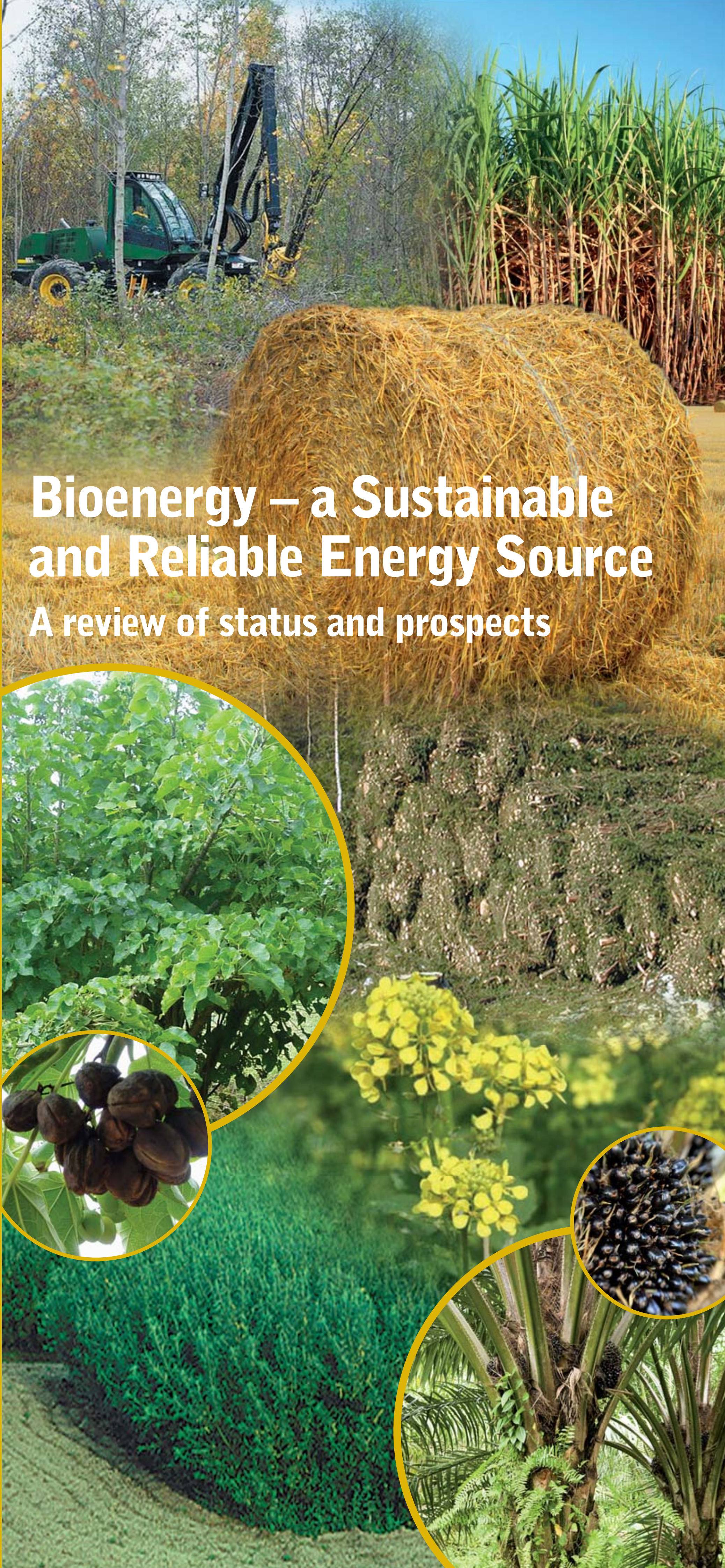
# Bioenergy – a Sustainable and Reliable Energy Source

## A review of status and prospects



This publication is the Executive Summary of a report jointly prepared for IEA Bioenergy by the Energy Research Centre of the Netherlands (ECN), E4tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht. The full report 'Bioenergy – a Sustainable and Reliable Energy Source' is available on the IEA Bioenergy website (www.ieabioenergy.com) and in hard copy.

The purpose of the project was to produce an authoritative review of the entire bioenergy sector aimed at policy and investment decision makers. The brief to the contractors was to provide a global perspective of the potential for bioenergy, the main opportunities for deployment in the short and medium term and the principal issues and challenges facing the development of the sector.

IEA Bioenergy

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# BIOENERGY – A SUSTAINABLE AND RELIABLE ENERGY SOURCE
## A review of status and prospects

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## EXECUTIVE SUMMARY[1]

### KEY MESSAGES

Bioenergy is already making a substantial contribution to meeting global energy demand. This contribution can be expanded very significantly in the future, providing greenhouse gas savings and other environmental benefits, as well as contributing to energy security, improving trade balances, providing opportunities for social and economic development in rural communities, and improving the management of resources and wastes.

Bioenergy could sustainably contribute between a quarter and a third of global primary energy supply in 2050. It is the only renewable source that can replace fossil fuels in all energy markets – in the production of heat, electricity, and fuels for transport.

Many bioenergy routes can be used to convert a range of raw biomass feedstocks into a final energy product. Technologies for producing heat and power from biomass are already well-developed and fully commercialised, as are 1st generation routes to biofuels for transport. A wide range of additional conversion technologies are under development, offering prospects of improved efficiencies, lower costs and improved environmental performance.

However, expansion of bioenergy also poses some challenges. The potential competition for land and for raw material with other biomass uses must be carefully managed. The productivity of food and biomass feedstocks needs to be increased by improved agricultural practices. Bioenergy must become increasingly competitive with other energy sources. Logistics and infrastructure issues must be addressed, and there is need for further technological innovation leading to more efficient and cleaner conversion of a more diverse range of feedstocks. Further work on these issues is essential so that policies can focus on encouraging sustainable routes and provide confidence to policy makers and the public at large.



[1]The full report 'Bioenergy – a Sustainable and Reliable Energy Source' is available on the IEA Bioenergy website (www.ieabioenergy.com) and in hard copy.

# INTRODUCTION

The supply of sustainable energy is one of the main challenges that mankind will face over the coming decades, particularly because of the need to address climate change. Biomass can make a substantial contribution to supplying future energy demand in a sustainable way. It is presently the largest global contributor of renewable energy, and has significant potential to expand in the production of heat, electricity, and fuels for transport. Further deployment of bioenergy, if carefully managed, could provide:

- an even larger contribution to global primary energy supply;
- significant reductions in greenhouse gas emissions, and potentially other environmental benefits;
- improvements in energy security and trade balances, by substituting imported fossil fuels with domestic biomass;
- opportunities for economic and social development in rural communities; and
- scope for using wastes and residues, reducing waste disposal problems, and making better use of resources.

This review provides an overview of the potential for bioenergy and the challenges associated with its increased deployment. It discusses opportunities and risks in relation to resources, technologies, practices, markets and policy. The aim is to provide insights into the opportunities and required actions for the development of a sustainable bioenergy industry.

# BIOMASS RESOURCES

At present, forestry, agricultural and municipal residues, and wastes are the main feedstocks for the generation of electricity and heat from biomass. In addition, a very small share of sugar, grain, and vegetable oil crops are used as feedstocks for the production of liquid biofuels. Today, biomass supplies some 50 EJ[2] globally, which represents 10% of global annual primary energy consumption. This is mostly traditional biomass used for cooking and heating. See Figure 1.

There is significant potential to expand biomass use by tapping the large volumes of unused residues and wastes. The use of conventional crops for energy use can also be expanded, with careful consideration of land availability and food demand. In the medium term, lignocellulosic crops (both herbaceous and woody) could be produced on marginal, degraded and surplus agricultural lands and provide the bulk of the biomass resource. In the longer term, aquatic biomass (algae) could also make a significant contribution.

Based on this diverse range of feedstocks, the technical potential for biomass is estimated in the literature to be possibly as high as 1500 EJ/yr by 2050, although most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of between 200 and 500 EJ/yr (excluding aquatic biomass). Forestry and agricultural residues and other organic wastes (including municipal solid waste) would provide between 50 and 150 EJ/year, while the remainder would come from energy crops, surplus forest growth, and increased agricultural productivity. See Figure 2.

Projected world primary energy demand by 2050 is expected to be in the range of 600 to 1000 EJ (compared to about 500 EJ in 2008). Scenarios looking at the penetration of different low carbon energy sources indicate that future demand for bioenergy could be up to 250 EJ/yr. This projected demand falls well within the sustainable supply potential estimate, so it is reasonable to assume that biomass could sustainably contribute between a quarter and a third of the future global energy mix. See Figure 2. Whatever is actually realised will depend on the cost competitiveness of bioenergy and on future policy frameworks, such as greenhouse gas emission reduction targets.

Growth in the use of biomass resources in the mid-term period to 2030 will depend on many demand and supply side factors. Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) are likely to lead to a significant increase in demand. This demand is likely to be met through increased use of residues and wastes, sugar, starch and oil crops, and

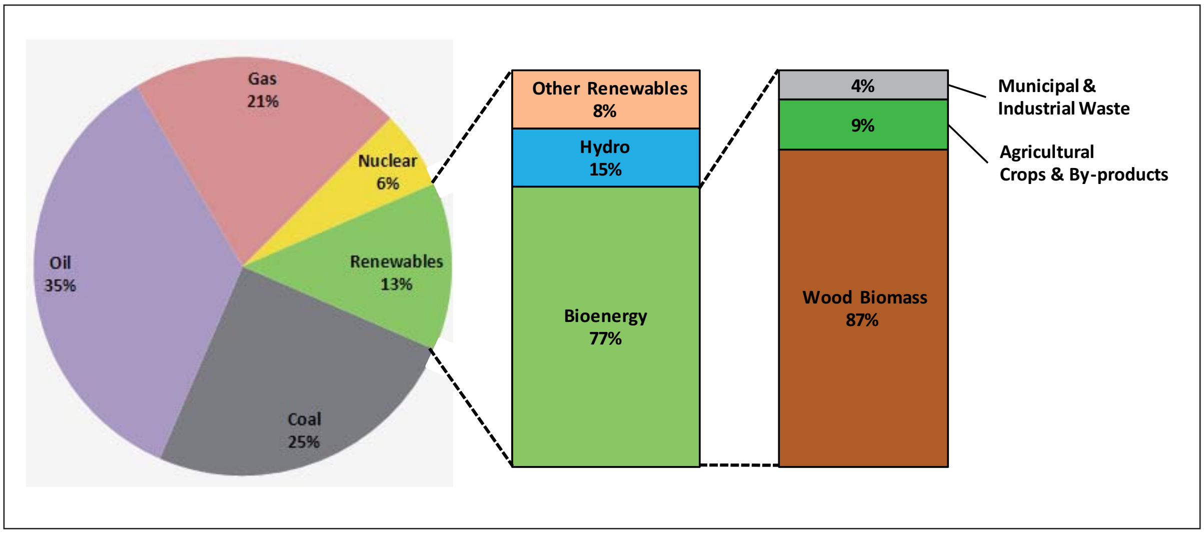



**Figure 1.** Share of bioenergy in the world primary energy mix. Source: based on IEA, 2006; and IPCC, 2007.

[2]1 EJ = $10^{18}$ Joules (J) = $10^{15}$ kilojoules (kJ) = 24 million tonnes of oil equivalent (Mtoe).

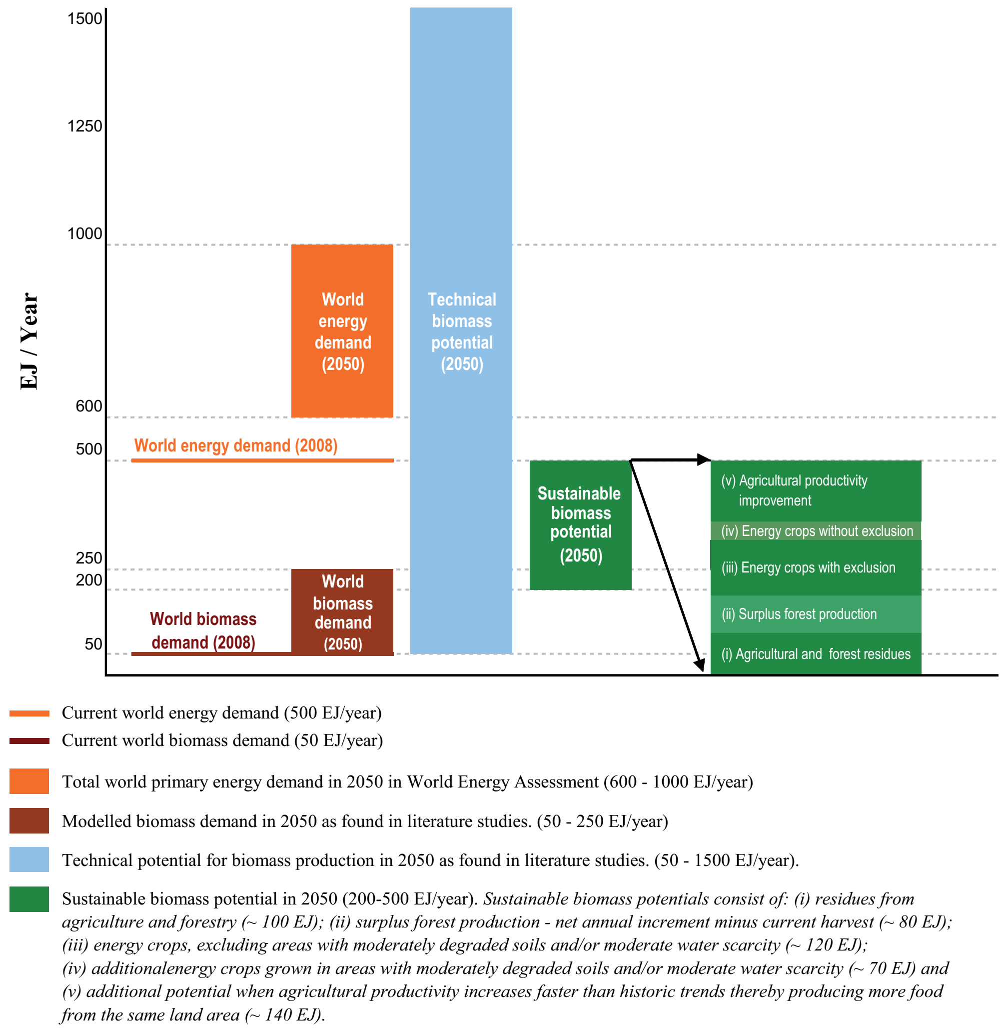



**Figure 2.** Technical and sustainable biomass supply potentials and expected demand for biomass (primary energy) based on global energy models and expected total world primary energy demand in 2050. Current world biomass use and primary energy demand are shown for comparative purposes. Adapted from Dornburg et al. (2008) based on several review studies.

increasingly, lignocellulosic crops. The contribution of energy crops depends on the choice of crop and planting rates, which are influenced by productivity increases in agriculture, environmental constraints, water availability and logistical constraints. Under favourable conditions substantial growth is possible over the next 20 years. However, estimates of the potential increase in production do vary widely. For example, the biomass potential from residues and energy crops in the EU to 2030 is estimated to range between 4.4 and 24 EJ.

The long-term potential for energy crops depends largely on:

- land availability, which depends on food sector development (growth in food demand, population diet, and increased crop productivity) and factors limiting access to land, such as water and nature protection;
- the choice of energy crops, which defines the biomass yield levels that can be obtained on the available land.

Other factors that may affect biomass potential include the impact of biotechnology, such as genetically modified organisms, water availability, and the effects of climate change on productivity.

The uptake of biomass depends on several factors:

- biomass production costs – US$4/GJ is often regarded as an upper limit if bioenergy is to be widely deployed today in all sectors;
- logistics – as with all agricultural commodities, energy crops and residues all require appropriate supply chain infrastructure;
- resource and environmental issues – biomass feedstock production can have both positive and negative effects on the environment (water availability and quality, soil quality and biodiversity). These will result in regulations restricting or incentivising particular practices (e.g. environmental regulations, sustainability standards, etc.).

Drivers for increased bioenergy use (e.g. policy targets for renewables) can lead to increased demand for biomass, leading to competition for land currently used for food production, and possibly (indirectly) causing sensitive areas to be taken into production. This will require intervention by policy makers, in the form of regulation of bioenergy chains and/or regulation of land use, to ensure sustainable demand and production. Development of appropriate policy requires an understanding of the complex issues involved and international cooperation on measures to promote global sustainable biomass production systems and practices.

To achieve the bioenergy potential targets in the longer term, government policies, and industrial efforts need to be directed at increasing biomass yield levels and modernising agriculture in regions such as Africa, the Far East and Latin America, directly increasing global food production and thus the resources available for biomass. This can be achieved by technology development, and by the diffusion of best sustainable agricultural practices. The sustainable use of residues and wastes for bioenergy, which present limited or zero environmental risks, needs to be encouraged and promoted globally.

## BIOMASS CONVERSION TECHNOLOGIES

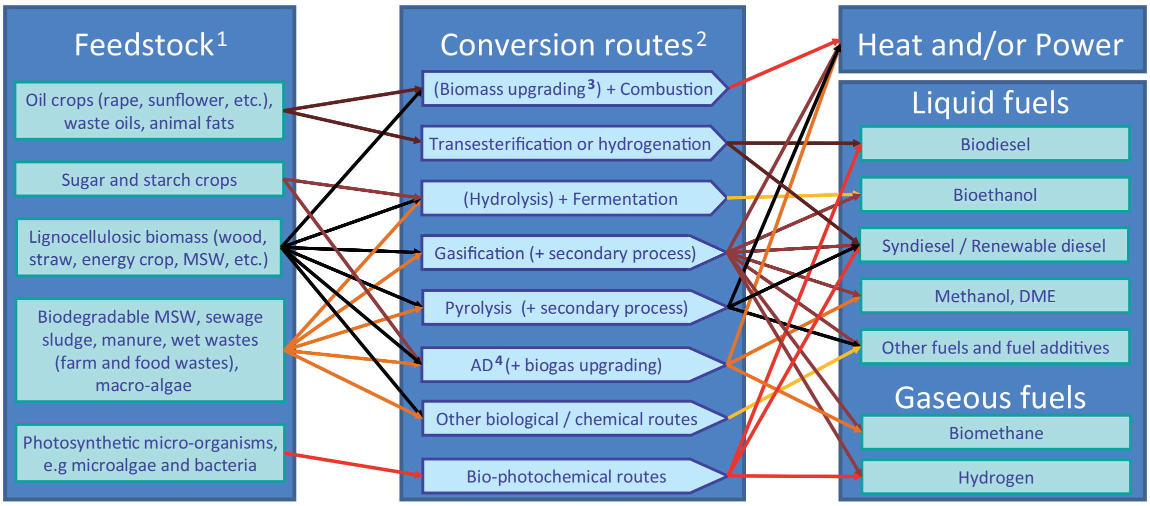
There are many bioenergy routes which can be used to convert raw biomass feedstock into a final energy product (see Figure 3). Several conversion technologies have been developed that are adapted to the different physical nature and chemical composition of the feedstock, and to the energy service required (heat, power, transport fuel). Upgrading technologies for biomass feedstocks (e.g. pelletisation, torrefaction, and pyrolysis) are being developed to convert bulky raw biomass into denser and more practical energy carriers for more efficient transport, storage and convenient use in subsequent conversion processes.

The production of heat by the direct combustion of biomass is the leading bioenergy application throughout the world, and is often cost-competitive with fossil fuel alternatives. Technologies range from rudimentary stoves to sophisticated modern appliances. For a more energy efficient use of the

*Ethanol pilot plant based on corn fibre and other cellulosic material, New Energy Company of Indiana, USA. (Courtesy DOE/NREL and W. Gretz)*

biomass resource, modern, large-scale heat applications are often combined with electricity production in combined heat and power (CHP) systems.

Different technologies exist or are being developed to produce electricity from biomass. Co-combustion (also called co-firing) in coal-based power plants is the most cost-effective use of biomass for power generation. Dedicated




[1] Parts of each feedstock, e.g. crop residues, could also be used in other routes

[2] Each route also gives co-products

[3] Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.)

[4] AD = Anaerobic Digestion

**Figure 3:** Schematic view of the wide variety of bioenergy routes. Source: E4tech, 2009.

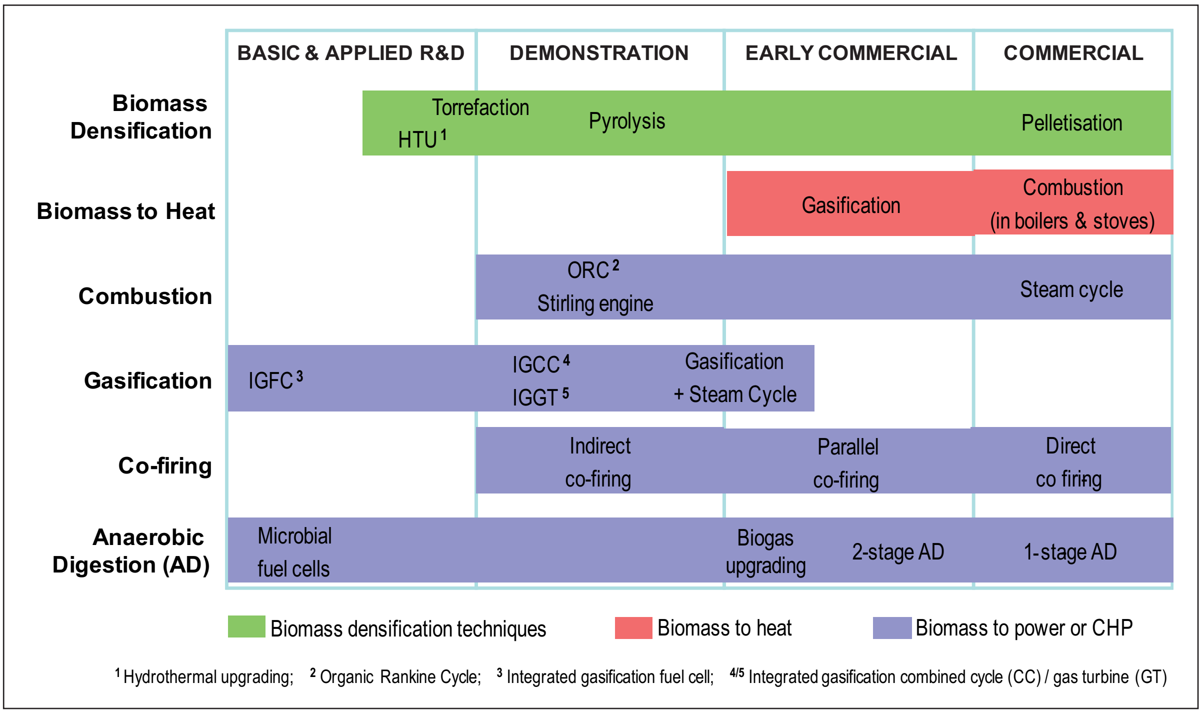



**Figure 4.** Development status of the main technologies to upgrade biomass and/or to convert it into heat and/or power. Source: E4tech, 2009.

biomass combustion plants, including MSW combustion plants, are also in successful commercial operation, and many are industrial or district heating CHP facilities. For sludges, liquids and wet organic materials, anaerobic digestion is currently the best-suited option for producing electricity and/or heat from biomass, although its economic case relies heavily on the availability of low cost feedstock. All these technologies are well established and commercially available.

There are few examples of commercial gasification plants, and the deployment of this technology is affected by its complexity and cost. In the longer term, if reliable and cost-effective operation can be more widely demonstrated, gasification promises greater efficiency, better economics at both small and large-scale and lower emissions compared with other biomass-based power generation options. Other technologies (such as Organic Rankine Cycle and Stirling engines) are currently in the demonstration stage and could prove economically viable in a range of small-scale applications, especially for CHP. See Figure 4.

In the transport sector, 1st generation biofuels are widely deployed in several countries mainly bioethanol from starch and sugar crops and biodiesel from oil crops and residual oils and fats. Production costs of current biofuels vary significantly depending on the feedstock used (and their volatile prices), and on the scale of the plant. The potential for further deploying these 1st generation technologies is high, subject to sustainable land use criteria being met.

1st generation biofuels face both social and environmental challenges, largely because they use food crops which could lead to food price increases and possibly indirect land use change. While such risks can be mitigated by regulation and sustainability assurance and certification, technology development is also advancing for next generation processes that rely on non-food biomass (e.g. lignocellulosic feedstocks such as organic wastes, forestry residues, high yielding woody or grass energy crops and algae). The use of these feedstocks for 2nd generation biofuel production would significantly decrease the potential pressure on land use, improve greenhouse gas emission reductions when compared to some 1st generation biofuels, and result in lower environmental and social risk. 2nd generation technologies, mainly using lignocellulosic feedstocks for the production of ethanol, synthetic diesel and aviation fuels, are still immature and need further development and investment to demonstrate reliable operation at commercial scale and to achieve cost reductions through scale-up and replication. The current level of activity in the area indicates that these routes are likely to become commercial over the next decade. Future generations of biofuels, such as oils produced from algae, are at the applied R&D stage, and require considerable development before they can become competitive contributors to the energy markets. See Figure 5.

Further development of bioenergy technologies is needed mainly to improve the efficiency, reliability and sustainability of bioenergy chains. In the heat sector, improvement would lead to cleaner, more reliable systems linked to higher quality fuel supplies. In the electricity sector, the development of smaller and more cost-effective electricity or CHP systems could better match local resource availability. In the transport sector, improvements could lead to higher quality and more sustainable biofuels.

Ultimately, bioenergy production may increasingly occur in biorefineries where transport biofuels, power, heat, chemicals and other marketable products could all be co-produced from a mix of biomass feedstocks. The link between producing energy and other materials deserves further attention technically and commercially.

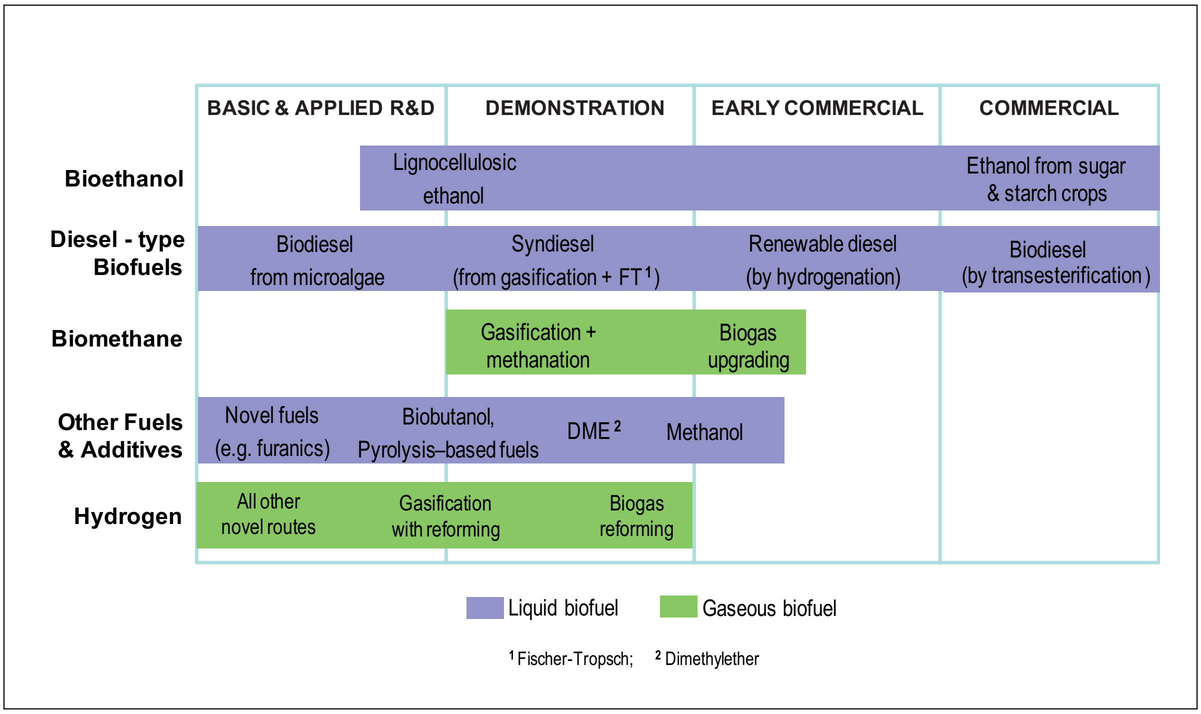



**Figure 5.** Development status of the main technologies to produce biofuels for transport from biomass. Source: E4tech, 2009.

## BIOENERGY MARKETS

The predominant use of biomass today consists of fuel wood used in non-commercial applications, in simple inefficient stoves for domestic heating and cooking in developing countries, where biomass contributes some 22% to the total primary energy mix. This traditional use of biomass is expected to grow with increasing world population, but there is significant scope to improve its efficiency and environmental performance, and thereby help reduce biomass consumption and related impacts. See Figure 6.

In industrialised countries, the total contribution of modern biomass is on average only about 3% of total primary energy, and consists mostly of heat-only and heat and power applications. Many countries have targets to significantly increase biomass use, as it is seen as a key contributor to meeting energy and environmental policy objectives. Current markets, growing as a result of attractive economics, mostly involve domestic heat supply (e.g. pellet boilers), large-scale industrial and community CHP generation (particularly where low cost feedstocks from forest residues, bagasse,

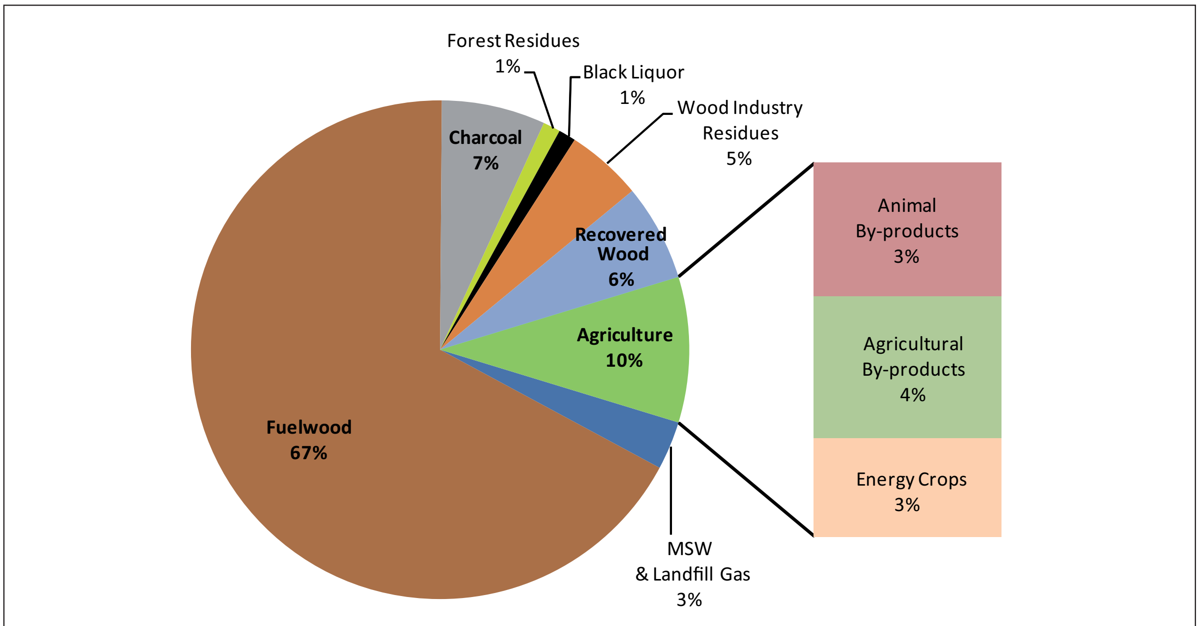



**Figure 6:** Share of the biomass sources in the primary bioenergy mix. Source: based on data from IPCC, 2007.

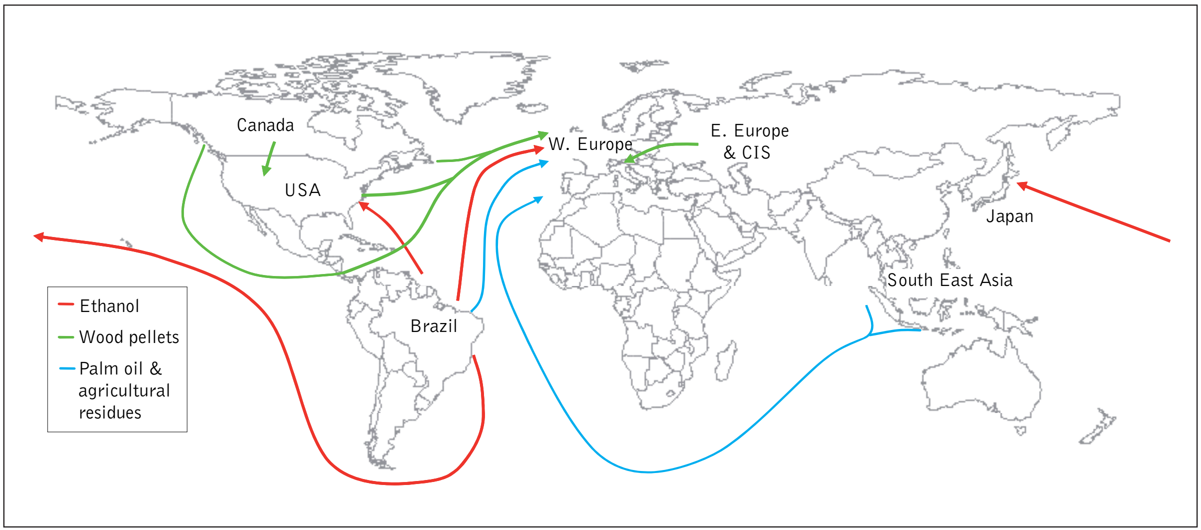



**Figure 7:** Main international biomass for energy trade routes. Intra-European trade is not displayed for clarity. Source: Junginger and Faaij, 2008.

MSW etc. are available), and co-firing in large coal-based power plants. The deployment of dedicated electricity plants has been mainly confined to low cost feedstocks in relatively small-scale applications, such as the use of biogas and landfill gas from waste treatment. Globally, the use of biomass in heat and industrial energy applications is expected to double by 2050 under business-as-usual scenarios, while electricity production from biomass is projected to increase, from its current share of 1.3% in total power production to 2.4 – 3.3% by 2030 (corresponding to a 5 - 6% average annual growth rate).

Transport biofuels are currently the fastest growing bioenergy sector, receiving a lot of public attention. However, today they represent only 1.5% of total road transport fuel consumption and only 2% of total bioenergy. They are, however, expected to play an increasing role in meeting the demand for road transport fuel, with 2$^{nd}$ generation biofuels increasing in importance over the next two decades. Even under business-as-usual scenarios, biofuel production is expected to increase by a factor of 10 to 20 relative to current levels by 2030 (corresponding to a 6 - 8% average annual growth rate).

Global trade in biomass feedstocks (e.g. wood chips, vegetable oils and agricultural residues) and processed bioenergy carriers (e.g. ethanol, biodiesel, wood pellets) is growing rapidly. Present estimates indicate that bioenergy trade is modest – around 1 EJ (about 2% of current bioenergy use). In the longer term, much larger quantities of these products might be traded internationally, with Latin America and Sub-Saharan Africa as potential net exporters and North America, Europe and Asia foreseen as net importers. Trade will be an important component of the sustained growth of the bioenergy sector. See Figure 7.

The quest for a sustainable energy system will require more bioenergy than the growth projected under the business-as-usual scenarios. A number of biomass supply chain issues and market risks and barriers will need to be addressed and mitigated to enable stronger sustained growth of the bioenergy sector. These include:

- **Security of the feedstock supply.** This is susceptible to the inherent volatility of biological production (due to weather and seasonal variations), which can lead to significant variations in feedstock supply quantity, quality and price. Risk mitigation strategies already common in food and energy markets include having a larger, more fluid, global biomass sector and the creation of buffer stocks.

- **Economies of scale and logistics.** Many commercially available technologies suffer from poor economics at a small-scale, but conversely larger scales require improved and more complex feedstock supply logistics. Efforts are required to develop technologies at appropriate scales and with appropriate supply chains to meet different application requirements.

- **Competition.** Bioenergy technologies compete with other renewable and non-renewable energy sources, and may compete for feedstock with other sectors such as food, chemicals and materials. Also, the development of 2$^{nd}$ generation biofuel technologies could lead to competition for biomass resources between bioenergy applications, and potentially with other industry sectors. Support needs to be directed at developing cost-effective bioenergy routes and at deploying larger quantities of biomass feedstocks from sustainable sources.

- **Public and NGO acceptance.** This is a major risk factor facing alternative energy sources and bioenergy in particular. The public needs to be informed and confident that bioenergy is environmentally and socially beneficial and does not result in significant negative environmental and social trade-offs.

However, the industry is confident such challenges can be met as similar challenges have been addressed in other sectors and appropriate technologies and practices are being developed and deployed.

## INTERACTIONS WITH OTHER MARKETS

Developments in the bioenergy sector can influence markets for agricultural products (e.g. food and feed products, straw) and forest products (e.g. paper, board). However, this impact is not straightforward due to:

- other factors, such as biomass yield variations and fossil fuel price volatilities influencing markets just as much or more than biomass;
- other policy domains, including forestry, agriculture, environment, transport, health and trade, also having influence on bioenergy policies; and
- a lack of transparency in many product and commodity markets, especially in forest products, making it difficult to assess the impact of bioenergy development.

While all forms of bioenergy interrelate with agriculture and/or forest markets through their feedstock demand, the impact of 1st generation liquid biofuels on food prices has been a topic of strong debate in recent years. Although different studies reveal a wide variety of opinions on the magnitude of these impacts, most model-based demand scenarios indicate a relatively limited risk of biofuels significantly affecting the price of food crops. In general, markets can work to dampen these effects.

Markets will need access to monetary and physical resources, and will need to function efficiently and transparently in order to counteract the pressure of increasing demand. There is therefore an important role for policy in providing support to an increasingly efficient industry, for example in terms of yields, use of residues and wastes, and land use, while providing regulation to avoid negative impacts associated with the exploitation of physical resources. This requires active coordination between energy, agriculture and forestry, trade and environmental policies.

## BIOENERGY AND POLICY OBJECTIVES

Bioenergy can significantly increase its existing contribution to policy objectives, such as $CO_2$ emission reductions and energy security, as well as to social and economic development objectives.

Appreciating where bioenergy can have the greatest impact on GHG emissions reduction relies on both an understanding of the emissions resulting from different bioenergy routes and the importance of bioenergy in reducing emissions in a particular sector. Bioenergy chains can perform very differently with regard to GHG emissions. Substituting biomass for fossil fuels in heat and electricity generation is generally less costly and provides larger emission reductions per unit of biomass than substituting biomass for gasoline or diesel used for transport. However, the stationary bioenergy sector can rely on a range of different low carbon options while biofuels are the primary option for decarbonising road transport until all-electric and/or hydrogen fuel cell powered vehicles become widely deployed, which is unlikely to be the case for some decades. In the long-term, biofuels might remain the only option for decarbonising aviation transport, a sector for which it will be difficult to find an alternative to liquid fuels.

Land suitable for producing biomass for energy can also be used for the creation of biospheric carbon sinks. Several factors determine the relative attractiveness of these two options, in particular land productivity, including co-products, and fossil fuel replacement efficiency. Also, possible direct and indirect emissions from converting land to another use can substantially reduce the climate benefit of both bioenergy and carbon sink projects, and need to be taken into careful consideration. A further influencing factor is the time scale that is used for the evaluation of the carbon reduction potential: a short time scale tends to favour the sink option, while a longer time scale offers larger savings as biomass production is not limited by saturation but can repeatedly (from harvest to harvest) deliver greenhouse gas emission reductions by substituting for fossil fuels. Mature forests that have ceased to serve as carbon sinks can in principle be managed in a conventional manner to produce timber and other forest products, offering a relatively low GHG reduction per hectare. Alternatively, they could be converted to higher yielding energy plantations (or to food production) but this would involve the release of at least part of the carbon store created.

The use of domestic biomass resources can make a contribution to energy security, depending on which energy source it is replacing. Biomass imports from widely distributed international sources generally also contribute to the diversification of the energy mix. However, supply security can be affected by natural variations in biomass outputs and by supply-demand imbalances in the food and forest product sectors, potentially leading to shortages.

The production of bioenergy can also result in other (positive and negative) environmental and socio-economic effects. Most of the environmental effects are linked to biomass feedstock production, many of which can be mitigated through best practices and appropriate regulation. Technical solutions are available for mitigating most environmental impacts from bioenergy conversion facilities, and their

*Tyseley Waste-to-Energy plant, Birmingham, UK. Built in 1996, the 28 MW plant with a 2-stream incinerator has a combined capacity of over 350,000 tonnes per year of municipal solid waste and a fifteen year Non-Fossil Fuel Obligation Contract. An award winning lighting system illuminates the plant at night.*

*Biomass contributes 12% of total energy consumption in Denmark and straw from agriculture is an important element. Consumption of biomass for energy production is now 100 PJ/year which is two-thirds of the total technical potential of domestic biomass resources. (Courtesy J. Bunger, Denmark).*

use is largely a question of appropriate environmental regulations and their enforcement. The use of organic waste and agricultural/forestry residues, and of lignocellulosic crops that could be grown on a wider spectrum of land types, may mitigate land and water demand and reduce competition with food.

Feedstock production systems can also provide several benefits. For instance, forest residue harvesting improves forest site conditions for planting, thinning generally improves the growth and productivity of the remaining stand, and removal of biomass from over-dense stands can reduce the risk of wildfire. In agriculture, biomass can be cultivated in so-called multifunctional plantations that – through well chosen locations, design, management, and system integration – offer extra environmental services that, in turn, create added value for the systems.

Policy around bioenergy needs to be designed so that it is consistent with meeting environmental and social objectives. Bioenergy needs to be regulated so that environmental and social issues are taken into consideration, environmental services provided by bioenergy systems are recognised and valued, and it contributes to rural development objectives.

## LESSONS FOR THE FUTURE

As the deployment of many bioenergy options depends on government support, at least in the short and medium term, the design and implementation of appropriate policies and support mechanisms is vital, and defensible, particularly given the associated environmental benefits and existing government support for fossil fuels. These policies should also ensure that bioenergy contributes to economic, environmental and social goals. Experience over the last couple of decades has taught us the following.

- A policy initiative for bioenergy is most effective when it is part of a long-term vision that builds on specific national or regional characteristics and strengths, e.g. in terms of existing or potential biomass feedstocks available, specific features of the industrial and energy sector, and the infrastructure and trade context.

- Policies should take into account the development stage of a specific bioenergy technology, and provide incentives consistent with the barriers that an option is facing. Factors such as technology maturity, characteristics of incumbent technologies, and price volatilities all need to be taken into consideration. In each development stage, there may be a specific trade-off between incentives being technology-neutral and closely relating to the policy drivers, and on the other hand creating a sufficiently protected environment for technologies to evolve and mature.

- There are two classes of currently preferred policy instruments for bio-electricity and renewable electricity in general. These are technology-specific feed-in tariffs and more generic incentives such as renewable energy quotas and tax differentiation between bioenergy and fossil-based energy. Each approach has its pros and cons, with neither being clearly more effective.

- Access to markets is a critical factor for almost all bioenergy technologies so that policies need to pay attention to grid access, and standardisation of feedstocks and biofuels.

- As all bioenergy options depend on feedstock availability, a policy strategy for bioenergy should pay attention to the sectors that will provide the biomass. For the agricultural and forestry sectors, this includes consideration of aspects such as productivity improvement, availability of agricultural and forest land, and access to and extractability of primary residues. For other feedstocks, such as residues from wood processing and municipal solid waste, important aspects are mobilisation and responsible use.

- A long-term successful bioenergy strategy needs to take into account sustainability issues. Policies and standards safeguarding biomass sustainability are currently in rapid development. Due to the complexity of the sustainability issue, future policy making and the development of standards will need to focus on integrated approaches, in which the complex interactions with aspects such as land use, agriculture and forestry, and social development are taken into account.

- Long-term continuity and predictability of policy support is also important. This does not mean that all policies need to be long-term but policies conducive to the growth of a sector should have a duration that is clearly stated and in line with meeting certain objectives, such as cost reduction to competitive levels with conventional technologies.

- The successful development of bioenergy does not only depend on specific policies which provide incentives for its uptake, but on the broader energy and environment legal and planning framework. This requires coordination amongst policies and other government actions, as well as working with industry and other stakeholders to establish a framework conducive to investment in bioenergy.

## A SENSIBLE WAY FORWARD

Climate change and energy security are problems for which solutions need to be developed and implemented urgently. The scale of the challenge is such that it will require contributions from disparate sources of energy. Bioenergy already contributes significantly to addressing these problems and can contribute much further through existing and new conversion technologies and feedstocks. Furthermore, bioenergy can contribute to other environmental and social objectives, such as waste treatment and rural development. However, policy makers and the public at large will need to be comfortable that this expansion is sustainable.

Bioenergy can result in many external benefits but also entails risks. A development and deployment strategy needs to be based on careful consideration of the strengths and weaknesses, as well as the opportunities and threats that characterise it.

- Current bioenergy routes that generate heat and electricity from the sustainable use of residues and wastes should be strongly stimulated. These rely on commercial technologies, lead to a better use of raw materials, and result in clear GHG savings and possibly other emission reductions compared to fossil fuels. The development of infrastructure and logistics, quality standards and trading platforms will be crucial to growth and may require policy support.

- Further increasing the deployment of bioenergy, and in particular of biofuels for transport in the short-term, should be pursued by:
  - paying specific attention to sustainability issues directly related to the biomass-to-energy production chain, and avoiding or mitigating negative impacts through the development and implementation of sustainability assurance schemes;
  - incentivising biofuels based on their potential greenhouse gas benefits;
  - considering potential impacts of biomass demand for energy applications on commodity markets and on indirect land use change; and
  - defining growth rates that result in feedstock demands that the sector can cope with on a sustainable basis.

- Development of new and improved biomass conversion technologies will be essential for widespread deployment and long-term success. Public and private funding needs to be devoted to research, development and deployment as follows:
  - for liquid biofuels - advanced technologies that allow for a broader feedstock base using non-food crops with fewer (direct and indirect) environmental and social risks, and higher greenhouse gas benefits;
  - for power and heat production - more efficient advanced technologies, such as gasification and advanced steam cycles, and technologies with improved economics at a smaller scale to allow for more distributed use of biomass; and
  - for novel biomass - upgrading technologies and multi-product biorefineries, which could contribute to the deployment and overall cost-competitiveness of bioenergy.

- As the availability of residues and wastes will limit bioenergy deployment in the long-term, policies stimulating increased productivity in agriculture and forestry, and public and private efforts aimed at development of novel energy crops, such as perennial lignocellulosic crops, and other forms of biomass, such as algae, are essential for a sustained growth of the bioenergy industry. These efforts need to be integrated with sustainable land use policies which also consider making efficient and environmentally sound use of marginal and degraded lands.

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IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

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