gasification appears to be a promising technology for clean and efficient electricity production and as a route to a variety of other biomass based products and fuels. However, there is little operating experience with gasification of biomass, especially integrated with electricity production and at scales above 10 MW_e.

There is still a large potential for energy from forestry residues in certain regions. In addition, agricultural residues and other organic waste streams represent significant energy potential. Energy crops remain a major potential resource that will need to be exploited if biomass is to become a widespread source of energy and a significant contributor to primary energy supply. Biomass has an important role to play as a source of non-intermittent renewable energy.

2.4 National policies supporting bioelectricity

All EU and most other countries in the OECD have set indicative or mandatory targets for energy from renewables and some have targets specifically for electricity from renewables. Many countries recognise biomass as being a major contributor toward meeting renewable electricity targets (e.g. bioelectricity expected to contribute about 1,500 MWe of the 8,300 MWe UK renewable electricity target by 2010), but only few have targets for production of electricity specifically from biomass. Table 12 in the appendix provides a summary of targets in the OECD countries studied, including bioelectricity targets where available.

Biomass is projected to be a major contributor to the EU's future primary energy mix. Currently it contributes about 60 % of the renewable energy sources share (98 % of renewable heat and 8 % of renewable electricity) and is believed to be the renewable energy resource with the largest growth potential. The White Paper on Renewable Energy estimates the contribution of biomass and waste in 2010 at 135 Mtoe[2], representing again about 60 % of primary renewable energy. It is estimated that an additional 18 Mtoe of biomass from energy crops could be used for the production of liquid biofuels (biodiesel and ethanol) and 72 Mtoe for heat and power applications, by 2010. Electricity production from biomass in 2010 could reach 230 TWh, equivalent to an installed capacity of about 44 GW. The EU Member State targets are generally in line with the indicative targets provided in the EU Directive on the promotion of renewable electricity (Directive 2001/77/EC), which sets an overall renewable electricity target for the EU of 22 % by 2010, compared to a renewable electricity share of 14 % in 1997.

2) This comprises an additional 15 Mtoe from biogas exploitation, 30 Mtoe from agricultural and forestry residues exploitation and 45 Mtoe from energy crops – requiring 10 Mha out of the 141 Mha of agricultural land in the EU – as a comparison current set-aside land in the EU15 is about 9.5 Mha and could grow to 30 Mha with EU enlargement.

Most OECD countries have some form of support programme for renewable energies, including biomass. Table 13 and Table 14 in the appendix provide a summary of general policies and financial incentives in selected OECD countries that support bioelectricity. Most country policies encompass a mix of the policy options discussed below (as shown in the country case studies below).

Feed-in tariffs have shown to be highly effective as a market stimulus of renewable electricity production in general, and biopower in particular, but have provided limited incentives for driving down price. In this system, an obligation is placed upon utilities to accept all renewably generated power, provided technical criteria are met. The power producers are paid a guaranteed price for their power – fixed according to technology type. This may be financed through a subsidy, from a levy on conventional generation for example, or borne by the utility and passed onto consumers.

The recent feed-in law in Germany (2000) is providing a strong incentive to the development of bioelectricity projects, and is designed such that the price support decreases with time. The price-support is complemented by the availability of investment subsidies and the exemption, for CHP schemes, from the eco-tax on energy. The role of taxation in the internalisation of the environmental costs of different energy sources is of key importance. It is the taxation of conventional fuels in Sweden, based on local and global environmental concerns that largely drove the significant introduction of biomass for district heating.

Other countries are implementing *Competitive bidding*, or *NFFO type*[3] schemes. Renewable energy developers are invited to bid for contracts to sell electricity at a fixed premium price for a fixed term. The premium price emerges from the competitive bidding process – the most competitive bidders being awarded contracts. In the schemes formerly runt in the UK and Ireland, the price premium was funded through a levy on conventional generation.

Recently, a number of countries have adopted *Renewables Portfolio Standards* (RPS) or obligation based schemes. This policy involves a target level of renewable generation, to be met at some point in the future, usually combined with tradable certificates for green electricity. Tradable certificates allow flexibility on the part of suppliers to either directly purchase/generate renewable electricity, or to purchase the equivalent certificates – which creates a competitive market for renewable power. These will tend to promote the least cost options with little scope for less mature and less competitive technologies in the absence of other support mechanisms.

3) Non Fossil Fuel Obligation, the UK scheme introduced in the mid 1990s, now superseded by the Renewables Obligation, an RPS scheme (see main text above).

Agriculture policies

The success of bioelectricity schemes depends much on a successful integration of energy, environment, agricultural and forestry policies. Agricultural and forestry policies in particular, are key factors relevant to biomass energy systems. The provision of support aimed at the supply of biomass feedstocks is crucial to the development of a biomass energy industry. Support for feedstock supply can be available in the form of taxes and incentives aimed at waste recovery or incentives aimed at the establishment of energy crops. Below we discuss the case of the European Union Common Agricultural Policy (CAP).

In 2001, 5.7 million ha of EU land were under compulsory or voluntary set-aside of which about 929,000 ha were dedicated to non-food crops (16% of set-aside land). Most non-food crops are aimed at the production of biofuels, as a result of additional fiscal incentives linked to transport fuels. The role of the EU Common Agricultural Policy in promoting the production of biomass-based products has been very modest. However, the CAP has the potential to act as a powerful framework and instrument in the development of a biomass energy resource base.

The Common Agricultural Policy (CAP) and Agenda 2000 are being reviewed with two main goals: the first is an increasing market orientation of the agricultural sector and the second a reinforcement of the structural, environmental and rural development aspects of sustainable agriculture. A number of measures, such as the removal of some direct price support to food crops, the continuation of a set-aside policy, including 'permanent' set-aside, and agri-environment and structural measures, may provide an opportunity for the development of non-food crops.

The proposed CAP reform also suggests actions aimed directly at the promotion of energy crops as part of actions aimed tackling climate change. An area-based energy crop payment is proposed (which is not crop specific). This is aimed at achieving carbon dioxide emissions reductions in the energy sector. The current suggestion is as follows:

- Payment level set at € 45/ha.
- Maximum Guaranteed Area (MGA) to be 1.5 million hectares.
- Paid to producers entering into a contract with a processor.

The allocation of the MGA between Member States would be in line with previous energy crop production on set-aside land and CO_2 commitment burden-sharing agreements. The arrangement would be reviewed five years after coming into force, taking into account the implementation of the EU Biofuels Directive. Indeed, at present, the energy crop payment would seem to be mainly directed at its support. Indicative calculations show that the payment level above may correspond to about a 10% reduction in energy crop production cost.

An energy crop payment on a cultivated area basis is a desirable incentive. However, energy crop production will only be stimulated if there is sufficient pull from elsewhere in the bioelectricity supply chain. Furthermore, energy crop payments should account for the significant variations in CO_2 benefits depending on the type of energy crop and its use and should be linked to measures that guarantee the crops are grown to satisfactory environmental standards.

The significance of the proposed measure, in terms of which biomass supply chains would be favoured and absolute climate benefits, needs to be considered. These will depend on the energy market structure, other incentives aimed at different fuel chains and the extent of the energy crop payment scheme.

Country case studies

Case study1: Germany

In 2001, Germany bioelectricity sector accounted around 1271 registered installations with a combined capacity of ~700 MWe producing ~2.4 TWh electricity from biomass[4]. Installations larger than >20 MWe are expected to be favoured in the future as a result of the Renewable Energy Resource Act. This sector is set to further increase as a result of strong linkage between energy policy and climate protection programmes and economic incentives, making biomass an increasingly attractive renewable option. Key policies include:

- *Production support* through the renewable energy sources act (EEG) of March 2000, which builds on the successful feed-in law (StrEG) of 1991 and includes a guaranteed price for renewable electricity starting at ~€ 0.1/kWh, reducing gradually from 2002. Clarification of the required definition of biomass and approved processes are given in the biomass ordinance (BiomasseV) of June 2001. Ecological tax reform, as a result of inter-ministry efforts to reduce CO_2 in 2000, introduced a step-wise increase in the prices of fossil fuels.

- *Investment support* and cheaper credit through low interest loans from institutions such as the Kreditanstalt fuer Wiederaufbau (Credit Institute for Restructuring) and the Deutschen Ausgleichsbank (Federal service and special purpose bank for SME entrepreneurs in Germany) have been offered through a market incentive programme since 1999. Limited grants are available through various federal and regional institutions. Support targeted at renewable energy and rational use of energy has risen slowly over the last ten years with € 100million paid out from Federal sources in 2000. Regional efforts provide an additional 25–30 %.

- *Market introduction measures* including credit guarantees administered through the regions received financial support in 2001 of ~€ 39.1 million, those at a federal level totalled ~€ 91.5 million. EU funding also contributes at a rate of about 35 % for approved demonstration projects. Targeted support for R&D, always conditional on high quality results, has proven well placed and a thriving home market and high quality technical capabilities are a strong basis for increasing exports.

- *Biomass Information Centres*[5] also provide information on technologies, available resources and sources of financial support. However, there is at present no direct support aimed at the establishment of energy crops. Other measures at both federal and regional level, including standards work by the VDI (German Society of Engineers) are aimed at removing the non-technical barriers to the use of biomass for electricity generation.

Two future trends are expected for bioelectricity. Firstly, an increase in wood waste[6] fuel use is expected, mostly in installations with over 20 MWe capacity, though the number of projects actually realised may be constrained by the lack of availability of suitably priced biomass. Secondly, biogas will be used more extensively, sourced primarily through anaerobic digestion of sewage.

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4) Source: Renewable Energy in Germany, 2001 Update (Regenerative Energien in Deutschland Stand 2001) Kaltschmitt, M., Merten, D. *et al*, Institut fuer Energetik und Umwelt gGmbH.
5) Hosted by the "Institut fuer Energetik und Umwelt" in Leipzig (www.biomasse-info.net)
6) More wood is likely to become available in 2005 when a regulation takes effect to ban the disposal of wood to landfill sites.

Case Study 2: Finland

Finland's extensive forests, totalling 24.4 million hectares, mean that it has significant *biomass resource* available as both by-product and wastes from its strong forestry, paper and pulp industries. In addition, these industrial activities utilise a good proportion of this resource as a local and highly desirable energy resource. Finland's large installed bioelectricity capacity (1300 MW) and its very high percentage of total capacity (8.1 %) show that this natural resource is being well used for bioelectricity. 50 % of Finland's population is connected to a district heating network, some of these plants use biomass co-firing, and many of the plants produce, in addition to heat, a significant proportion of the local area's electricity needs.

However the high bioelectricity figures are also testament to the outcome of many years of targeted actions by the Finnish government. There exists a political will to increase national energy security, promote the industry and to meet Kyoto targets. This has been translated into successful public support measures, including:

- *National plan*. Political will supporting bioelectricity at the highest level is reflected in the existence of a national biomass strategy, launched in 1994. It was followed by a renewable energy action plan in 1999 with targets to increase the consumption of renewable energy sources 50 % (from 3 to 6.1 Mtoe) by 2010 compared with 1995 levels. In 2001 a total of € 21m of public funding support was provided to the biomass industry.

- *Fiscal incentives*. In terms of legislative measures, liberalisation of the electricity market started in 1995 with a significant measure being the fixing of the cost of transmission to enable transparent and predictable economic planning. Finland also has a history of taxes that aid bioelectricity uptake. In 1990 a CO_2 tax on fossil fuels was introduced. This was superseded in 1994 by a combined CO_2 and energy tax based on carbon content of the fuel with an exemption for renewable energy. In 1997 taxation on electricity at distribution level was introduced with a refund for electricity from renewable sources amounting to € 0.042/kWh for biomass. Small scale <1 MW plants are entitled to reduced VAT on plant purchases.

- *R&D investment* is provided mainly through Tekes[7], Finland's national technology agency, with companies offered part-funding for research (about 50 %). Demonstration of new technology and systems and combining demonstration with research is promoted. This has assisted a thriving home and export industry especially in combustion technology and emissions control. Forestry and associated equipment is also successfully developed in Finland. For example, the Tekes wood energy technology programme[8] (1999–2003, with Tekes funding € 11.5 m out of a total of € 35 m) is currently working to reduce the cost of wood chip supply. This will be achieved by introducing mass-produced, purpose-designed technology to enable transport of baled bundles instead of chips, with eventual chipping at the user site (i.e. the power plant). The overall aim of the programme is to increase the use of wood chips fivefold primarily in power plants, and to improve the quality of those wood chips.
- *Information programme*. Finland has several information/education mechanisms including regional energy management agencies. These operate on a local level to increase the use of renewable energy sources, energy conservation and energy efficiency through promotion of new energy-saving technologies and methods and the exchange of experience and know-how[9].

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7) Tekes website: www.tekes.fi
8) The Tekes Wood Energy Technology programme, concentrating on logging residues and small-sized trees: http://akseli.tekes.fi/Resource.phx/enyr/puuenergia/en/index.htx
9) For example: www.vsenergiatoimisto.fi

Case Study 3: Sweden

Many factors have influenced the success of biomass use for electricity including Sweden's cold climate, well-established urban district heating, vast areas of forest and correspondingly large related industries. Commitments to phase out nuclear electricity mean discussions with industry are currently ongoing about the pace of the phase out plan for each of the 11 plants left in operation.

Replacement sources are envisaged to come from renewables (along with increased CHP and improvements in energy efficiency) but the sheer scale of the challenge has, amongst other factors, slowed progress. Nevertheless bioelectricity does seem to have benefited from this move away from nuclear power. Currently ~24 of the ~150 biomass fired district heating plants operate on a CHP basis and combined with many industrial biomass fired plants give the current 1508 MWe installed bioelectricity generating capacity. This represents approx. 4.6 % of total capacity.

Despite being allowed slight CO_2 emission increases under Kyoto (to allow decommissioning of its nuclear reactors), a domestic target is in place to reduce emissions by 50 % with 2 % annual reduction by the period 2008–2012. Sweden has two key policy objectives that may lead to increased bioelectricity in the future: the phasing-out of nuclear power and meeting EU renewables targets – an increase from ~50 % to ~60 % energy from renewables by 2010. Sweden also has a policy objective to replace electric domestic heating with CHP or district heating, and especially with biomass fuelled CHP district heating.

Measures designed to stimulate this area include studying options for an emissions trading scheme to start in 2003–4 and green electricity certificates trading, which is expected to begin in earnest in May 2003 after Parliament finalises a requirement of at least 7.4 % renewable electricity.

Liberalisation has provided straightforward access to the electricity market for small producers, with utilities obliged to purchase from small generators at agreed prices. Temporary price support of € 0.009/kWh was available and small generators can also obtain discounts on grid-use costs.

Biomass electricity plants are exempt from three major taxes: energy tax, CO_2 tax and SO_x tax. With CO_2 tax currently at approx. € 0.39–0.64/kWh[10] and SO_x tax currently at approx. € 0.11–0.21/kWh, this is a sizeable incentive. A number of coal fired CHP plants have changed to fire biomass as a direct result of the introduction of these taxes and their effect on the cost of coal fired CHP. In addition small generators (<25 GWh/year generated using all fuels) are exempt from a NO_x levy (currently at approx. € 4.65/Kg_{NOx}). Investment grants are available for up to 30 % of investment in biomass-fired CHP.

Government funding for biomass RD&D currently amounts to an annual SEK 400 million (€ 36 million) with funding also coming from electricity companies and other industries. Areas being targeted include fuel production and supply, combustion and other conversion technologies, and ash recycling.

Biomass use is well established and accepted in Sweden. Farmers and forest companies are supportive due to the extra income potential, wood users e.g. sawmills benefit from an additional market for wood waste. In addition, high levels of environmental awareness in Sweden, especially regarding alternatives to fossil fuel energy sources make biomass and bioelectricity relatively acceptable to the public.

10) Tax rates for industry.

Case Study 4: USA

The US bioelectricity industry is primarily located in the Northeast, Southeast and West Coast regions, representing a $15 billion investment and 66,000 jobs. It is based on wood and forestry residues. 26 utility-owned plants are currently operating, of which the largest is the 75 MW Bay Front Plant owned by Northern States Power Co. in Wisconsin, which uses wood and wood waste.

At federal level, bioelectricity growth has been initially stimulated by the Public Utility Regulatory Policies Act of 1978 (PURPA) (part of the Carter Energy Plan), which was an energy conservation measure in reaction to escalating oil prices. It opened up the market for Qualifying Facilities (QF)[11] to sell renewable or cogenerated[12] electricity to utility companies at a price[13] usually favourable to the QF. Whilst PURPA resulted in a significant growth in biomass fired plants in mid-1980s and 90s, there have also been problems with the implementation of the act, partly due to discretion given to States. Typical problems include very long contract periods with no opportunities for renegotiation, price floors, definitions of surplus power, single buyers and access to transmission. PURPA is still in force but there have been many attempts to both amend and repeal the act. More recent federal measures to support the deployment of bioelectricity markets include:

- *National plan*. President Clinton's Executive Order 13134 of August 1999 provided a mandate for DoE, USDA, EPA, NSF[14] and others to work together to co-ordinate efforts in biobased products and bioenergy that were previously disjointed. He set a goal of tripling use of biobased products and bioenergy by 2010. An interagency council must formulate an annual plan to implement the order, reviewing legislation and agency regulations, incentives and programs to ensure that they are being used effectively to promote the use of bioproducts and bioenergy. The programme is driven by a growing acceptance of the need for change in electricity generation, energy security, realisation of massive biomass resource availability and a drive to create a world class industry sector

11) QFs are either small-scale producers of commercial energy who normally self-generate energy for their own needs but may have occasional or frequent surplus energy, or incidental producers who happen to generate usable electric energy as a byproduct of other activities.
12) As a byproduct of other industrial processes.
13) The price is based on a concept of avoided cost cogenerated energy which is intended to prevent waste and improve both efficiency and cleanliness by ensuring that fair market prices are paid for energy generated from renewable resources.
14) Department of Energy (DOE), United States Department of Agriculture (USDA), Environmental Protection Agency (EPA) and National Science Foundation (NSF).

- *R&D Programme*. The Biomass Program is a good example of the integration of many types of policy, and is part of the activities of the US DoE through its Office of Energy Efficiency and Renewable Energy. This program works on the Biomass Research and Development Initiative, co-ordinating and accelerating all federal biobased products work and work on bioenergy in accordance with the Biomass Research and Development Act of 2000[15] which gave the legislative basis for the programme. DoE sponsored technology R&D is currently focussing on small modular biomass power (1 kW–5 MW) and gasification for biomass derived H_2. Past work has been on cofiring with coal.

- *Fiscal incentives* include a federal tax credits of 1.5¢/kWh for "closed-loop biomass"[16] bioelectricity; the Renewable Energy Production Incentive[17] of 1.5¢/kWh, adjusted annually for inflation; the Alcohol Fuels Credit: up to 60¢/gallon for converting biomass into ethanol or methanol; accelerated depreciation of bioelectricity plant over 5 years and tax-exempt financing aimed at improving access to investment funds.

- *Information campaign*. Part of the work of Biomass programme is also informing the public of the benefits for America such as improving rural incomes, job creation and balance of trade. Information about policies is readily available through the Biomass Program website[18]. The EPA's landfill methane outreach programme (LMOP) works to disseminate information, put potential partners in contact and promote landfill gas (LFG) as a biopower fuel[19]. The EPA also runs the AgSTAR programme on anaerobic digestion of manure collected at confined animal feeding operations, producing fuel for bioelectricity.

At *state level*, Renewable Portfolio Standards are already in place in certain states e.g. California: Utilities are required to increase the use of renewable energy by 1 % p.a. until 20 % of retail sales are generated from renewables. Systems benefit charges are a state level method of collecting funds from electricity customers usually through a small cents/kWh charge collected through the utility bill to provide a clean energy fund. Eligible projects for "public benefit" apply for the funds, which have been setup in California, Connecticut, Illinois, Massachusetts, Montana, New Jersey, New Mexico, New York, Pennsylvania, and Rhode Island. Indications show that biomass projects appear to be successful in accessing funding[20].

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15) Short title for The National Sustainable Fuels and Chemicals Act.
16) A narrow definition of biomass as fuel where a crop is grown specifically for energy production. Talks are underway to extend the definition to open-loop biomass.
17) 1992 Energy Policy Act.
18) www.eren.doe.gov/biopower/policy/index.htm
19) The US is historically strong in this area, in the early 90s, USA was the only IEA country utilising gas from biomass for electricity.
20) www.mtpc.org/Grants_and_Awards/Awards/unsol/awards.htm#gpp and www.eren.doe.gov/buildings/state_energy/pdfs/a3_benecharges.pdf

3. Bioelectricity potential and benefits

This section provides an assessment of the global and OECD resource base for bioelectricity. An indicative resource potential is estimated, based on assumptions relating to the availability of land and agricultural, forestry and livestock residues. The potential is based on the modelling of resources that could be practically recovered or grown for biomass energy, however, it does not account for competing uses for biomass resources, for stationary of transport applications for example.

3.1 Biomass resources

Biomass resources can be divided into three major categories: i) residues (crop residues, animal dung, and forest felling and saw-mill residues) which arise from non-energy production activities such as food and fibre production; ii) dedicated biomass production for energy ('energy plantations') which can be either agricultural or forestry-based and consist of annual agricultural crops and short rotation tree plantations; and iii) utilisable fuelwood from multi-purpose forests (currently existing and newly[21] created).

These resource categories are dependent on the quantity and quality of land committed to biomass production for food, industrial and energy crops and forestry, and the management practices followed. The OECD has about 1,544 Mha of crop, forest and woodland, of which about 460 Mha are cropland. Global crop, forest and woodland area is about 5,670 Mha, of which 1,501 Mha are cropland (FAOSTAT 2003).

An additional biomass resource arises from the build-up of wood that is currently occurring in the northern-hemisphere's forests. This 'build-up' is resulting from an in-balance between the rate of growth (forest area and productivity) and harvesting in the managed forests, with harvesting significantly lower than growth. It is estimated by Pollard (2004) that for East and Western Europe, Scandinavia, the Mediterranean and NW Russia, the total net annual forest increment is equal to 880 Mm^3. Of this, only about 420 Mm^3 is currently being harvested commercially, and therefore, a significant share of the remainder (460 Mm^3) might be available for sustainable bioenergy production. This data is corroborated by Nabuurs *et al.* (2003)[22] which estimates that a sustainable supply of just over 200 Mm^3 per year of wood might be available in addition to forecast commercial felling, containing about 1 EJ of primary energy.

21) D.Pollard. Surplus Net Annual Increment in Northern Hemisphere Forests. Pers. Comm. 18/feb/2004.
22) Nabuurs, G.J., Paivinen, R., Pussinen, A., and Schelhaas, M.J. Development of European Forests Until 2050. ISBN 900412311 3. Leiden; Boston; Colone; Brill: Koninklijke Brill NV. European Forest Institute Research Report; No. 15:1-250, 2003. Forecast for Europe (30 countries) up to 2050.

Residues

The energy potentially available from residues, both globally and for the OECD, is generally significantly underestimated. Conservative estimates for global and OECD technical potentials for energy production from crop, forestry and animal residues are provided in Table 4. Biomass energy estimates from residues are based on the energy content of potentially harvestable residues based on residue production coefficients applied to FAOSTAT data on primary crop and animal production. Forestry residues are calculated from FAOSTAT 'Roundwood' and 'Fuelwood and Charcoal' production data again using standard residue production coefficients (see Table 15 and Woods and Hall, 1994, for more details).

Residues are used in a number of OECD countries for energy production, primarily for heat and/or electricity generation. Much of the development of bioelectricity generation in OECD countries has been based on the exploitation of residues, in particular from the forestry and wood processing industries in the USA and in European countries such as Finland, Sweden, Denmark and Austria.

Agricultural residues, primarily straw, are already used in modern conversion facilities for energy production in some OECD countries e.g. the UK. The rationale for the development of residue-based bioenergy industries is that the feedstock costs are often low or even negative where a 'tipping fee' is commanded. Globally, about 50 % of the potentially available residues are associated with the forestry and wood processing industries, about 40 % are agricultural residues, e.g. straw, sugarcane residues, rice husks and cotton residues, and about 10 % animal manure. The quantification of residues remains uncertain and the values provided should be taken as indicative rather than as a precise quantification of the resource.

Globally about 70 EJ may be available from residues, of which 24 EJ in OECD countries. However, there is considerable variation in the potential energy available from residues amongst OECD countries. This variability in the resource base extends to the share of crop, forest or dung residues available, as can be seen from the country-by-country assessment provided in in the appendix.

Table 4: Energy potential from residues (EJ)

Area	Crop	Forest	Dung	Total
World	24	36	10	70
OECD of which:	7	14	2	24
North America	4	9	0.7	14
Europe	3	5	1	9
Asia Pacific/Oceania	0.8	0.8	0.4	2

Rounding errors may mean that columns do not add, see Table 15 for details.

Table 5 provides an indication of the biomass energy potential that would derive from exploiting 25 % of the biomass residue's technical potential and its relative contribution to current energy consumption and to the IEA reference case scenario for total energy demand in 2020. The technical potential for energy available from residues represents close to 3 % of OECD countries primary energy consumption, but it varies greatly from country to country, ranging from less than 1 % for the few OECD countries with the least potential to over 5 % for the 8 OECD countries with the largest potential (Table 15). The energy potential associated with residues could contribute up to about 6 % of current OECD electricity consumption.

Although the 24 EJ of energy potentially available from residues in OECD countries and the 70 EJ globally, could provide a significant contribution to biomass-based primary energy provision, they fall significantly short of the biomass energy contributions anticipated by most energy scenarios (see section 4.2.). Therefore, whilst the development of an initial bioelectricity industry can be based on residues, dedicated energy crops will be needed to provide the greater share of biomass-based primary energy if biomass is to fulfil the role projected by most energy scenarios. The potential for energy crops to meet this demand is discussed below.

Table 5: Potential contribution of biomass energy from residues by 2020

Area	Biomass potential based on 25 % residue use (EJ)	Share of primary energy (1998)	Share of electricity consumption (1998)[23]	Share of primary energy (2020)	Share of electricity consumption (2020)
World	17.5	4 %	12 %	3 %	8 %
OECD of which:	6.0	3 %	8 %	2 %	6 %
North America	3.3	5 %	9 %	3 %	7 %
Europe	2.1	4 %	9 %	2 %	6 %
Asia Pacific/ Oceania	0.5	4 %	4 %	2 %	3 %

23) Assumes a 35 % conversion efficiency to electricity.

Energy crops

Energy crop[24] production is intensive in its land use requirement. The potential land area and share of land that could be dedicated to energy crops will vary widely for different countries. However, sufficient areas of cropland and unexploited plantation forest and woodland are likely to be available in most countries to provide a significant biomass energy contribution. The technical potential for energy provision from dedicated 'energy crops' including short, medium and long rotation forestry is indeed large. For example, half the global cropland area would be sufficient to satisfy current primary energy needs based on a global average yield of 10 dry tonnes of biomass per hectare. Future biomass energy production will be sited on a combination of cropland, forest and woodland and yields will vary for different land types and climates.

Surplus food production in OECD countries has lead to cropland areas being left fallow. In the European Union about 15 % of cropland is currently under voluntary set-aside and not used for food production. Also, the UNECE temperate and boreal forest resource assessment (TBFRA) indicates that only about half of the wood from forestry available for wood supply (FAWS) is exploited. Hence, there is a significant potential for using crop, forest and woodland for biomass energy.

Biomass energy estimates from dedicated plantations are based on assumptions on land available for non-food biomass production and an average yield for energy plantations. Table 6 provides an indication of the biomass potential that would derive from dedicating 5 % of OECD crop, forest and wood land to the supply of raw material for biomass energy. The calculations assume an average yield of 10 air dry tonnes of biomass per hectare. The biomass energy potential from residues and energy crops calculated above represent a simplified 'bottom-up' approach by which the biomass energy potential is derived from an analysis of each country's resource base.

Table 6: Potential contribution of biomass energy from energy plantations by 2020

Region	Potential based on 5 % of crop, forest and wood land and average 150 GJ/ha yield(EJ)	Share of primary energy (1998)	Share of electricity consumption (1998)[25]	Share of primary energy (2020)	Share of electricity consumption (2020)
World	42.5	12 %	29 %	6 %	17 %
OECD of which:	11.6	5 %	12 %	3 %	9 %
North America	7.8	7 %	16 %	5 %	13 %
Europe	2.2	4 %	7 %	2 %	6 %
Asia Pacific/ Oceania	1.5	4 %	10 %	5 %	7 %

24) 'Energy crops' for bioelectricity are likely to include perennial herbaceous energy grasses e.g. miscanthus, reed canary grass, switchgrass, etc.) and woody (short, medium and long rotation) crops.

5) Assumes a 35 % conversion efficiency to electricity.

3.2 Setting a target of 15 % bioelectricity by 2020

Biomass features strongly in virtually all the major global energy supply scenarios. For instance, the IPCC Third Assessment Report 'TAR' (2001) estimates that by 2025 between 5 and 21 EJ/yr of primary energy will be supplied by biomass in OECD countries and between 9 and 31 EJ/yr by 2050 (see Table 7 and Table 8). However, the development of scenarios for biomass energy contribution is complex due to the range of biomass energy end-uses and supply chains and the competing uses of biomass resources.

The figures in Table 8 are based on the estimation of future global energy needs and the determination of the related primary energy mix, including biomass energy share, based on resource, cost and environmental constraints (i.e. a 'top-down' approach). In order to achieve realistic scenarios for biomass energy use and its role in satisfying future energy demand and environmental constraints, it is important to reconcile 'top-down' and 'bottom-up' modelling approaches. Therefore, this study assesses the likely contribution of bioelectricity to power consumption by 2020 on the basis of realistic assumptions regarding residues and land availability.

Table 7: IPCC TAR scenario for biomass contribution to primary energy in the OECD (EJ)

Scenario	Biomass Primary Energy Supply	
	2025	2050
IPCC (2001) – TAR	5–21	9–31

Significant areas of cropland are becoming available in order to reduce agricultural production surpluses in OECD countries, particularly in the EU and USA. There is a pressing need to find alternative economic opportunities for the land and associated rural populations, and biomass energy systems could provide such opportunities. The establishment of biomass energy systems is often characterised by relatively long lead times, in particular in the case of energy crops. There is an important strategic element in developing a biomass energy industry which needs to address the introduction of suitable crops, logistics and conversion technologies. This may account for and involve a transition over time to more efficient crops and conversion technologies.

Table 8: Scenarios of potential biomass contribution to global primary energy (EJ)

Scenario	Biomass Primary Energy Supply		
	2025	2050	2100
Lashof & Tirpack (1991)	130	215	
Greenpeace (1993)	114	181	
Johansson *et al* (1993)	145	206	
WEC (1994)	59	94–157	132–215
Shell (1996)	85	200–220	
IPCC (1996) – SAR	72	280	320
IEA (1998)	60		
IIASA/WEC (1998)	59–82	97–153	245–316
IPCC (2001) – TAR	2–90	52–193	67–376

Present biomass energy use is about 55 EJ/yr.
'TAR' – IPCC Third Assessment Report, 2001.
'SAR' – IPCC Second Assessment Report, 1996.

However, the main constraints to increasing electricity production based on biomass resources in the OECD are commercial and policy barriers rather than technical barriers. Furthermore, despite the potential availability of 'excess' food production land in OECD countries, bioelectricity production systems will have to compete with a number of other potential productive uses e.g. fibre, liquid biofuels, extensive (organic) crop and livestock production, recreation, etc.

We estimate that an ambitious but realistically achievable target could consist of exploiting 25 % (6 EJ) of the potentially harvestable residues (agricultural, forestry and livestock residues) and by dedicating 5 % of crop, forest and woodland area (about 75 Mha) to biomass growth for energy.

Over a 20-year period this would require an average conversion of 1.25 Mha of land per year to energy plantations. A yield of 10 air dry tonnes per ha is considered to be an attainable average yield across the OECD region, and would provide about 10 EJ from 5 % of OECD crop, forest and woodland area. Assuming that modern biomass conversion technologies can convert biomass to electricity at an average efficiency of 35 %, the 16 EJ of residue and energy crop resource exploited would represent about 20 % of current OECD electricity consumption and 16 % of the electricity demand estimated in the IEA reference scenario for 2020.

Table 9 provides a summary of the estimated biomass energy potential achievable by 2020 and its relative contribution to primary energy and electricity consumption. The IEA reference scenario for 2020 assumes a 2 % average annual economic growth rate for OECD countries (3.1 % for the world) and an average annual population growth of 0.3 % (1.1 % for the world).

A recent study by Ecofys (2002) for WWF indicates that demand side measures could significantly reduce electricity demand by the year 2020. In the case of the European Union, electricity demand could be reduced by about 27 % by 2020 compared to a 'business as usual' scenario, which indicated an electricity growth similar to that of the IEA reference scenario.

Table 9: Summary of biomass energy potential by 2020

Region	Potential based on exploiting 25 % of residue potential and 5 % of crop, forest and wood land for energy plantations (EJ)	Share of primary energy (1998)	Share of electricity consumption (1998)[26]	Share of primary energy (2020)	Share of electricity consumption (2020)
World	59.9	16 %	40 %	9 %	24 %
OECD of which:	17.5	8 %	19 %	6 %	14 %
North America	11.3	10 %	24 %	8 %	19 %
Europe	4.4	7 %	14 %	5 %	10 %
Asia Pacific/ Oceania	2.0	6 %	13 %	5 %	11 %

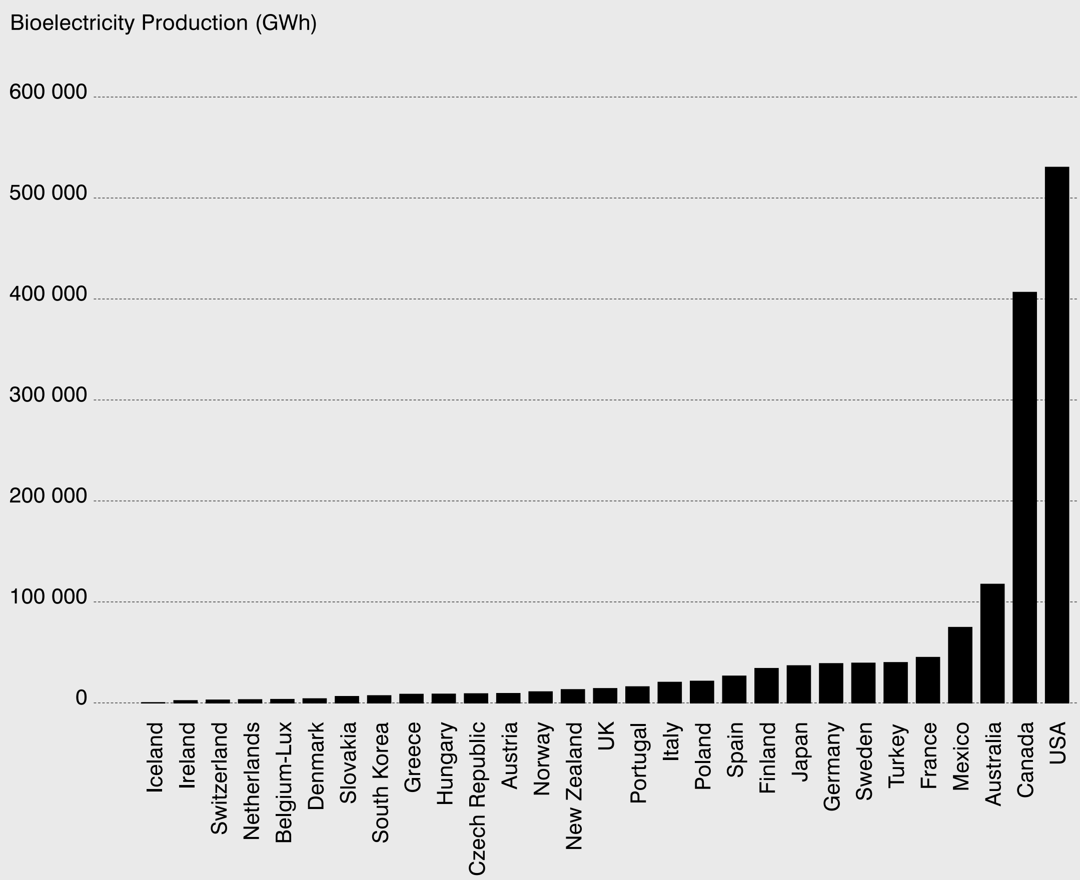
26) Assumes a 35 % conversion efficiency to electricity.

Figure 4 shows the large potential for bioelectricity production in the OECD under these assumptions, relative to current total electricity production. A small number of countries could produce 50 % or more of their current electricity demand from biomass, most countries over 10 % and a few countries less than 10 %. When compared to the current installed bioelectricity capacity of only 1 % of the total installed capacity, it is obvious that there is a very significant potential to increase renewable electricity supply from biomass in the OECD.

The estimated electricity production from biomass would require an installed capacity of over 200 GW. In fact, assuming an average utilisation factor of 60 % for biomass plants, i.e. the plants operate on average at 60 % of rated power, an installed capacity of about 370 GW is needed.

The absolute potential and potential relative to domestic electricity production is not evenly distributed amongst different countries, as illustrated in Table 9. (See Table 17 in appendix for details) However, virtually all the countries could achieve significant increases in bioelectricity production with a reasonable demand on resources. Bioelectricity could then play a major role in meeting national renewable electricity targets.

Figure 4: Potential bioelectricity production in OECD countries by 2020



3.3 The climate benefits

The potential implications of climate change may call for increasingly stringent CO_2 reduction measures and the scope for CO_2 reduction from the substitution of fossil fuels by biomass energy is very large. Bioelectricity chains can produce large quantities of renewable energy with relatively low non-renewable energy inputs to the chain (e.g. fossil fuel required to power feedstock production and transport equipment).

However, quantifying the emissions depends on the type of conversion system used. For example, in the case of biomass gasification integrated with gas and steam turbine combined cycles, the energy ratio[27] could be about 8 (15 in the case of combined heat and power production) and CO_2 emissions would be reduced by a factor of 20 compared to electricity from modern coal plants and by a factor of 10 compared to electricity from natural gas combined cycle plants.

CO_2 emissions are estimated at about 1 054 g/kWh$_e$ for modern coal to electricity fuel chains and at about 411 g/kWh$_e$ for natural gas fuel chains using combined cycle gas turbine plants. CO_2 emissions could vary widely for different types of bioelectricity chains. It is estimated that bioelectricity from forest residues results in CO_2 equivalent emissions of about 8 to 16 g/kWh$_e$ and bioelectricity from short rotation coppice in CO_2 equivalent emissions of about 44 to 109 g/kWh$_e$. Based on averages from the previous values, an indication can be provided of the CO_2 emissions that could be saved by switching from coal and natural gas to biomass.

Inductively by 2020, between 538 and 1 739 Mt of CO_2 emissions could be saved per year. As a comparison, the OECD's total CO_2 emissions for the year 1997 were estimated at 11 467 Mt CO_2 equivalent and CO_2 emissions from power generation were estimated at 4 103 Mt CO_2. The IEA reference case scenario projects total CO_2 emissions to be 14 298 Mt CO_2 and CO_2 emissions from power generation to be 5 473 Mt CO_2 by 2020.

In addition to the direct reductions in GHG emissions, the long-term establishment of biomass energy on agricultural land is likely to result in an increase in biomass standing stock, in particular in the case of woody energy crops with rotations longer than a year, which act as a carbon store (Schlamadinger *et al.*).

There is also considerable debate about energy substitution benefits that would result from biomass energy replacing fossil fuels and knock-on effects due to substitution and/or the loss of longer term biomass products such as furniture (Leach, 2002). These effects may have a major impact on the overall net carbon balances for biomass use but as yet the methodology for accounting for these activities is still being developed.

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27) That is the useful renewable energy output – e.g. electricity – divided by the non-renewable energy input to the fuel chain.

3.4 The employment potential

Employment creation in rural areas is one of the key aspects of rural development and one of the main objectives of rural development policies. The European Commission funded 'Biocosts' study (EC JOR3-CT95-0006) assessed the private and external costs of different biomass fuel chains across the European Union, and included a study of the employment effects of biomass energy systems. It concluded that the use of biomass energy has some employment benefits over using fossil fuels at a national level if there is a substantial employment generation effect from producing the biomass fuel, especially if it substitutes imported fuels. But, the greatest value of bioelectricity schemes with regard to employment lies in the fact that quality jobs could be generated where there is great need for them, in particular in rural areas where job maintenance and creation and economic growth are of issues of concern.

The 'Biocosts' study determined the direct employment generated by biomass energy schemes by a detailed analysis of the activities involved at each stage of the fuel chain. Indirect employment effects on other sectors of the economy have also been calculated based on input-output analysis. Direct employment associated with bioelectricity fuel chains is estimated to range between 0.19 and 0.32 person-hours per MWh of bioelectricity generated for residues and energy crop based fuel chains. Based on these values, it is possible to provide a rough indication of the labour that could be needed to achieve the suggested target of 15 % bioelectricity, corresponding to over 200 GW of installed bioelectricity capacity by 2020. The total labour requirement to 2020 could be somewhere between 200,000 and 320,000 full time equivalent jobs. If indirect job creation were considered, total employment generated could be in excess of 400,000 full time equivalent jobs.

3.5 Issues affecting bioelectricity penetration

Converting 75 Mha out of the 1,544 Mha of crop, forest and wood land in OECD countries over the next 20 years for biomass energy production is an ambitious, but realistic target that should not entail significant issues in relation to land-use, resource competition and environmental pressure if suitably managed. Also, the exploitation of 25 % of technically recoverable agricultural, forestry and livestock residues is estimated to be a commercially and environmentally viable proposition. However, biomass energy projects must be carefully sited and potential environmental impacts assessed in the local and regional context. The development of efficient and environmentally sound fuel chains is key to the successful development and dissemination of bioelectricity.

National strategies need to build on local agricultural and forestry resources (e.g. forestry industry) available and be integrated with the energy services needed (e.g. combined heat and power). A number of countries are already developing bioenergy industries which reflect the underlying residue resource base and the need to supply specific energy services, such as the use of forestry residues for district heating and combined heat and power in Sweden. National policies will have to reconcile the local availability of resources with national targets and competition for the resources.

There are a number of environmental advantages that could arise from the sustainable production of biomass for electricity (see section 5). These provide a powerful argument for accelerating the introduction of biomass energy in virtually all OECD countries.

4. Bioelectricity economics

Costs of electricity from biomass vary widely because of the variety of biomass sources, conversion technologies and logistics associated with different biomass fuel chains. Nevertheless, some indication of costs, relative importance of different stages of the fuel chain and cost reduction potentials can be provided for different fuel chain types.

4.1 Biomass feedstocks costs

The cost of biomass fuel supply depends on the cost of producing or recovering the biomass feedstock and costs incurred for its transport and pre-processing prior to use in an electricity generating plant. Biomass feedstock costs vary widely from negative values, in the case of some residues requiring disposal, to relatively high costs in the case of some dedicated energy crops.

Wastes that have no current use (e.g. agriculture waste and organic fractions of municipal solid wastes) and which require some form of disposal are available at negative cost. A range of residues from the agricultural products and wood processing industries (e.g. sugarcane bagasse and sawmill waste), available in concentrated form at specific sites and requiring little handling, are generally available at zero or low cost. Residues from forestry operations and the harvesting of agricultural crops (e.g. residues from tree felling and straw) generally incur costs for collection and some form of pre-processing and will be characterised by a relatively higher cost.

Energy crops have similarities with agricultural production and will generally incur the highest cost. Costs are associated with land rent, land preparation, planting, agrochemical inputs, crop management and harvesting. Also, they are very sensitive to yields and these are affected by land quality, species selection and crop management techniques. The price of biomass feedstocks will generally depend on their alternative uses and demand. While the recovery cost of certain feedstocks may be very low, their opportunity cost will depend on demand.

Most biomass feedstocks will require some form of pre-processing prior to delivery to the bioelectricity plant (e.g. drying, chipping, baling, pelletising and briquetting). Pre-processing of biomass may be required for a variety of reasons, to preserve or improve the quality of the feedstock, to satisfy fuel quality requirements imposed by the bioelectricity plants and to improve transport efficiency. Also, pre-processing of the feedstock at the bioelectricity plant may be required in order to make the most efficient use of the fuel. Fuel standardisation is an important step in ensuring that suitable quality biomass fuels are delivered to bioelectricity plants.

Biomass fuels are characterised by a lower energy density compared to solid and liquid fossil fuels. The cost of transporting biomass fuels is, as a consequence, relatively high and transport distance plays an important role in biomass fuel economics, particularly road transport. Appropriate transportation methods will depend mainly on distance, but also on the transport infrastructure available and applicable regulations (e.g. maximum payload in terms of weight or volume transported).

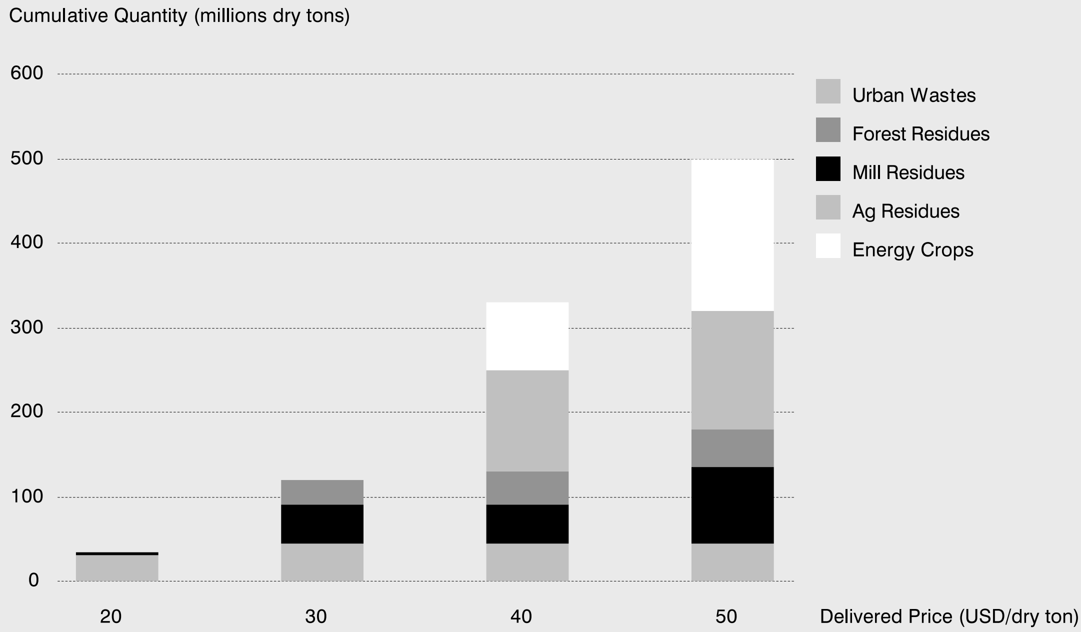


Figure 5: Biomass resource availability estimates at different costs | Source: ORNL

Road transport may be suitable only for relatively short distances (<150 km). Other transportation methods, such as rail, barge and ship, would be preferred over longer distances. In general, road transportation contributes significantly to the delivered cost of biomass fuel. For example, in the case of wood chips from short rotation coppice (SRC) a return transport distance of about 60 km is estimated to contribute about 15 % to the delivered cost of the fuel. In the case of wood chips from forest residues, a return transport distance of 200 km contributes about 33 % to delivered cost of the fuel. Because of the significance of transport costs and of the relatively low present demand, biomass feedstocks tend to be used near to their place of production or recovery. However, there have been examples of long-distance transport of wood fuel, between Canada and Sweden for example.

Current average costs of biomass feedstocks from woody and grass energy crops in North America and Europe are estimated to be about € 4/GJ. Under good crop management and feedstock logistics conditions, costs can be as low as € 2–2.5/GJ. Further reductions in cost could be achieved, in particular through improvements in yields. Most residues are estimated to be available at a cost below € 2.5/GJ. In countries with important forestry industry activities and related infrastructure, such as Finland, it is estimated that wood chips could be available at a cost below € 2/GJ after a 100km transport distance. As a comparison, the international steam coal import price for OECD countries is about € 1.6/GJ and natural gas import prices range between € 1.5 and € 3/GJ.

Figure 4 provides an indication of resource availability estimates for different feedstock production and recovery cost levels in the US. The figure indicates that about 9 EJ of biomass energy may be available at a cost below € 3/GJ. This represents about 10 % of US primary energy supply and could supply about 25 % of current electricity consumption (1 dry ton = 1.1023 dry metric tonne; 1 dry metric ton of biomass has a heating value of about 15 GJ).

4.2 Bioelectricity cost

Direct combustion of biomass in dedicated plants or co-firing with fossil fuels, mainly coal, are the main routes at present for electricity production from biomass. Dedicated bioelectricity plants are usually of modest scale (<50 MWe) because of the dispersed nature of biomass supplies, their low energy density and consequently high transportation costs. But, combustion systems using steam turbine-based power generation are characterised by higher specific capital costs (€/kW) and lower efficiency at smaller scales, with the lower capacity limit for a combustion plant is estimated to be around 5 MWe. As a result, most existing plants have electrical efficiencies between 15 % and 25 % due to small scale and trade-offs between investments in more expensive equipment and efficiency reductions. In many cases, incentives aimed at bioelectricity have not promoted the use of the most efficient solution (e.g. certain fixed price schemes such as the US PURPA).

Efficiencies greater than 35 % can be achieved with state-of-the-art technology in bioelectricity plants above capacities of about 10 MW_e. An example of such plant is the 38 MW_e circulating fluidised bed combustion combined heat and power (CHP) plant in VÍ xj÷, Sweden. However, the relatively high investment costs of these systems make them generally uneconomic unless they are fired with very low cost feedstock, used in cogeneration applications or supported by suitable incentives.

Gasification technology holds promise for electricity generation at different scales. At capacities between a few tens of kW and 5 MW_e, fixed bed gasifiers coupled with reciprocating engines and small turbines could generate electricity with efficiencies of about 25 %.

At capacities above 30 MW_e, circulating fluidised bed gasifiers coupled with combined cycle steam and gas turbines could generate electricity with efficiencies between about 40 and 50 %. However, gasification systems are currently at the pre-commercial stage and demonstration projects are required to prove the long-term reliability of the technology and reduce its costs. Co-firing could allow an efficient use of biomass and favour its early uptake, with an estimated 10–20 GW co-firing potential in the next 20 years in the US. This represents roughly 1.5 to 3 % of total current US installed capacity.

The cost of electricity depends on the supply economics of biomass feedstock, power generation technology, scale of operation and the extent to which retrofit is possible in the case of co-firing or parallel-firing with fossil fuel (e.g. coal). The latter case allows for the displacement of fossil fuels at a potentially lower cost compared to dedicated bioelectricity plants depending on the retrofit requirements. Table 10 provides an indication of capital costs and efficiencies of the main bioelectricity conversion technologies. Combined heat and power operation results in a more efficient use of biomass and could contribute significantly to the economic viability of electricity from biomass.

Current bioelectricity costs from new dedicated combustion plants range between € 60 to € 120/MWh depending on the type of combustion technology used and fuel cost. However, much lower costs could be achieved in co-firing applications, where suitable quantities of biomass can be supplied to existing coal plants. In some cases, low electricity generation costs can result from refitting fossil-fuelled plants to be fuelled with biomass. Also, combined heat and power plants could generate electricity at a lower cost. It is estimated that municipal biomass CHP plants in Scandinavia can achieve electricity generation costs as low as € 30/MWh. The largest potential for cost reduction lies with gasification technologies, in part because of the efficiency gains over combustion plants.

Table 10: Capital costs and efficiencies of principal bioelectricity and competing conversion technologies

Power generation technology	Capital cost €/kWe		Electrical efficiency	Cost of electricity (2020)[b]
	2002	2020		
Existing coal – co-firing	250	250	35–40 %	€ 0.024–0.047/kWh
Existing coal – parallel-firing	700	600	35–40 %	€ 0.034–0.059/kWh
Existing natural gas combined cycle – parallel firing	700	600	35–40 %	€ 0.034–0.059/kWh
Grate/fluid bed boilers + steam turbine[a]	1500–2500	1500–2500	20–40 %	€ 0.057–0.14/kWh
Gasification + diesel engine or gas turbine[a]	1500–2500	1000–2000	20–30 % (50 kWe–30 MWe)	€ 0.050–0.12/kWh
Gasification + combined cycle	5000–6000	1500–2500	40–50 % (30 MWe–100 MWe)	€ 0.053–0.10/kWh
Wet biomass digestion + engine or turbine[a]	2000–5000	2000–5000	25–35 %	€ 0.052–0.13/kWh
Landfill gas + engine or turbine	1000–1200	1000	25–35 %	€ 0.026/kWh
Pulverised coal – 500 MWe	1300	1300	35–40 %	€ 0.048–0.050/kWh
Natural gas combined cycle – 500 MWe	500	500	50–55 %	€ 0.023–0.035/kWh

a) Smaller scale systems will be characterised by the higher costs and lower efficiencies indicated in the value ranges. Larger scale systems will be characterised by the lower costs and higher efficiencies indicated in the value ranges.
b) 15 % discount rate; biomass fuel cost between € 2 and € 4/GJ except for digestion and landfill gas plants where fuel cost assumed to be zero; coal cost € 1.6/GJ; natural gas cost between € 1.5 and € 3/GJ. The cost of electricity is calculated for supply of electricity only and the supply of combined heat and power could reduce the electricity cost significantly.

Co-firing and dedicated modern combustion systems are commercial technologies which could see a rapid uptake in the next years fuelled mainly with residues streams from the agricultural and forestry sectors. Energy crops could begin to play an important role within the next five to ten years and disseminate rapidly thereafter. Small-scale gasification systems could see a rapid uptake in the next years, in particular in wood chip fuelled combined heat and power applications and certain industrial applications. Large-scale gasification systems could achieve commercial status in the next five to ten years and a rapid uptake may result thereafter. Systems fuelled with agricultural and forestry residues and energy crops will represent the bulk of bioelectricity production and will be complemented by a number of other sources, such as electricity from sewage gas and sludge.

Future bioelectricity cost from dedicated plants fuelled with energy crops could be as low as € 50–60/MWh. Its cost is likely to remain higher than coal and natural gas fuelled options, though the cost difference would diminish with time. Bioelectricity could however be competitive with fossil fuelled options when economic benefits of its decentralised nature and environmental benefits are taken into account. For bioelectricity to become widespread, it may require support in the order of € 10 to € 40/MWh. The way support is provided to biomass fuel chains will be crucial to their development.

5. Bioelectricity and the environment

Bioelectricity has a major role to play in an environmentally sustainable energy future. Nevertheless, bioelectricity schemes must be designed to minimise potentially negative environmental impacts and enhance positive ones. Biomass is produced using widely varying strategies related to site-specific parameters, the scope of which makes it difficult to provide more than general guidelines or principles.

The evaluation of environmental impacts arising from bioelectricity production is highly dependent on the resource used, location of the fuel chain, the system being replaced for both the production of electricity and the supply of biomass, and the technologies used throughout the production and conversion chain. Below, we focus on two streams of biomass feedstocks that can be used for electricity production:

- Residues (agricultural e.g. straw, forestry and animal e.g. manure)
- Energy crops (e.g. short rotation coppice, longer rotation forestry and energy grasses)

Proper regulation and guidelines should ensure that bioelectricity schemes maximise the social benefits and that the social benefits are recognised in economic terms. They must also ensure that negative impacts are minimised and kept within safe limits. It is essential that strategies for sustainable biomass growth be developed at a regional level. Despite the focus on potential negative impacts in this section, properly planned and implemented bioenergy systems are likely to have positive environmental impacts.

5.1 Environmental issues

The use of biomass for energy has effects on all the environmental media i.e. soil, water and air. In addition, these effects may have impacts on human and animal health and welfare, soil quality, water use, biodiversity and public amenity. These impacts arise from each of the individual stages of the biomass energy fuel chains.

Wastes as biomass feedstocks

A major problem that arises in quantifying environmental impacts from bioelectricity is that there is no universally accepted definition for ‘biomass’ in terms of its use for energy provision. In addition, very different impacts are likely to arise depending on which category of biomass feedstock is used and which technologies are used to convert the biomass to useful energy. Contamination with non-biomass or modified biomass streams also represents a particular problem as, even in very small quantities, these contaminants can lead to measurable toxic emissions and health hazards.

The use of waste streams e.g. sewage sludge, recovered domestic and municipal waste and construction timber are particularly prone to contamination. Separation of the biodegradable and non-biodegradable fractions and the monitoring of waste are essential to sustainable waste management and waste-to-energy solutions. Several options, including anaerobic digestion, are available for treating and recovering energy from biodegradable waste. Energy crops and residues (agricultural, forestry and animal manure) can be kept relatively free from such contamination.

Residues as biomass feedstocks

Residue-based biomass fuel production should not result in any significant impacts if suitably managed. However, when agricultural and forestry residues are removed from the field, care must be taken with regard to soil quality and biodiversity issues in determining the amount of residues removed and the practice followed in doing so. Over-exploitation of agriculture and forestry residues and/or removal of too much leaf material at harvest has been shown to reduce soil organic matter leading to soil degradation and declining soil-carbon levels.

The nutrient content of the soil is critical for two reasons: i) the soil-based nutrient reserves are exploited by plants in order to grow, and ii) the rhizome (living matter in the soil) is also dependent on nutrients for biological activities such as growth and degradation of the detritus and therefore, the recycling of nutrients. A functioning rhizome is correlated with good soil organic matter contents which in turn promotes good soil structure, water and nutrient retention and biodiversity. Nutrients can be removed from the soil, either by physical removal of the plant mass (e.g. human or animal harvesting) or by leaching when the soil organic matter and therefore structure is damaged. Such damage can occur physically e.g. by using heavy machinery at inappropriate periods during the year, most commonly when the soil is too wet, or by damaging the rhizome.

Energy crops as biomass feedstocks

Any significant level of biomass energy provision will need to rely on energy crops. Large-scale energy crop production is likely to have a similar range of potentially positive and negative environmental impacts as those found in existing conventional agriculture. However, because electricity production relies on thermal conversion technologies a much broader range of lignocellulose-producing crops are available compared to food crops and therefore energy crops provide a pathway for the farming sector to switch to more sustainable, less intensive perennial crops such as SRC and energy grasses (e.g. miscanthus). Research is already highlighting benefits and areas of concern with large-scale bioenergy plantations.

5.2 Environmental benefits

The potential environmental benefits and damage that could result from bioelectricity schemes need to be understood and then quantified in order to formulate effective good practice. A number of studies have begun to define the key issues in quantifying sustainable bioenergy systems. One such study, the European Commission funded 'Biocosts' study (EC JOR3-CT95-0006), provides a comprehensive comparative study of the environmental effects of different bioenergy and reference fuel chains in the European Union and is used as the basis for the discussions in this section. A second study by Greene and Martin (2002)[28], carries out a similar evaluation but specifically for bioelectricity production in the USA.

The potential environmental benefits that can arise from well-managed energy crops, particularly perennial energy crops, include:

- Providing a CO_2 neutral fuel source as a substitute for fossil fuel use.

- Lower emissions of other atmospheric pollutants, such as sulphur, compared to use of certain fossil fuels.

- Soil and watershed protection.

- Raising or maintaining biodiversity.

- Other benefits such as reduced fire risk in forestry.

These potential environmental benefits need to be considered in conjunction with other potential socio-economic benefits such as rural development and improved energy security. Despite the site-specific nature, heterogeneity and complexity of bioenergy production chains there are some general environmental considerations that can be applied to electricity production schemes from biomass in OECD countries.

Soil

It is likely that bioelectricity production will be based on the use of dedicated perennial woody and herbaceous crops and residues (forestry and agricultural). The use of perennial crops, where they replace annual crops, will result in reduced soil disturbance, greater soil cover and hence lower erosion, improved soil organic matter and soil carbon levels and increased biodiversity, particularly where the change results in a decreased application of inputs (fertilisers and pesticides).

The recycling of ash from the conversion facility back to the fields will also be an important component of nutrient management. However, care should be taken to monitor the composition of the ash as plants can selectively and actively absorb toxins, including heavy metals and ash recycling could cause such toxins to be concentrated in the bioenergy plantation's soils. This characteristic of certain plant species to selectively absorb toxins is sometimes used to rehabilitate polluted soils in a process known as phytoremediation.

28) Greene, N. and Martin, J.H. From Plants to Power Plants: cataloging the environmental impacts of biopower, Final Draft: revision G2, NRDC, Washington D.C. (2002)

The reduction in the use of fertilisers in particular will result in decreased N_2O and NH_4 (powerful GHGs) emissions and reduce or eradicate nutrient run-off into local water courses and the associated nitrification problems. Where electricity production is to be based on exploiting agricultural and forestry residues monitoring may be required to ensure that soil organic matter and nutrient levels are maintained or even improved. Improved productivities may occur with the careful exploitation of residues and fire risks can be substantially reduced, particularly in arid and semi-arid areas.

Water

The use of perennial crops and no-till buffer zones along water courses is already being actively considered as a cost effective method for reducing chemical and biological oxygen demand (COD and BOD) levels in agricultural water courses. This can occur directly as a result of decreased applications of fertilisers in vulnerable areas or as a result of the active interception and uptake ('filtering') of nutrients leached off adjacent intensively farmed land. Energy crops may allow the productive use and therefore income generation from these vulnerable areas but careful consideration is needed to ensure that biodiversity is protected or enhanced.

However, there may also be negative impacts from the introduction of energy crops on local and regional hydrology. For example, a recent study on the potential impacts of short rotation coppice (SRC) in South East England found that a significant increase in the interception and use of rainfall could result from a wide spread implementation, with potentially substantial reductions in rainfall infiltration (Lyons *et al.* 2001)[29] and negative impacts of aquifers in the region.

29) Lyons, H.A, Anthony, S.G. and Johnson, P.A. Impacts of increased poplar cultivation on water resources in England and Wales. Wellesbourne, UK:AAB. Aspects of Applied Biology 65:83-90, 2001. 0265-1491.

In addition, the safe 'disposal' of livestock manure continues to be a major issue for livestock production. Examples of commercial energy production (heat and electricity) from the large-scale anaerobic digestion of centrally collected animal manure are now well established in Denmark and Germany in particular. This method of treating livestock manure not only reduces methane emissions (see below) but also reduces nutrient leaching, primarily nitrogen and phosphorous, into water courses and decreases the levels of water-borne pathogens e.g. E. coli and salmonella.

Atmospheric (Air)

Atmospheric emissions can result from all stages of the bioelectricity production chain, but it is critical to evaluate these emissions against the reference electricity production system or alternative use of the biomass feedstock in order to gain a realistic overview of the net benefits of the bioelectricity production system. Again, a life-cycle approach is necessary as significant emissions may result from displaced activities such as fertiliser manufacture or from alternative uses. For example, GHG emissions, primarily the powerful GHG methane, that result from simply venting landfill gas to the atmosphere can be used to gain useful energy (electricity) and at the same time convert the methane to CO_2 and hence significantly reducing the GHG warming potential.

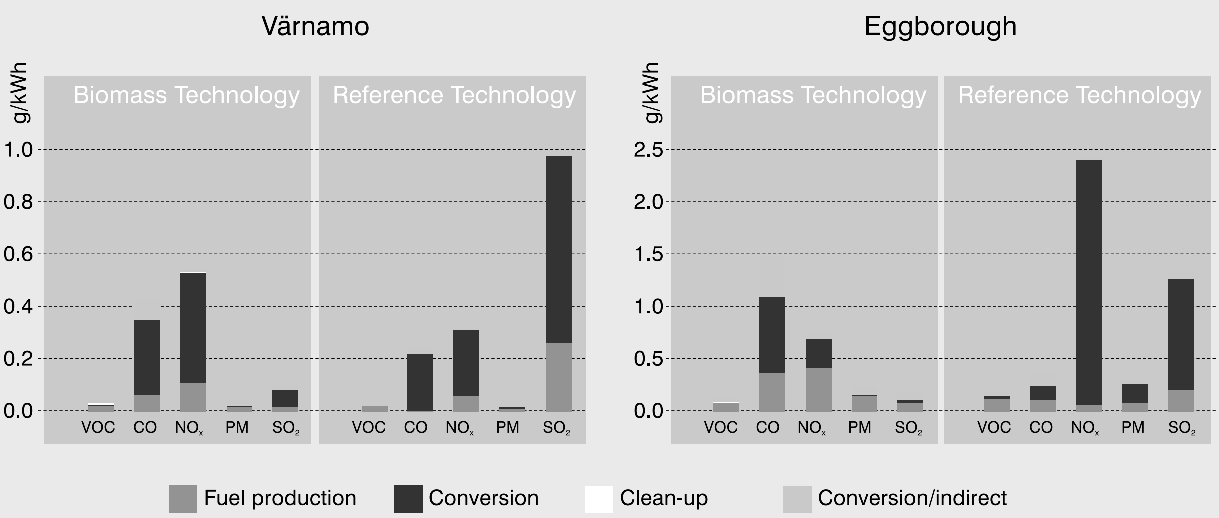
Impacts from the biomass conversion stage in power plants will depend on the conversion technology used and need to consider alternative electricity sources. The greatest environmental and economic benefits are likely to occur by substituting coal or oil-based electricity compared to substituting natural gas-based electricity. The greatest benefit from the use of biomass compared to fossil fuels is likely to be in terms of CO_2 emissions.

Benefits with regard to emissions of other atmospheric pollutants (SO_x, volatile organic compounds, CO, NO_x and particulates) will depend on the conversion technology used and comparisons with alternative electricity sources. Modern 'conventional' conversion technologies can result in very low levels of atmospheric pollutants. Figure 6 illustrates some useful results in this area. In general, with regard to emissions affecting air quality, the 'BioCosts' study concludes that:

'… the energy use of biomass can have significant environmental advantages compared to the use of fossil fuels if it is organised appropriately… While there is always an advantage of biomass with respect to SO_2, there are cases where some of the other emissions are higher for the biomass fuel cycle than for the application of fossil fuels. However, in well managed cases, the difference is either small or emissions occur at low levels.'

Specific guidance on emissions related to conversion of biomass to electricity has been developed by the Dutch utilities in collaboration with WWF as shown in section 6.3. below.

Figure 6: Specific emissions of air pollutants from the Biomass Gasification/Combined Cycle plants at VÍ rnamo, Sweden, and Eggborough, UK and their respective reference technologies (coal-based, different scales). | Source: 'BioCosts', 1998



Biodiversity

Quantifiable evaluations of the impacts on biodiversity of producing significant levels of bioelectricity are not yet possible. Again there will be both positive and negative impacts from the introduction of biomass feedstocks for energy production which will be highly dependent on both the feedstock chosen and the system being replaced. Where perennial systems replace existing intensive annual agriculture, biodiversity will generally increase, as will be the case with carefully managed exploitation of residues.

Managing biodiversity is a complex task and impacts will depend on the spatial structure of the operation. For example, a short-rotation tree plantation may be just as poor in terms of biodiversity as a cereal field. If small fields of different annual crops are substituted by large tracts of monoculture plantations, the impact on biodiversity may be unfavourable. Where existing grasslands or forests are to be replaced by energy crops negative impacts on biodiversity are likely and implementation would have to be balanced with the likely benefits arising from well-managed bioenergy.

5.3 Examples of good practice guidelines

Without careful planning, implementation, monitoring and regulation, there is no guarantee that bioelectricity schemes will be beneficial to the environment by default. For example, where biomass production takes place outside existing active agricultural or managed forest areas, careful impact assessment will be necessary. As discussed above, it is extremely difficult to envisage any benefits to the environment occurring by replacing existing nature reserves with commercial biomass production for food or fuel. However, carefully implemented biomass growth for energy could provide valuable buffer zones around such areas where good practice is followed and may be used to make existing food production more sustainable.

Examples of 'good practice guidelines' do exist, amongst the earliest of which was a collaboration between Shell International Plc and WWF that resulted in the publication of the 'Tree Plantation Review' (SIPC/WWF 1993)[30]. The continuing work by the Forestry Stewardship Council (FSC) and the International Tropical Timber Organisation (ITTO) also provides important practical guidance on the management and use of wood. Good practice guidelines for the development of short rotation coppice are available from the UK government. Forestry operators in Sweden have developed guidelines aimed at ensuring that the collection of felling residues does not result in any significant impacts and is in fact potentially beneficial.

30) SIPC/WWF. Guidelines: Tree Plantation Review. Volume 1 of 13. London, UK: Shell Publicity Services. 1993.

The Shell/WWF review used Shell's long term experience with large scale forestry plantations in developing countries to develop 'best practice' guidelines for the future sustainable management of plantations. Amongst the lessons learnt during this process were: the need for continued monitoring, the long-term active participation and involvement of local people in the management of the plantations so that they derived clear benefits, and the need to develop local varieties of trees that best suited the local soils and climatic conditions.

In addition to these more general findings, over the last decade, there has been an increasing understanding by plantation managers and owners of the potential benefits that can be derived by the maintenance of 'biological reserves' on significant proportions of the plantation area e.g. between 1/5 to 1/3 of the total area left as 'natural vegetation'. Maximum benefits are derived where riparian zones are maintained as natural vegetation, extending as 'fingers' throughout the plantation and providing corridors for animals and insects (including natural predators) to move throughout the plantation area. In addition, the location of natural vegetation along water courses and their immediate surroundings, protects the soils and may intercept nutrients and pesticides which would normally be washed off the plantation into the rivers (Woods *et al.* 2002)[31].

Often, extremely detailed guidance is required in order to ensure positive impacts on the environment from productive uses of the land. However, generally, the guidance will not need to be developed de novo for bioenergy crops as it can be developed from existing industry guidance. For example, the UK Forestry Commission has just released a guide on managing deadwood in forests (conifer and broadleaved) to enhance biodiversity, carbon storage, soil nutrient cycling, energy flows, hydrological processes and natural regeneration of trees. Although the guide reiterates the current general guidance that a 'minimum of at least 3 standing and 3 fallen pieces of deadwood or at least a volume of 5 m^3 per ha of pieces >15–20 cm diameter should be maintained, on average, across the forest area as a whole.', it's primary aim is to tailor the guidance to five sub-categories of woodlands in order to enhance the value in each of these forestry systems (Forest Enterprises, 2002)[32]. Specific good practice guidelines for the implementation of short rotation coppice have also been developed for the UK and elsewhere. For example, 'Short Rotation Coppice for Energy Production: good practice guidelines' provides guidelines, including on how to consult the local community during the planning phase as well as coppice management practice (British Biogen, 1999).

31) Woods, J., Ristori, G., D'Acqui, L.P., Pardo, M.T., Almendros, G., Kgathi, D.L., Sekhwela, M.B.M, Issufo, A., Sambane, E., Fraser, C.G.C, Watson, H., and Hachileka, E. Southern African Savannas: sustainble management of natural resources (soil, water, flora and fauna) – a synthesis study of human impacts and enhancements of economic and social benefits. EU, Brussels: EU. ERBIC18CT980277:1-100, 2002. www.savannas.net

32) Forest Enterprise. Life in the Deadwood: a guide to managing deadwood in Forestry Commission forests. Environment and Communications. Edinburgh: Forestry Commission. p.1–19. 2002. www.forestry.gov.uk/website/pdf.nsf/pdf/lifeinthedeadwood.pdf/$file/lifeinthedeadwood.pdf

Where biomass production occurs on degraded lands, practices must concentrate on the protection and then replenishment of soil organic matter that in turn will increase the water and nutrient retention capacities of the soils, leading to improved productivity. In semi-arid to arid areas water consumption for the production of biomass may mean that the greatest opportunity is provided by the most water-use-efficient crop able to grow under the prevailing climate, either with or without irrigation.

One example of good policy development, which regulates the water implications of biomass production, is the South African new regulatory policy instrument, enacted in 1998, which requires all the stream flow reduction activities (SFRAs) to obtain a license. A SFRA is defined as any land-based activity which is likely to reduce the availability of water in a particular catchment, including afforestation and crop production (Woods *et al.* 2002). These type of principles are also being developed in the European Union's new 'Water Framework Directive' where bioenergy plantations will have to be planned within the context of individual 'river basin management plans'.

Guidance on permitted emissions from biomass is being developed through collaboration between NGOs and The Netherlands government as part of the national green electricity label. The latest proposal from the NGO's (including WWF) are:

- 2 g/GJe for small particulates (PM 10)
- 30 g NO_x/GJ_e by 01-01-2006
- 30 g SO_2/GJ_e by 01-01-2006
- for all other emissions the ALARA principle should be used

These criteria are achievable in the modern biomass conversion plants, including cofiring of biomass in coal-fired power plants. However, emissions vary significantly between different combustion plants according to technology used and scale.

5.4 Principles for environmentally sustainable bioelectricity production

A number of key principles are required to ensure that biomass is produced and used effectively for sustainable electricity production as summarised below:

1. Life Cycle Analysis (LCA) principles should be applied to bioelectricity chains to ensure that any significant impacts are dealt with and benefits are captured.

2. Bioelectricity schemes need to be subject to rigorous Environmental Impact Assessments prior to implementation to address local potential negative impacts and capture value of benefits.

3. Good agricultural/forestry practices must be followed which have been developed to suit local conditions.

4. The continuous development and introduction of new varieties that are suited to local soils and climate is necessary to optimise productivity and minimise inputs.

5. Biomass production practices must protect and/or enhance soil organic matter.

6. Water use should be assessed throughout the production and conversion chain with particular emphasis on impacts on watersheds.

7. Best available conversion technologies should be used to minimise emission to air and to other environmental media. Combined heat and power (CHP) systems are preferred.

8. Ash quality from conversion processes should be monitored and efforts made to recycle ashes back to land.

Policies and regulation need to be in place to ensure that the above principles are followed. Market incentives that account for the benefits of bioelectricity should contribute towards the viability and profitability of different stages of the fuel chain. Cross-sector cooperation is a pre-requisite to both the establishment of environmentally sustainable biomass production and conversion chains.

6. Bioelectricity: the way forward

6.1 Bioelectricity as a policy priority

This study indicates that a 15 % contribution from bioelectricity to electricity generation in OECD countries is an ambitious but realistic target by 2020. The benefits could be multiple in terms of avoided environmental damage from substituted fossil fuel sources, rural development, improved energy security, and in general terms a move to a more sustainable electricity production.

Clearly, biomass will only be a component of a increasingly based on renewable resources. Provided that good practice is followed and that continued improvements in biomass production, logistics and conversion are obtained, the development of bioelectricity could be achieved with no significant environmental drawbacks and with an increasing economic viability.

A significant bioelectricity penetration will depend on the competitiveness of bioelectricity with other electricity sources and competition between alternative uses of biomass. Policies and regulations have a fundamental role to play in promoting biomass energy use, bioelectricity in particular, and in ensuring the sustainability of biomass fuel chains. Bioelectricity can contribute significantly to a number of national and international policy priorities:

- Address local, regional and global pollution issues
- Improve security of energy supply
- Stimulate employment and rural development
- Promote technological innovation

6.2 Measures required

In order to achieve a significant bioelectricity penetration, action needs to be taken to:

- Stimulate the market uptake of technically proven and commercial bioelectricity chains, and the development of a feedstock supply infrastructure.
- Stimulate the development and demonstration of advanced conversion technologies and sustainable energy plantations.
- Encourage the development of industry-wide good practice guidelines and standards for different stages of the fuel chain, as well as their implementation.
- Raise public awareness about bioelectricity.

Policy measures and other government actions, across the energy, environment, and agriculture and forestry sectors, have a key role to play in achieving the above aims:

1. Energy-related measures

- Economic incentives and mandates aimed at bioelectricity, e.g.
  - Feed-in prices with suitable price bands for different bioelectricity chains
  - Renewable Portfolio Standards with specific bioelectricity targets
- Development of regional biomass energy plans that account for local environmental characteristics and energy service needs
- Elimination of barriers to the development of decentralised electricity generation.

2. Environment-related measures

- Taxes and levies on environmental pollutants
- Carbon accreditation of bioelectricity schemes for international trading of carbon credits
- Carbon trading schemes
- Development and dissemination of good practice guidelines

3. Agriculture and forestry-related measures

- Economic incentives to energy crops with different bands according to environmental criteria and commercial status
- Economic incentives to the use of forestry products for bioelectricity
- Economic incentives aimed at rural diversification and development

4. Innovation-related measures

- Research and development on energy crops and their environmental implications
- Research and development on advanced biomass to electricity conversion devices
- Demonstration of pre-commercial energy crops and advanced combustion and gasification conversion technologies.

6.3 Towards a blueprint for bioelectricity

The proposed target of about 16 EJ of biomass use in OECD countries for electricity by 2020, equivalent to about 2,000 million tonnes of air dry biomass, implies a more than twenty-fold increase in bioelectricity capacity over a period of about 20 years. Bioelectricity capacity would increase from about 18 GW to close to 370 GW and represent about 15 % of installed capacity relative to the IEA reference case scenario for electricity capacity in 2020.

The target will rely on an extensive use of agricultural and forestry residues and energy plantations. It is estimated that roughly a third of the bioelectricity could come from residues and the rest from dedicated plantations. An additional 3.75 Mha of crop, forest and woodland area will have to be dedicated annually to energy plantations, for a total of about 75 Mha over the next 20 years.

The development of a bioelectricity industry will require early uptake of bioelectricity through commercial conversion technologies, mainly combustion-based technologies, and in co-firing applications with fossil fuels. Currently, there is little market pull in most OECD countries for biomass feedstocks for electricity generation other than landfill and sewage gas and some agricultural and forestry residues. A few countries, such as Sweden, have established markets for wood fuel for example. A market needs to be created for additional feedstock that can be derived from agricultural and forestry residues, and from an environmentally sustainable exploitation of available forest resources and land taken out of food production.

Bioelectricity growth will not happen without greater integration between energy, environment, and agricultural and forestry policies and a carefully designed mix of incentives aimed at the energy, and agriculture and forestry sectors. Dissemination programmes by which local and regional governments, project developers and other stakeholders are made aware of opportunities and good practice, and the public made aware of the benefits of bioelectricity are crucial to its successful development. The public also needs to endorse environmentally sound biomass energy projects, and NGOs can play a key role in ensuring sustainable practices are being followed and in reaching out to the public. Policy commitments need to be long-term to stimulate investment in bioelectricity and governments should be setting targets and defining policy measures that will apply throughout the timeframe considered in this document.

The support of bioelectricity is fundamental in developing sustainable, low-carbon energy options for the long-term. Bioelectricity will tend to be more expensive than other renewable electricity sources, such as wind, but is likely to compete with future costs of electricity from fossil sources, in particular if environmental costs are accounted for. The costs of bioelectricity could be lower in applications where other products such as heat and transport fuels are generated. Such applications need to be encouraged. Also, the decentralised nature of bioelectricity could result in savings and benefits with regard to electricity transmission and distribution. These need to be accounted for through proper electricity sector regulation.

While the market pull for energy crops for electricity production will need to come from the energy sector, agricultural and forestry policy needs to provide the conditions for biomass feedstock to be delivered in an efficient and environmentally sound way. Agricultural and forestry policy should be aimed at rural development by making the most productive use of land while fostering the environment and nature conservation. Food security does not appear as a matter of concern in OECD countries, and agricultural policy needs to establish a level playing field between crops, where economic incentives are based on environmental and rural development concerns. The environmental and rural development benefits of energy plantations are likely to be significant and should be more strongly reflected in incentives aimed at their development.

Continued research, development and demonstration (RD&D) related to improved crop types and management techniques and advanced conversion technologies (e.g. gasification and integration with gas turbines and fuel cells) is necessary for a gradual introduction of technically, economically and environmentally more efficient bioelectricity schemes.

Finally, there is need for greater dialogue. Governments need to establish biomass industry and stakeholder forums to identify the opportunities and needs of the industry, define targets related to research, development, demonstration and implementation, discuss barriers to market uptake and policy measures aimed at overcoming them. The outcomes of such forums then need to be translated in to action plans.

Appendix

Table 11: Installed Bioelectricity generation capacity in OECD Countries

OECD Region	OECD Country	Installed bioelectricity capacity (MW)[a]	% of Total Installed Generating Capacity[b]
OECD Europe	Austria	747.0	4.3%
	Belgium	86.0	0.6%
	Czech Republic	98.0	0.7%
	Denmark	126.0	1.0%
	Finland	1 300.0	8.1%
	France	336.4	0.3%
	Germany	474.0	0.4%
	Greece	1.0	0.0%
	Hungary	1.0	0.0%
	Iceland	0.0	0.0%
	Ireland	15.0	0.3%
	Italy	359.0	0.5%
	Luxembourg	0.0	0.0%
	Netherlands	125.8	0.6%
	Norway	35.0	0.1%
	Poland	9.0	0.0%
	Portugal	361.0	3.7%
	Slovak Republic	0.0	0.0%
	Spain	172.0	0.3%
	Sweden	1 508.0	4.6%
	Switzerland	31.96	0.2%
	Turkey	75.0	0.3%
	United Kingdom	648.0	0.9%
OECD North America	Canada	1 138.0	1.0%
	Mexico	300.0	0.8%
	United States	7 443.0	1.0%
OECD Pacific	Australia	790.0	2.0%
	Japan	1 609.0	0.7%
	Korea	479.0	1.0%
	New Zealand	105.0	1.3%

a) IEA Renewables Information 2000 (published 2002). Category used: Net installed capacity based on solid biomass and gas from biomass, except for A) Czech Republic, France, Netherlands: gross electricity generated using solid biomass and gas from biomass and 60% capacity factor, B) Canada, Korea: Capacity of Combustible renewables non-specified.
b) IEA 1998.

Table 12: OECD country renewable energy targets

	OECD Country	Target
OECD Europe	Austria	National: Renewables to account for 3% of electricity sales by 2005, 4% by 2007.EU directive indicative renewable electricity target: 78.1% by 2010 from 70% in 1997.
	Belgium	Flanders: Renewables to account for 3% of primary energy in 2004, 5% in 2010. Wallonia: Renewables to account for 5% of primary energy in 2003, 6% in 2004. EU directive indicative renewable electricity target: 6% by 2010 from 1.1% in 1997.
	Czech Rep.	Not available.
	Denmark	National: 20% renewable electricity target by end 2003, 50% by 2030. Target to use 1.4 million t of biomass in CHP plants by 2005. Energy from biomass (PJ) 2005: 84.9; 2010: 95.9; 2030: 145.7; of which electricity from biomass (PJ) 2005: 15.5; 2010: 18.0; 2030: 31.3. EU directive indicative renewable electricity target: 29% by 2010 from 8.7% in 1997.
	Finland	National: biomass strategy launched 1994 aims to increase biomass use 25% by 2005 from 1992 levels and increase the consumption of renewable energy sources in absolute terms by 50% by 2010 from 1995 levels – from 3 Mto_e to 6.1 Mto_e. EU directive indicative renewable electricity target: 31.5% by 2010 from 24.7% in 1997.
	France	National: 10% supply renewable energy by 2010, 50% by 2050.EU directive indicative renewable electricity target: 21% by 2010 from 15% in 1997.
	Germany	National: 10% renewable electricity target by 2010. EU directive indicative renewable electricity target: 12.5% by 2010 from 4.5% in 1997.
	Greece	EU directive indicative renewable electricity target: 20.1% by 2010 from 8.6% in 1997.
	Hungary	National: Increase share of renewable energy sources in total energy consumption to 55 PJ by 2010 from 39 PJ (of which 33 PJ biomass).
	Iceland	No target available. Small biomass resource. Almost all stationary energy provided by renewables, but most energy for transport and fishing fleet comes from oil.
	Ireland	EU directive indicative renewable electricity target: 13.2% by 2010 from 3.6% in 1997.
	Italy	National: Italian White Paper on Renewable energy of 1999. 25 GW of renewable electricity by 2012 (additional 8 GW compared to 1997 level). Electricity from biomass: 2002: 500 MW; 2006: 900 MW, 2008–10: 2300 MW. Biofuels: 2002: 12 PJ ; 2006: 23 PJ ; 2008–10: 39 PJ. Biomass and biogas thermal: 2002: 59 PJ; 2006: 67 PJ; 2008–10: 73 PJ. EU directive indicative renewable electricity target: 25% by 2010 from 16% in 1997.
	Luxemb.	EU directive indicative renewable electricity target: 5.7% by 2010 from 2.1% in 1997.
	Netherlands	National: Increase renewable energy to 5% of primary energy consumption by 2010, 10% by 2020 (9% of electricity consumption by 2010, 17% by 2020). Plans for 40% proportion co-firing with coal.EU directive indicative renewable electricity target: 9% by 2010 from 3.5% in 1997.
	Norway	Focus on biomass for heating (currently electricity is used as heating source) no specific targets for renewable energy as a whole or biomass.
	Poland	Not available.
	Portugal	EU directive indicative renewable electricity target: 39% by 2010 from 38.5% in 1997.
	Slovak Rep.	Not available.
	Spain	National: 12.3% renewable energy supply by 2010, compared to 6.2% in 1998. Contribution of biomass to primary energy to rise from 169 kto_e to 5,269 kto_e. Increase in installed bioelectricity capacity of about 1.7 GW. EU directive indicative renewable electricity target: 29.4% by 2010 from 19.9% in 1997.
	Sweden	National: Renewable electricity obligation and green certificate introduction in 2003 to increase renewable electricity by 10 TWh in period 2003–2010. EU directive indicative renewable electricity target: 60% by 2010 from 49.1% in 1997.
	Switzerland	Increase renewable electricity (exclude hydro) to 0.5 TWh or 1% of total electricity production, and in the case of heating energy to 3 TWh or 3% of the total by 2010. Aim to double biomass energy production.
	Turkey	Not available.
	United Kingdom	National: 10% renewable electricity by 2010 (8300 MW, including large hydro and energy from waste). EU directive indicative renewable electricity target: 10% by 2010 from 1.7% in 1997.

	OECD Country	Target
OECD North America	Canada	Increase bioenergy contribution by 100 % by 2020 compared to 1994 level.
	Mexico	Not available.
	United States	Triple use of bio-based products and bioenergy by 2010 over 2000 levels and 10-fold by 2020 (estimated to contribute about 25 % of primary energy consumption).
OECD Pacific	Australia	2 % renewable electricity generation by 2010.
	Japan	Threefold increase in the use of renewable energy sources by 2010. 330 MW bioelectricity target by 2010.
	Korea	Not available.
	New Zealand	Renewable energy target of 31 % in 2012 (50 PJ increase over current level).

Table 13: Policies and support mechanisms influencing bioelectricity in selected European OECD countries

OECD Country	General policy	Price support / market mechanisms	Subsidies, loans and tax measures
Austria	Fully liberalised market since October 2001. Renewable electricity mandate on distribution network operators (DNOs). Penalty to 'green energy fund' if renewable electricity not cheaper.	Feed-in price support varies for different LÍ nder and range between € 0.028–0.04/kWh.	Federal programme covers 30 % of eligible investment costs. LÍ nder have additional programmes.
Denmark	Fully liberalised electricity market planned for 2003. Green certificate system planned for 2003.	Utility buy-back rate for renewable electricity of 85 % of consumer price (average €cents 0.043/kWh).	Additional support from CO_2 tax reimbursement. Investment subsidies up to 30 % of investment.
Finland	Liberalisation ongoing. Grid open to all producers at fixed transmission cost. National action plan for renewables focused heavily on biomass in near term. 10 Regional energy management agencies.	Wood fuel derived electricity receives subsidy.	Investment subsidies up to 30 % of investment. Bioelectricity is exempt from the electricity tax and allocated a tax relief rate of €cents 0.3/kWh.
Germany	Fully liberalised market since 1998. Mechanisms being introduced to encourage CHP grid connection.	20 year fixed feed-in price for renewable electricity. Bioelectricity prices: €cents 10.2/kWh <500 kW, €cents 9.2/kWh 500 kW–5 MW, €cents 8.7/kWh >5 MW. 1 % annual decrease 2002+.	Market Incentive Programme provides 20 % investment subsidy on average. Efficient CHP is exempted from ecotax.
Italy	Electricity market liberalised for large energy consumers. Renewable electricity prioritised for remote grids. Renewable electricity obligation of 2 % new renewable electricity by 2002 (based on 1997 levels) and expected to increase in line with White Paper.	Green certificate market. Average price of green certificates estimated at €cents 5.5/kWh.	
Sweden	Liberalisation ongoing. Renewable electricity obligation and green certificate introduction in 2003.	Temporary support of €cents 0.9/kWh.	Investment grants of up to 25 % or a maximum of € 360/kW. Lower or no energy taxation for small-scale renewable electricity production. Sulphur taxation: biofuels exempt.
United Kingdom	Fully liberalised market. Renewable obligation from 2002 on electricity generators. Climate Change Levy (energy tax) on fossil and nuclear energy. Future Energy green electricity accreditation scheme for voluntary market. Gas and Electricity Regulator addressing distributed generation issues. Biomass co-combustion incentives end 2006.	Renewable obligation certificates (ROCs) market to meet renewable obligation of 10 % by 2010. Generator buy-out price of about € 4.5/kWh .	Investment subsidies through The Carbon Trust in progress. Bioenergy Capital Grants scheme from the DTI/National Lottery/DEFRA aimed at biomass for energy and in particular establishment of energy crops. Enhanced capital allowances on investments in energy savings.

Table 14: Policies and support mechanisms influencing bioelectricity in selected North American and Pacific OECD countries

OECD Country	General policy	Price support/market mechanisms	Subsidies, loans and tax measures
United States	Market liberalisation level varies for different States. President Clinton's August 1999 Executive Order 13134 sets goal to triple use of bioenergy and bioproducts by 2010 in the US.	Possible Federal Renewable Portfolios Standard (RPS) with penalty for non-compliance. Some States have RPS with penalties (e.g. MA, CA) others to follow (e.g. FL).	Current Federal Renewable Energy Production Tax Credit through Internal Revenue Code: 1.5 ˘/kWh for "closed-loop biomass" electricity. Renewable Energy Production Incentive: part of 1992 Energy Policy Act 1.5 ˘/kWh for bioelectricity. Farm Bill May 2002 offers assistance with loans, loan guarantees and grants. Possible grants under value added agricultural market development programme. Examples of State initiatives: Iowa (IA): property taxes, an alternative energy revolving loan program, and Iowa Energy Bank Programs. Wisconsin (WN): Energy public fund for renewable power projects.
Australia	Liberalisation ongoing. The renewable electricity target of 2 % renewable electricity generation by 2010 applies to electricity retailers.	The penalty for non compliance with target is set at Aus$ 40/MWh.	Capital subsidies for off-grid renewables, as part of Renewable Power Generation Program, with rebates up to 50 % of system cost where replacing diesel generation.
Japan	1997 Law promoting new energies. New energy defined as oil-alternative energy sources not yet widely exploited.	Renewable electricity target to be supported by "Green Credit System" designed to give electricity producers incentives to purchase renewable energy.	Businesses given financial assistance to use "unconventional" energy. Revised Energy Savings Law, 1999, calls on central/local government to provide incentives promoting "greener" products and technologies.

Table 15: Energy potential from residues in OECD countries

Country	Energy content of potentially harvestable residues (PJ)				Total primary energy[a] (including electricity) and electricity-only consumption		Share of primary energy provided by 25 % residue use	Share of electricity provided by 25 % residue use[b]
	Crop[c]	Forest[d]	Dung[e]	Total	PJ Primary	PJ Electricity	%	%
World	24 000	36 000	10 000	70 000	367 600	42 412	4.2 %	11.7 %
OECD	7 497	14 062	2 299	23 858	217 266	33 009	2.7 %	6.3 %
Australia	422	259	232	913	4 483	672	5.1 %	11.9 %
Austria	47	183	16	246	1 167	219	5.3 %	9.8 %
Belgium-Lux.	31	50	23	104	2 807	329	0.9 %	2.8 %
Canada	512	2 357	73	2942	10 281	1 948	7.2 %	13.2 %
Czech Rep.	65	155	22	243	1621	213	2.9 %	7.7 %
Denmark	70	25	20	115	874	127	3.3 %	7.9 %
Finland	31	630	8	670	1 196	293	14.0 %	20.0 %
France	469	508	136	1113	11 159	1 615	2.5 %	6.0 %
Germany	349	586	140	1107	13 919	1 873	1.9 %	5.0 %
Greece	66	32	20	118	1 275	201	2.3 %	5.1 %
Hungary	134	71	24	229	1 017	141	5.6 %	14.1 %
Iceland	0	0	1	1	67	28	0.4 %	0.3 %
Ireland	18	17	28	63	613	81	2.6 %	6.7 %
Italy	241	104	71	415	7 123	1 178	1.5 %	3.1 %
Japan	239	374	72	685	21 481	3 774	0.8 %	1.6 %
Mexico	458	214	212	883	5 755	710	3.8 %	10.9 %
Netherlands	31	15	46	92	3 575	376	0.6 %	2.1 %
New Zealand	15	135	89	239	606	105	9.9 %	19.8 %
Norway	11	141	7	159	1 116	447	3.6 %	3.1 %

Country	Energy content of potentially harvestable residues (PJ)				Total primary energy[a] (including electricity) and electricity-only consumption		Share of primary energy provided by 25 % residue use	Share of electricity provided by 25 % residue use[b]
	Crop[c]	Forest[d]	Dung[e]	Total	PJ Primary	PJ Electricity	%	%
Poland	254	283	75	611	3 736	450	4.1 %	11.9 %
Portugal	24	132	16	172	1 105	136	3.9 %	11.0 %
Slovakia	34	82	12	128	722	110	6.3 %	14.5 %
South Korea	121	65	21	208	8 132	1 027	0.6 %	1.8 %
Spain	200	201	59	460	5 328	776	2.2 %	5.2 %
Sweden	51	677	11	739	1 893	541	9.8 %	12.0 %
Switzerland	10	55	11	76	1 051	215	1.8 %	3.1 %
Turkey	351	164	107	622	3 717	422	4.2 %	12.9 %
UK	232	84	94	411	9 542	1 331	1.1 %	2.7 %
USA	3 010	6 432	652	10 094	99 183	13 670	2.5 %	6.5 %

The energy content of potentially harvestable residues is calculated from FAOSTAT data on primary crop and animal production using residue production coefficients. Forestry residues are calculated from FAOSTAT 'Roundwood' and 'Fuelwood and Charcoal' production data again using standard residue production coefficients.

a) 'Primary Energy' does not include biomass energy. Including biomass energy, total global energy consumption for 2000 is estimated at 420 EJ and for the OECD countries at 225 EJ.

b) Assumes residues are converted to electricity with an efficiency of 35 % i.e. 35 % of the energy in the residues is converted to electrical energy.

c) The "potentially harvestable residue" resource from crops is estimated using residue production coefficients. These allow rough estimates to be made of the amounts of residues available per tonne of product; thus it is effectively a by-product to product ratio. For cereals, an average figure of 1.3 has been used, i.e. for every tonne of wheat, corn, barley, etc, grain harvested there is the potential to harvest 1300 kg (air dry) of residues, primarily straw ("Potentially Harvestable"). Crop production data is derived from the FAOSTAT database (2002). Air dry cereal residues are assumed to have an energy content of 12 GJ/t. For details of the methodology see Woods & Hall (1994).

d) The "potentially harvestable residue" resource from forestry consists of tree felling residues and sawmill residues. It assumes that 40 % of the standing biomass in a harvested forest is left on site and is theoretically available for collection. The other 60 % of the standing biomass is harvested as 'roundwood' and may be used for fuelwood or as 'industrial roundwood' in sawmills. 50 % of the industrial roundwood is assumed to available as residue (calculated on a country-by-country basis). In practice, the timber industry has become more efficient and produces a range of products such as chipboard and MDF board that reduce the amount of residues available for energy.

e) The "potentially harvestable residue" from dung production is calculated by using production factors per animal per day and assuming that only 25 % of this production might be available. National animal numbers for: cattle, sheep & goats, pigs, equines, buffalo & camels, and chickens, are taken from FAOSTAT (2002).

Table 16: Energy potential from energy plantations in OECD countries

Country	Energy (PJ) from 5% cropland, forest & woodland yielding 10 t/ha.yr (150 GJ/ha)			Share of primary energy[a]	Share of electricity[b]
	Crop-land	Forest & woodland	Total PJ	%	%
World	11 261	31 293	42 554	11.6%	28.7%
OECD	3 451	8 131	11 582	5.3%	12.3%
Australia	359	801	1 160	26.0%	60.4%
Austria	11	28	40	3.7%	6.3%
Belgium-Lux	6	6	12	0.4%	1.3%
Canada	346	3 273	3 619	37.2%	65.0%
Czech Republic	25	20	45	2.8%	7.4%
Denmark	20	4	23	2.9%	6.4%
Finland	18	174	192	18.4%	23.0%
France	144	113	257	2.4%	5.6%
Germany	93	76	170	1.2%	3.2%
Greece	30	43	73	5.8%	12.7%
Hungary	40	12	52	5.3%	12.9%
Iceland	0	1	1	1.2%	1.0%
Ireland	8	3	10	0.1%	4.5%
Italy	91	60	151	0.7%	4.5%
Japan	35	190	225	4.2%	2.1%
Mexico	185	363	548	15.3%	27.0%
Netherlands	7	3	9	1.6%	0.9%
New Zealand	4	71	75	6.9%	24.9%
Norway	6	65	72	1.9%	5.6%
Poland	111	65	176	16.4%	13.7%
Portugal	21	22	43	7.6%	11.0%
Slovakia	12	15	27	3.7%	8.6%
South Korea	16	37	53	0.7%	1.8%
Spain	153	81	234	4.4%	10.6%
Sweden	22	209	231	13.9%	14.9%
Switzerland	3	8	12	1.1%	1.9%
Turkey	207	151	359	11.5%	29.8%
UK	53	16	69	0.7%	1.8%
USA	1424	2 220	3 644	3.8%	9.3%

a) 'Primary Energy' does not include biomass energy. Including biomass energy, total global energy consumption for 2000 is estimated at 420EJ and for the OECD countries 225EJ. (Based on BPAmoco.com, 2002; and internal estimates)
b) Assumes residues are converted to electricity at 35% efficiency i.e. 35% of the energy in the residues end up as electrical energy. Based on 1998 electricity consumption data.

Table 17: Potential electricity production from biomass in OECD countries

Country	1998 Electricity Consumption (GWh)	Energy Production: 25 % residues + 5 % of crop, forest and wood land at 150 GJ/ha (10 t/ha.yr) (electrical efficiency 35 %)		Bioelectricity as % of 1998 Electricity Consumption (35 % electrical efficiency)
		PJ (biomass)	GWh (electricity)	
World	14 403 050	59 945	5 828 017	40 %
OECD	9 169 300	17 538	1 705 094	19 %
Australia	186 600	1 388	134 937	72 %
Austria	60 800	101	9 825	16 %
Belgium-Luxemb.	91 400	38	3 684	4 %
Canada	541 000	4 354	423 335	78 %
Czech Republic	59 200	92	8 945	15 %
Denmark	35 400	52	5 046	14 %
Finland	81 400	360	34 976	43 %
France	448 600	536	52 075	12 %
Germany	520 200	438	42 607	8 %
Greece	55 700	102	9 937	18 %
Hungary	39 300	109	10 609	27 %
Iceland	7 900	1	105	1 %
Ireland	37 900	26	2 536	11 %
Italy	22 600	255	24 814	8 %
Japan	1 048 400	396	38 523	4 %
Mexico	197 300	769	74 738	38 %
Netherlands	104 400	32	3 149	3 %
New Zealand	29 300	135	13 115	45 %
Norway	124 300	112	10 841	9 %
Poland	125 000	329	31 959	26 %
Portugal	37 900	86	8 363	22 %
Slovakia	30 600	73	7 066	23 %
South Korea	285 200	105	10 180	4 %
Spain	215 600	349	33 957	16 %
Sweden	150 300	416	40 431	27 %
Switzerland	59 700	30	2 961	5 %
Turkey	117 200	515	50 026	43 %
UK	369 600	172	16 702	5 %
USA	3 797 300	6 168	599 653	16 %

PowerSwitch!

FROM COAL TO CLEAN

With **PowerSwitch!**, WWF challenges the power sector – the companies producing electricity and the people in finance and politics guiding their decision-making.

The power sector should become CO_2-free in developed countries by mid of this century, and make a major switch from coal to clean in developing countries.

There‘s no shortage of solutions – we‘ve just got to do it.

www.panda.org/powerswitch

WWF

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which human live in harmony with nature, by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption

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