HOW2GUIDE for

Bioenergy

Roadmap Development and Implementation

International Energy Agency
Secure
Sustainable
Together

Food and Agriculture Organization of the United Nations

About the IEA

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

About the FAO

The Food and Agriculture Organization (FAO) is a specialised agency of the United Nations. As an intergovernmental organisation, FAO has 194 Member Nations, two associate members and one member organisation, the European Union. FAO's mandate is to support members in their efforts to ensure that people have regular access to enough high-quality food.

The mandate of FAO is further defined around three main goals:

- the eradication of hunger, food insecurity and malnutrition
- the elimination of poverty and the driving forward of economic and social progress for all
- the sustainable management and utilisation of natural resources, including land, water, air, climate and genetic resources for the benefit of present and future generations.

Access to modern energy, including bioenergy, is essential to achieving food security. FAO supports its Member Nations to develop sustainable bioenergy, fostering opportunities for responsible investment in sustainable agriculture and rural development.

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Contact information: www.iea.org/aboutus/contactus

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Foreword

Bioenergy is the largest source of renewable energy today, providing heat and electricity, as well as transport fuels. The use of biomass power has continued to grow in recent years and can play a key role in decarbonising electricity systems by providing a stable source of low carbon baseload electricity. Biomass for heat has grown more slowly and with limited policy support. Policy uncertainties – mostly related to the debate on appropriate sustainability criteria – plus other structural challenges have constrained the expansion of biofuels for transport after a period of rapid growth, with current low oil prices further complicating the outlook.

More needs to be done to bolster bioenergy, which has considerable potential to help drive the energy transition. The International Energy Agency (IEA) projects that modern bioenergy will be a key part of the solution in limiting long term global temperature increases to below 2° C and could contribute over 1 500 million tonnes of oil-equivalent, or 10%, to global final energy consumption in 2040. Bioenergy can thus contribute to global efforts to achieve the United Nations' Sustainable Development Goals and to implement commitments relating to the Paris Agreement reached at COP21. However, if suitable policies and practices are not adopted in a timely manner, bioenergy development may also present risks, such as increased pressure on land and water resources and greater emissions of lifecycle greenhouse gases and particulate matter, as well as biodiversity losses.

In the established energy systems, as well as in the dynamic markets of emerging and developing economies, bioenergy policy formulation, food security and water management are interwoven. Government intervention, sustained investment in infrastructure, collaborative research and innovation, and deeper regional co-operation and integration are needed to support the growth of sustainable bioenergy markets. Substantial potential exists to expand both food and fuel supply along bioenergy pathways that are economically, socially and environmentally viable.

Recognising the importance of taking a cross-cutting approach to bioenergy strategies that rely on sustainable biomass use, the IEA and the Food and Agriculture Organization of the United Nations (FAO) have jointly prepared this *How2Guide for Bioenergy*. Our aim is to provide practical tools and a conceptual framework to support policy makers to pursue the desired level of bioenergy deployment, and to inform the decisions of key stakeholders, from industry to the financial sector.

This publication is part of a series of manuals under the IEA Technology Roadmap programme – the How2Guides – that offer guidance on the key steps to developing and implementing a national or regional roadmap for some of the most important technologies. At a time when there are rising expectations of access to modern energy services, new milestones in the combat against climate change, and signs that growth in the global economy and energy related emissions may be decoupled, it is our hope that this publication will support efforts at both national and regional levels to fully realise the potential and benefits of bioenergy.

Dr. Fatih Birol
Executive Director
International Energy Agency

Maria Helena Semedo
Deputy Director General
Food and Agriculture Organization

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For further information on this document, contact:

Simone Landolina, IEA
Tel. +33 (0)1 40 57 66 14
Email: Simone.Landolina@iea.org

Irini Maltsoglou, FAO
Tel. +39 06 57 05 36 39
Email: Irini.Maltsoglou@fao.org

Introduction

About technology roadmaps

The primary goal of a technology roadmap is to highlight and accelerate the deployment of a specific technology or group of technologies. A roadmap is, simply put, a strategy or a plan describing the steps to be taken in order to achieve stated and agreed goals on a defined schedule. It determines the technical, policy, legal, financial, market and organisational barriers that lie before these goals, and the range of known solutions to overcome them. Roadmaps can be developed for different levels of deployment, including global, national or regional, and can be sector- or technology-specific.

The evolving process by which a roadmap is created, implemented, monitored and updated is referred to as roadmapping. The way this process is organised is crucial to achieving the goals set out by the roadmap. An effective roadmapping process maximises participants' engagement in creating the plan, thereby building consensus, increasing the likelihood that those involved will implement the roadmap priorities and together seek early solutions to anticipated potential barriers. Ideally, a roadmap is a dynamic document, incorporating metrics to facilitate monitoring of progress towards its stated goals, with the flexibility to be updated as the market, technology and policy context evolve.

About the *How2Guide for Bioenergy*

This *How2Guide for Bioenergy* (hereinafter the *H2G.BIO*) is designed to provide stakeholders from government, industry and other bioenergy-related institutions with the methodology and tools required to successfully plan and implement a roadmap for bioenergy at the national or regional level.

As a guide addressed to decision makers in developing, emerging and developed economies, the *H2G.BIO* does not attempt to cover every aspect of bioenergy conversion technology and deployment, or to be exhaustive in its reference to biomass resources and technologies at the country and regional levels. Rather, the aim is to provide a comprehensive list of steps and issues to be considered at each phase of bioenergy roadmapping and deployment. Selected case studies provide the reader with an overview of the wide array of technology applications that exist.[1] Key drivers for and barriers to the deployment of bioenergy are discussed in detail throughout and realistic options for action are suggested, along with tools and useful information sources for decision makers. Important considerations when devising a roadmap for bioenergy include food security, land use, water scarcity, and the potential impacts of bioenergy production on agricultural systems.

The guide draws on pre-existing work as well as on new evidence collected specifically for the production of this document. Three sets of written sources have been particularly relevant:

i) the conceptual framework of the International Energy Agency (IEA) generic roadmap methodology manual, *Energy Technology Roadmaps: A Guide to Development and Implementation* (IEA, 2014a);

ii) two bioenergy-related analyses by the IEA, namely, the global *Technology Roadmap: Biofuels for Transport* (IEA, 2011a) and the global *Technology Roadmap: Bioenergy for Heat and Power* (IEA, 2012); and

iii) the experience developed by the Food and Agriculture Organization of the United Nations (FAO) in the framework of its *Support Package to Decision-Making for Sustainable Bioenergy* (FAO, 2013).

Data, information and resources were compiled with contributions from several regions around the world and with the help of policy makers, experts from the bioenergy industry, research centres, finance institutions and other international organisations, notably the International Renewable Energy Agency (IRENA). In 2014, the IEA and FAO jointly organised three expert workshops, which provided important insights into regional contexts for bioenergy deployment in Southern Africa, Southeast Asia and South America respectively (Box 1).

1. In this respect thanks are given to the Netherlands Enterprise Agency (RVO) for providing inputs and lessons learnt from over 40 bioenergy projects funded worldwide. Further information is available at www.rvo.nl/biomass.

Box 1: *H2G.BIO* expert workshops to source information for this publication

As part of the framework of activities for the *H2G.BIO*, in 2014 the IEA, together with other organisations, conducted the following expert workshops in key world regions to test the methodological approach, ensure local relevance and collect case studies:

- Southern Africa expert workshop on biogas and biomass waste-to-energy: 29-30 April 2014, Durban, South Africa, organised by the IEA and FAO in collaboration with the South African National Energy Development Institute (SANEDI) and the Renewable Energy and Energy Efficiency Partnership (REEEP).
- Southeast Asia expert workshop on sustainability of biomass: 23-24 July 2014, Bangkok, Thailand, organised by the IEA, FAO and IRENA in collaboration with the Ministry of Energy of Thailand.
- South America expert workshop on biofuels: 27-28 November 2014, São Paulo, Brazil, organised by the IEA and FAO in collaboration with the Ministry for Mines and Energy of Brazil (MME).

Additional information and material from the workshops are available from the IEA webpage www.iea.org/aboutus/affiliatedgroups/platform/how2guides/.

Guide structure and roadmapping process

The *H2G.BIO* is structured according to the four key phases of the roadmapping process:

Phase 1: Planning and preparation

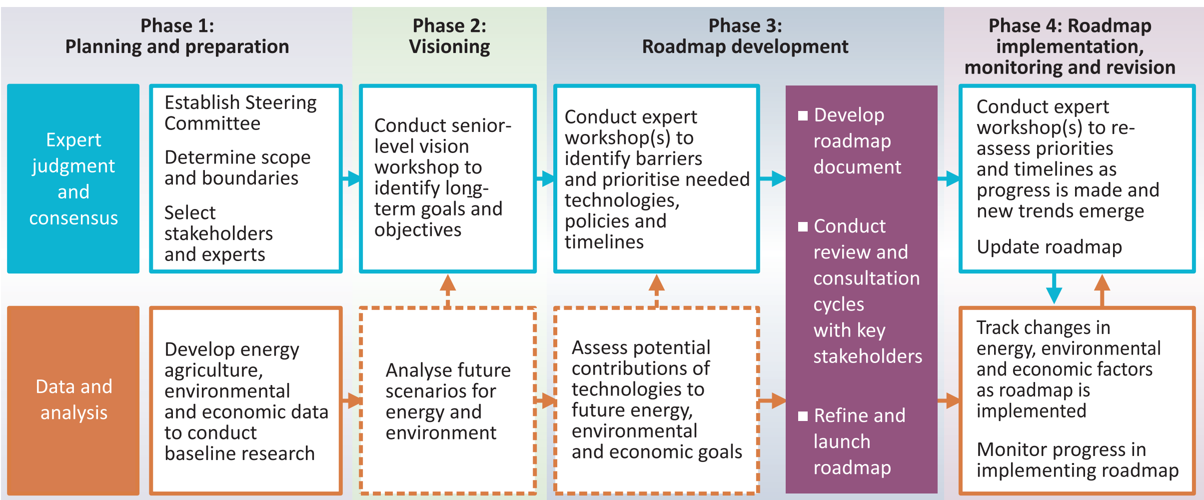
Phase 2: Visioning

Phase 3: Roadmap development

Phase 4: Implementation, monitoring and revision.

As shown in Figure 1, the roadmapping process includes two streams of activities: those focused on analysis (depicted in orange) and those centred on decision making and consensus building (in blue). Sound data and analysis should be used to support expert judgment in establishing current baseline conditions, so that milestones and performance targets can be set and technology pathways defined to achieve the roadmap goals. It is recommended that this process is followed for the development of an effective sustainable bioenergy roadmap for a defined region or country.

Figure 1: The roadmapping process



Notes: dotted orange lines indicate optional steps, based on analytical capabilities and resources.

Source: adapted from IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*.

Before analysing each of the four phases of the roadmapping process in more detail in their own sections, the remainder of this introduction presents the main characteristics of bioenergy, its sources and uses, as well as current market trends. Box 2 provides key definitions used in this publication.

Box 2: Definitions

Biomass: any organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, and organic waste from municipal and industrial sources.

Bioenergy: energy generated from the conversion of solid, liquid and gaseous products derived from biomass.

Traditional biomass use: the use of solid biomass such as wood, charcoal, agricultural residues and animal dung converted with basic techniques, such as a three-stone fire, for heating and cooking in the residential sector. It tends to have very low conversion efficiency (10% to 20%) and often relies upon an unsustainable biomass supply. The methodology and tools presented in the *H2G. BIO* are not intended to support the expansion of traditional biomass use.

Biofuels: liquid fuels derived from biomass. They include **ethanol**, a liquid produced from fermenting any biomass type high in carbohydrates, and **biodiesel**, a diesel-equivalent processed fuel made from both vegetable oil and animal fats. In this report, biofuels are classified as "conventional" and "advanced" according to the technologies used to produce them and their respective maturity.

- **Conventional biofuels**, also referred to as first-generation (1G), are obtained through well-established processes and include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil. Common feedstocks used in these processes include sugar cane and sugar beet, starch-bearing grains such as corn and wheat, oil crops such as oil palm, soya, rape, sunflower and canola, and in some cases used frying oil and animal fats.
- **Advanced biofuels,** also referred to as second- or third-generation (2G or 3G), are based on non-food crop feedstocks, which are capable of delivering significant lifecycle greenhouse gas (GHG) emissions savings compared to fossil fuel alternatives, and which do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts. Related technologies include lignocellulosic ethanol, hydrotreated vegetable oil (HVO) produced fully from waste and residue feedstocks, biomass to liquid (BtL), and biofuels produced from innovative feedstocks such as algae. Classification as advanced does not necessarily infer greater sustainability versus all conventional biofuels *per se*; however, making a distinction is useful when considering the level of technical maturity and requirements for policy support.

Biogas: a mixture of methane (CH_4) and carbon dioxide (CO_2) used as fuel and produced by bacterial degradation of organic matter or through gasification of biomass. **Anaerobic digestion** is the biological degradation of biomass in oxygen-free conditions to produce biogas, that is, a methane-rich gas. Anaerobic digestion is particularly suited to wet feedstocks such as animal manure, sewage sludge from wastewater treatment plants and wet agricultural residues, and the organic fraction of municipal solid waste (MSW), including that in landfill sites. **Gasification** occurs when biomass is transformed through a thermochemical process into fuel gas. It is a highly versatile process because virtually any dry biomass feedstock can be efficiently converted to fuel gas. The output of this process is referred to as bio-synthetic gas (syngas).

Bioenergy pathway: the process that starts with the selection of a particular biomass source and, through the application of a conversion process, culminates in the generation of bioenergy in a form suitable to satisfy the energy demand profile of the end-use sector (industry, transport, buildings, and others).

Notes: the definitions provided in this box are tailored to the context and aims of this publication and might partly differ from those contained in other OECD/IEA or FAO publications. The FAO Unified Bioenergy Terminology provides an alternative, comprehensive repository of definitions for biomass-related terms used in FAO and other databases (FAO, 2004).

About bioenergy pathways

Bioenergy is a unique renewable energy source in that it can be used to produce heat, electricity or transport fuels. The process of converting a feedstock into a product that can be used for electricity, heat or transport is called the bioenergy pathway. Each bioenergy pathway consists of several steps, including biomass production, collection or harvesting, pre-processing and storage, transport, storage after transport, conversion of biomass to energy or energy carrier, transport of energy carrier and energy consumption. The number of these steps may differ depending on the type, location and source of biomass, conversion of the biomass into an energy carrier, the final energy form, and the technology utilised to serve the relevant final energy use.

When assessing sustainable bioenergy options, it is necessary to consider numerous aspects, including:

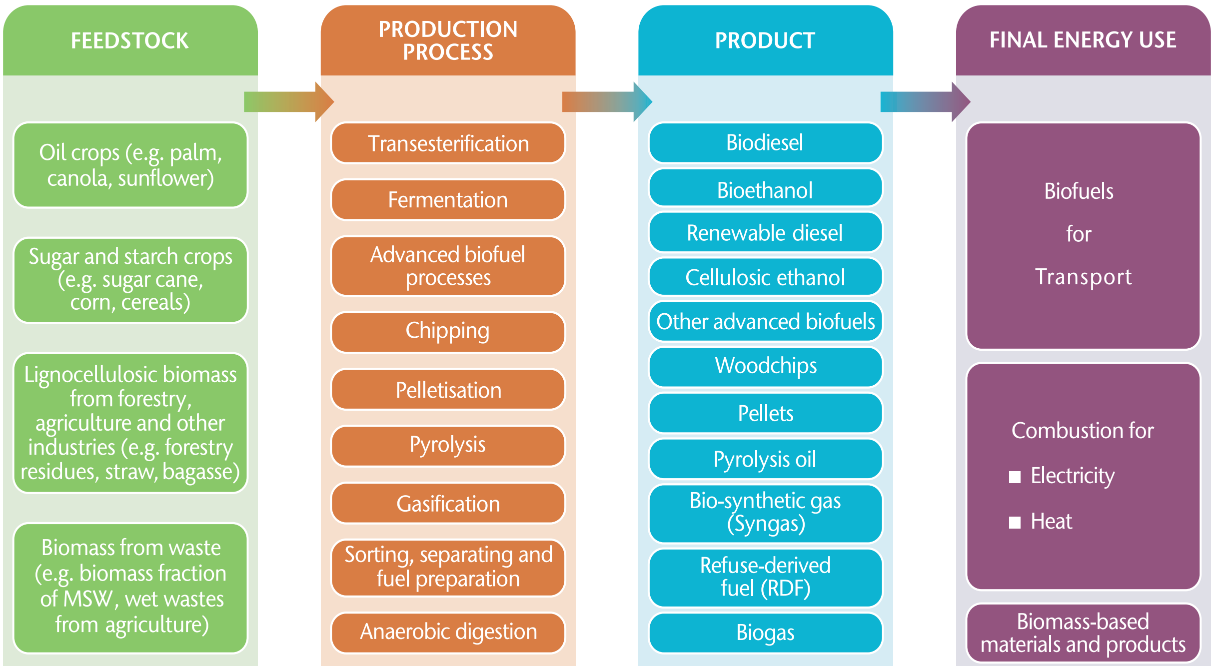
i) the objectives and uses for which bioenergy is being considered,

ii) the national economy, factoring in the agricultural, forestry and biomass processing sector in particular, and

iii) current and projected energy balances. This information, combined with the assessment of sustainable feedstock resources, will determine the possible and cost-effective bioenergy pathway options, within the country context, for the bioenergy technology roadmap.

Figure 2 illustrates a range of the main options under the most important bioenergy pathways available for the production of energy for transport, electricity generation, and heat from biomass. A significant number of feedstocks and production processes can be combined to deliver products appropriate for the conversion routes that meet the end-use requirements.

Figure 2: Possible configurations of bioenergy pathways: from biomass to final energy use



Note: while a considerable number of combinations are available to convert each feedstock type, certain applications require specific bioenergy pathways. Certain products and production processes are feedstock specific and Figure 2 does not imply that all feedstocks are suitable for meeting all energy end-use requirements in an efficient and cost-effective manner.

Sources: adapted from IEA (2012), *Technology Roadmap: Bioenergy for Heat and Power*, and FAO (2014a), *Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manual Introduction*. Additional references are available within these source documents.

The various steps in a bioenergy pathway require unique sets of knowledge, technology and feasibility assessment. The production of bioenergy requires biomass to be grown/produced, harvested/collected, transported, stored and, depending on the final use and biomass type, pre-processed before being converted into energy. The next section looks at the three main uses of bioenergy: heat, electricity and transport.

Biomass for heat

The most widespread use of biomass for heat is in open fires or low-efficiency traditional cooking stoves, mostly in developing countries. As a result of the negative health impacts of these methods (mainly related to smoke inhalation) and their environmental effects (e.g. forest degradation, emission of methane and black carbon), efforts are being made to introduce more efficient cooking stoves or to provide more modern alternative systems (IEA, 2016b). Modern technologies for domestic heating, e.g. pellet boilers, are fairly mature, fully controllable, and may reach high thermal efficiencies. These technologies are already widely deployed in a number of member countries of the Organisation for Economic Co-operation and Development (OECD) and other developed countries.

Biomass is also used in industries that consume large amounts of heat (either hot water or steam) and have large volumes of biomass residue at their disposal, such as the paper and pulp industry and the wood-processing sector. Other industrial processes, such as in the food and chemical sectors, could potentially provide a large market for biomass heating, but these opportunities are currently not widely exploited. Bioenergy is one of few renewable energy options that can be used directly in high-temperature applications, e.g. in the iron and cement industry. However, policies that increase the attractiveness of biomass over other sources are needed to improve the economics of these systems.

The production of heat from bioenergy can be cost-competitive with fossil fuel alternatives, although its attractiveness has been strongly reduced in the current environment of low fossil fuel prices. A number of critical factors can affect the project economics of biomass use for heat, including feedstock availability and cost, as well as the characteristics of heat load, e.g. daily and seasonal demand patterns. Since capital costs comprise a significant part of the unit cost for heat generation, biomass use in industrial applications with a constant load can present a more favourable business case than in the buildings sector, as the heat load tends to be seasonal in space-heating applications. Bioenergy can also provide heat for domestic, commercial and industrial applications via district heating networks, which provide a significant share of the heating demand in several northern European countries.

Biomass for electricity generation

Generally, either solid or gaseous biomass is used to generate electricity, although liquid biofuels are used to some extent to replace liquid fossil fuels in small-scale power generators. In larger-scale plants, the heat produced by direct combustion of solid biomass alone, or when co-fired with fossil fuels, can be used to generate electricity via a steam turbine. Biomass electricity generators can support the deployment of variable renewable sources by providing a source of baseload power, potentially increasing the overall deployment of renewables in the energy mix. In this respect, biomass dispatchable power can offer significant added value, in addition to helping cope with load variations at fairly short notice.

The co-firing of solid biomass fuels with coal in existing large power stations requires investment in biomass storage and fuel handling equipment, but profits from the comparatively higher conversion efficiencies of these coal plants. Although the proportion of biomass that can be combusted with coal in the boiler and co-fired is limited without more significant investment in plant and equipment, co-firing provides an immediate, relatively low-cost option to replace coal with biomass. In addition, a number of projects have taken place in OECD Europe and Canada to convert coal power stations to operate fully on biomass (IEA, 2015f).

The cost efficiency of power generation from biomass depends critically on the scale of the plant. However, at most scales of operation the electrical efficiency of the steam cycle tends to be lower than that for conventional fossil fuel plants. The availability and quality of feedstock is also an important factor. Moreover, as for all power plants, the cost of biomass electricity generation is highly sensitive to the cost or interest rate at which capital for the project is made available through equity and debt funding.

Alternatively, biomass can be converted by gasification into syngas or via anaerobic digestion into biogas. In each case, this gas can be used directly to produce electricity via gas turbines or engines at higher efficiency than via a steam cycle, particularly in small-scale plants (<5-10 megawatts electric, [MW_e]). Moreover, biogas can be upgraded to biomethane and injected into natural gas grids or used in transport applications. While biogas production from anaerobic digestion is a mature technology, also widely utilised in developing countries, further research and development (R&D) is needed for thermal gasification processes that rely on pressurised operations. This is particularly important for large applications, while ensuring that produced syngas can be cleaned sufficiently for use in an engine or turbine for electricity or co-generation also presents a development challenge.

Co-generation allows for the economic use of the heat produced in power generation, thereby increasing the overall efficiency of a power plant and hence its competitiveness.[2] When there is a good match between heat production and demand, such co-generation plants typically have overall (thermal and electrical) efficiencies in the range of 80-90% (IEA, 2014d).

Biofuels for transport

A range of technologies is commercially available to produce conventional biofuels. Sugar- and starch-based feedstocks can readily be converted to ethanol via fermentation. Oil crops and other biomass feedstocks can be converted to produce biodiesel via transesterification. Certain by-products of the fuel production process are used as animal feed. The costs of such processes depend heavily on the feedstock costs.

Scope currently exists to improve yields, conversion efficiencies and energy balances of production, for example by using residues to provide the energy needed for the conversion process, and by optimising the production and use of by-products. Innovative technology applications, such as the hydrogenation of vegetable oil, are available on the market and considerable volumes of this biofuel have been produced.

A range of advanced biofuels is in use that may not directly compete for agricultural land with food and feed crops. Some of these alternative biofuels require production processes that are still at the early stages of commercialisation or demonstration, including both biochemical and thermochemical processes such as:

- Hydrogenation of vegetable oils, pyrolysis, or thermal liquefaction of biomass residues to produce a diesel substitute.
- Enzymatic hydrolysis of lignocellulosic raw materials followed by simultaneous saccharification and fermentation to alcohol (ethanol and butanol).
- Gasification of biomass materials to produce a syngas, which can be used in gas-powered vehicles or to produce liquid hydrocarbons, including transport fuels.

A range of other production and conversion technologies remains at the R&D or pilot stage (including the production and processing of algae and microalgae with the primary purpose of serving as feedstock for bioenergy generation), along with a number of novel crops which may show promising potential as sources of bioenergy from marginal or unproductive land (see IEA ETSAP TCP and IRENA, 2013).

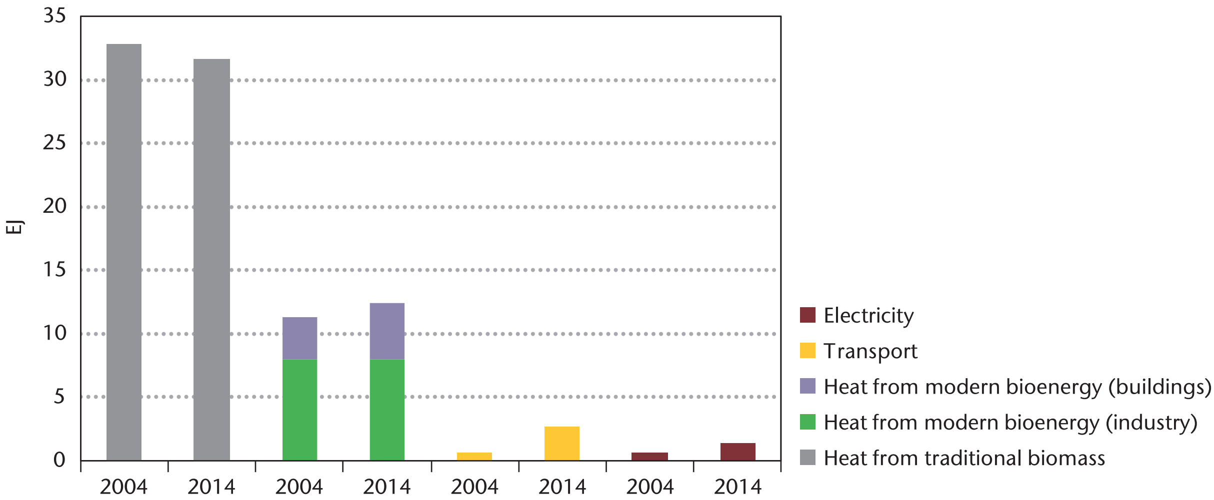
Market overview and trends

Since the turn of the century, growth has been evident in the use of biomass fuels and feedstocks in all energy end-use sectors, although to differing extents. Figure 3 shows the total final consumption of bioenergy in the heating, electricity and transport sectors respectively. Globally, most bioenergy is still associated with unsustainable, traditional biomass use in the residential sector.

Electricity generation: Electricity generated from biomass has grown steadily since the year 2000, reaching around 430 terawatt hours (TWh) by 2014, with associated worldwide installed capacity at 90 gigawatts (GW), which amounts to an almost 6% year-on-year increase since 2013. Power generation from biomass is still concentrated in OECD countries, but China and Brazil are also becoming increasingly important producers thanks to support programmes for biomass electricity generation, in particular from agricultural residues. The United States continues to be the largest generator of electricity from biomass worldwide, followed by Germany and China (IEA, 2015f). In 2014 global electricity generation from biomass represented about 8% of renewable generation and nearly 2% of electricity generation worldwide. Biomass power production is projected to reach in the order of 590 TWh by 2020, with a 5.5% compound annual

2. Co-generation refers to the combined production of heat and power.

Figure 3: Total final bioenergy consumption worldwide for heat, transport and electricity (2004-14)



Notes: this figure differentiates total final consumption of heat from traditional use of biomass and from modern bioenergy; the latter is broken down into buildings and industry; EJ = exajoule.

Source: IEA analysis based on 2014 data (IEA [2016e], *World Energy Outlook 2016*).

growth rate over 2014-20. Worldwide installed capacity is forecast to reach in the order of 125 GW by 2020 (IEA, 2015f). Key factors underpinning global bioenergy-related power capacity additions are Asian countries, such as China, Thailand and India, utilising significant domestic resources to serve growing demand, and activity in OECD Europe to fulfil National Renewable Energy Action Plans (NREAPs) related to the EU 2020 target for energy from renewables.

Heat: Growth rates for the production of heat from modern renewable energy sources have increased more slowly than those for renewable electricity generation and the production of transport biofuels. This reflects the fact that the heat sector has received less attention from policy makers historically. However, this is starting to change, reflecting the significant potential for renewable technologies in the heat sector, both within buildings and in industry. Final energy consumption of heat from renewable sources has risen globally, and it is estimated that bioenergy currently accounts for around 90% of total modern renewable heat consumption and 10% of total heat in industry and buildings. Modern bioenergy for heat, i.e. excluding traditional biomass use, stood at an estimated 13.3 EJ in 2013 and is forecast to grow at a compound annual growth rate of just under 2.5% to 15.7 EJ in 2020 (IEA, 2015f; IEA, 2014b).

Biofuels: From the year 2000 until 2010 the global production of biofuels (ethanol and biodiesel) grew strongly as a result of increased policy support, principally in the form of biofuels mandates, and an environment of favourable agricultural feedstock costs combined with increasing petroleum-based transport fuel prices. Although growth rates have since slowed, increases in annual production have still been evident and are forecast to continue. In 2015 conventional biofuels provided around 4% (134 billion litres production) of world road transport fuel and are expected to reach almost 4.5% in 2020, with an average annual growth rate of 2.5% 2015-20 (IEA, 2015f; IEA, 2016a). Globally, the two largest biofuels producers are the United States and Brazil (principally ethanol). However, other significant producers are the European Union, Argentina and Indonesia (principally biodiesel).

Phase 1: Planning and preparation

The first phase of the roadmap process involves planning to identify key stakeholders, to establish institutional frameworks for implementing the roadmap, and analysis to gather relevant and adequate information. This section of the *H2G.BIO* focuses on three specific aspects of roadmap development tailored to bioenergy: conducting baseline research, assessing the biomass resource potential, and identifying stakeholders. The three steps in the planning and preparatory phase on which this guide is focused are shown in green in Figure 4. It should be noted that while the steps are represented linearly in Figure 4, in practice many activities could occur simultaneously and each step would be part of an iterative process. For example, an initial stakeholder list could be identified at the outset of the process, and would evolve as more information was gathered.

Figure 4: Planning and preparation phase

Notes: in this figure, and in Figures 10, 14 and 15 below, each arrow represents a substep in one of the four phases of the roadmap process set out in the IEA *Roadmap Guide* and in Figure 1 of this report; green-shaded arrows indicate substeps that are also discussed in this *H2G.BIO*; for further information on the steps in blue, see the IEA *Roadmap Guide* (IEA, 2014a).

Placing bioenergy in context: Conducting baseline research

Considering that bioenergy supply chains bridge a number of disciplines and sectors, basic analysis of the country context and identification of the most relevant end uses should be the starting point for assessing the feasibility and sustainability of bioenergy options. This so-called “baseline research” is also needed to clarify what a roadmap can be expected to achieve and subsequent timelines. The main areas to analyse are the general economic and socioeconomic context and conditions of the country or region, as well as the relevant key sectors to bioenergy, such as agriculture and forestry. It is also important to consider the configuration of the national and local energy market to assess how bioenergy might play a role in light of current and future supply and demand of energy. Examples of questions to facilitate analysis of these factors are given in Table 1.

Due to strong linkages between bioenergy and the agricultural and forestry sectors, attention should be given to food security and environmental protection (see also OECD/FAO, 2012; OECD, 2013). Determining the key food staples, current production levels and locations, net trade positions, and major agricultural and forest export crops will provide insight into potential competition between sectors or the potential for synergies.

The baseline research aims to identify where, how, and for what purposes bioenergy is and could be used, its role in the energy mix, whether there are any potential gaps in supply, and the potential to increase energy access. Baseline research should include data on current primary energy supply and final consumption, as well as the profiles of end-use energy demand in the industrial, residential and transport sectors. Information on competing fuel costs incurred by these sectors is also relevant to complete the demand-side picture. Detailed information about energy end uses in these sectors is also necessary. For example, specific industrial considerations would include the type of heat services required, as well as the associated temperature and pressure in the case of a hot water or steam system. This information will be used to determine what combination of biomass source and bioenergy technology can provide these services.

Table 1: Key questions for baseline research on bioenergy

Category of question	Description

Resources	• How accurate and up-to-date is the existing assessment of biomass resources (crops and forestry feedstocks, residues and waste streams)?
	  ◦ What energy crops and food crop residues are available for bioenergy?
	  ◦ What wood products and residues from forestry activities are available for bioenergy?
	  ◦ What industrial and municipal waste streams are available for bioenergy? What is the composition of industrial, commercial and municipal wastes and the hierarchy of waste management options?
	• How is arable, forest and pasture land currently being used? Is there underutilised land?
	• Can there be a sustainable expansion of the land used for biomass cultivation, taking into consideration competing demands for land, especially for food production, forestry and biodiversity conservation, and which use has the highest potential for carbon sequestration?
	• What are the current production levels and uses of local biomass resources? What economic activities use biomass resources and how? Is biomass traded (imported/ exported)?
	• Is it feasible to increase agricultural production while meeting food demand and produce additional amounts that can be used as bioenergy feedstock? How could this be done sustainably in the long term?
	• How will biomass and biofuel developments affect water resources, soil quality and carbon sequestration?

Technology and market	• Which bioenergy processing technologies and end-use options are viable in the country? • Which feedstocks, management practices and processing technologies can deliver the largest GHG emission savings? Are these in line with the requirements of potential export markets? • How does the cost of bioenergy compare with alternative energy sources in the country? Is domestically produced bioenergy cost-competitive on international markets? • What trends are having or are likely to have an impact on the electricity, heat and transport markets in the roadmap timeframe (e.g. demand growth, supply deficit, ageing infrastructure, public-sector investment, electricity sector restructuring)? • How could bioenergy development affect the profitability of different crops at farm and woodland level? What could be the resulting changes in farmers' production choices? Could this have an impact on food security? • How are bioenergy supply chains structured? Are there potential synergies with existing industrial activities? • Is the country dependent on imported fuels for energy production? To what extent is the country exposed to global commodity price fluctuation? • What are the current market and regulatory frameworks for bioenergy? • How much biomass is currently traded (imported and/or exported)? Which primary and refined biomass products (e.g. pellets, woodchips) are currently traded? • What are the current market and regulatory frameworks for bioenergy? • To what degree could bioenergy development contribute to energy access for each end use (heat, electricity and transport)?

Table 1: Key questions for baseline research on bioenergy (continued)

Category of question	*Description*
Public policy	• Do national/regional policy makers have a comprehensive energy strategy? Are there policy goals for specific energy technologies or end use sectors at the national, regional and local levels? ◦ Does the country/region have specific plans or targets for modernising its electricity grids, integrating renewables, decarbonising the transport sector, etc.? • What is the current and projected future energy mix? Do national/regional policy makers have targets for renewable energy supply? • Do national/regional policy makers have targets for carbon emission reductions? Does a dedicated policy framework or end use target (e.g. for the transport sector) exist? • Does the country/region already have a technology roadmap or strategy for bioenergy? What is the timeframe (e.g. 5 20, or 50 year plan)? • Do national/regional policy makers have coherent agriculture and forestry bioenergy targets, strategies and policies? • Are all the relevant government ministries or agencies involved and co operating? Are there sufficient personnel within key bodies to implement national/regional targets? Are responsibilities clearly assigned to each party? • What are the key drivers for enhancing the use of bioenergy (e.g. energy security, GHG emission reductions, rural development, poverty reduction, food security)? • What policy measures are needed to ensure implementation of sustainability standards for bioenergy production? • How can bioenergy production represent an opportunity for rural development and poverty reduction? • What is the employment generation potential of bioenergy development? • Can smallholders be involved in bioenergy production without compromising profits? • How could access to land by local communities be affected by bioenergy development? • What are the likely trade offs in choosing a particular bioenergy development path? What are the concerns? Have the risks of negative externalities (e.g. from direct or indirect LUC) been assessed?

Sometimes critical information on the variables that affect the current status and future conditions may not exist or may be difficult to obtain. Mapping biomass resources that feed into detailed and reliable energy statistics is a complex undertaking. If comprehensive baseline data are not available, policy and decision makers may find it useful to work with international organisations, expert networks and/or non-governmental organisations for support in compiling this information. The Bioenergy and Food Security (BEFS) Approach (Box 3) by FAO, REmap (Box 4) by IRENA and the Energy Sector Management Assistance Program (Box 5) by the World Bank are examples of valuable resources in this respect. Additional tools are set out under Phase 3: Roadmap development.

Box 3: BEFS Approach and Rapid Appraisal

The Bioenergy and Food Security (BEFS) Approach has been developed by FAO to support countries in understanding the linkages between food security, agriculture and energy. The BEFS Approach supports policy makers in designing and implementing sustainable bioenergy policies and strategies, by ensuring that bioenergy development fosters both food and energy security and that it contributes to agricultural and rural development.

The BEFS Rapid Appraisal is an integral part of the BEFS Approach, and more specifically of the Sustainable Biomass Assessment component of the BEFS Approach. The BEFS Rapid Appraisal consists of a set of easily applicable methodologies and user-friendly tools which allow countries to get an initial indication of their sustainable bioenergy potential and of the associated opportunities, risks and trade-offs.

The tools of the BEFS Rapid Appraisal assist policy makers and technical officers in:

- Outlining the country's energy, agriculture and food security context.
- Outlining the sustainable bioenergy options of interest.
- Obtaining initial estimates of which sustainable bioenergy supply chains are viable in the country, based on economic profitability, financial viability, investment requirements, labour implications and smallholder inclusion.
- Identifying options of interest that require more in-depth analysis, for example through the BEFS Detailed Analysis.

The BEFS Rapid Appraisal covers the whole biofuel supply chain from feedstock production to processing plant gate. In the case of electricity, distribution is addressed as well. It considers all bioenergy options, including solid, liquid and gaseous biofuels, and covers the following energy end uses: heating and cooking, electricity and/or heat, and transport. Feedstock options investigated comprise agriculture residues, fuelwood and wood residues, and crops.

Source: FAO (2014a), *Bioenergy and Food Security Rapid Appraisal (BEFS RA) User Manual Introduction,* www.fao.org/energy/befs/en/; FAO (2014b), *FAO's BEFS Approach: Implementation Guide*, www.fao.org/energy/befs/rapid-appraisal/en/; FAO (2014c), *Bioenergy and Food Security: The BEFS Analytical Framework*, www.fao.org/docrep/013/i1968e/i1968e.pdf.

Box 4: REmap 2030: A renewable energy roadmap

REmap 2030 is an initiative launched by IRENA as a tool to support the doubling of the share of renewables in the world's energy mix by 2030. Covering all three end-use sectors (buildings, transport and industry), REmap is a tool to determine the potential for scaling up renewables at national and global level, and identifies concrete technology options and transition pathways for countries, regions and sectors to achieve the set objective. The scheme is not a target-setting exercise, but rather helps actors make informed decisions in their efforts to ensure a sustainable energy future.

Initiated in 2010, REmap is currently applicable to 40 countries representing 80% of global final energy consumption. The methodology consists of four steps:

1) Collection of final energy use data by sector under current and future policies for 2010 (base year of the analysis) and 2030 (represents the so-called "Reference Case").
2) Identification of the realistic potential of renewable energy sources beyond the Reference Case; these are the so-called "REmap Options" which, combined with the Reference Case, represent the "REmap 2030" roadmap for the target country.
3) Estimation of the cost and benefits of the "REmap Options".
4) Identification of technology, funding and policy options to operationalise these estimates.

Throughout the process, teams of country experts and IRENA work in close collaboration.

Source: IRENA (2016), *REmap: Roadmap for a Renewable Energy Future*; IRENA (2014), *Global Bioenergy supply and demand projections: A working paper for Remap 2030*, http://irena.org/remap/.

Box 5: Energy Sector Management Assistance Program (ESMAP)

The Energy Sector Management Assistance Program (ESMAP) is an initiative set up by the World Bank to support governments and businesses seeking to scale up renewable electricity generation by improving country-level evidence on the location and economic viability of potential areas for development. It provides analytical and advisory services to low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions using biomass, small hydropower, solar and wind resources for poverty reduction and economic growth.

Launched in 2012 as a four-year programme, ESMAP has allocated USD 11.6 million to nine projects in Indonesia, Lesotho, Madagascar, Maldives, Pakistan, Papua New Guinea, Tanzania, Viet Nam and Zambia, and may be expanded given the strong interest in the area.

Country-specific information on renewable energy resources is one of the prerequisites for developing targeted policies and investing in clean energy. Through ESMAP project financing, renewable energy mapping includes activities such as scoping exercises, retrieval of existing usable data on renewables, high-resolution modelling, ground-based measurements and data collection, production of resource atlases, geospatial analysis, strategic environmental and social assessment, policy integration, and capacity building at local level. ESMAP funding is provided by World Bank Group operational units, which work closely with client country governments to prevent overlaps with parallel initiatives and to build on existing expertise. The ESMAP budget receives contributions from Australia, Denmark, Finland, France, Germany, Iceland, Lithuania, the Netherlands, Norway, Sweden, the United Kingdom and the World Bank.

Source: ESMAP (2013), *ESMAP Initiative in Support of Renewable Energy Resource Mapping and Geospatial Planning*.

Assessing biomass potential and resources

One of the key steps in the bioenergy planning process is to estimate biomass potential through a resource assessment. The biomass resource assessment identifies the types, amount and availability of organic matter that can be used as bioenergy feedstock. In practice, the resource assessment is an iterative process and the amount of potential biomass resources will change over time as more information is gathered about feedstocks, technologies, costs, and the impacts of exploiting the resources. One way of conceptualising the biomass resource assessment is to think about different "potentials" that emerge over time, as more information is collected.[3]

This report identifies three biomass potentials that emerge during the baseline research phase:

- *Theoretical potential:* The overall maximum amount of terrestrial biomass that can be considered theoretically available for bioenergy production within fundamental bio-physical limits.
- *Technical potential:* The fraction of the theoretical potential that is available under current framework conditions: available infrastructure, capacity and technology (such as harvesting techniques, infrastructure and accessibility, processing techniques).
- *Sustainable potential:* The share of the technical potential that meets criteria of economic profitability, while being environmentally and socially sustainable.

In practice, the assessment of the *theoretical potential* will consider all biomass in the area analysed, while the *technical potential* will focus on biomass available and accessible for energy production within the bounds of existing infrastructure and technologies. This will provide a somewhat more realistic idea of the available biomass, as well as land resources potentially available for bioenergy production. Such general categorisation of the biomass potential, however, needs to be further refined to assess the *sustainable potential* of the available resources. Sustainability is determined by the actual costs of biomass

3. See also the conceptual framework in Vis and Van den Berg, 2010.

production and collection and thus the economics of different conversion routes, taking into account the environmental and social impacts. Ultimately, the assessment of biomass potential should also take into account a range of institutional and geo-political considerations that will affect the implementation of bioenergy projects in the target region and within the roadmap timeframe.

The availability of sufficient amounts of biomass resource is one of the key factors determining the potential role of bioenergy in the national or regional energy system considered in the roadmapping process. In this respect, it is important that the estimation of biomass potential takes into account the possible types and origins of biomass resource.

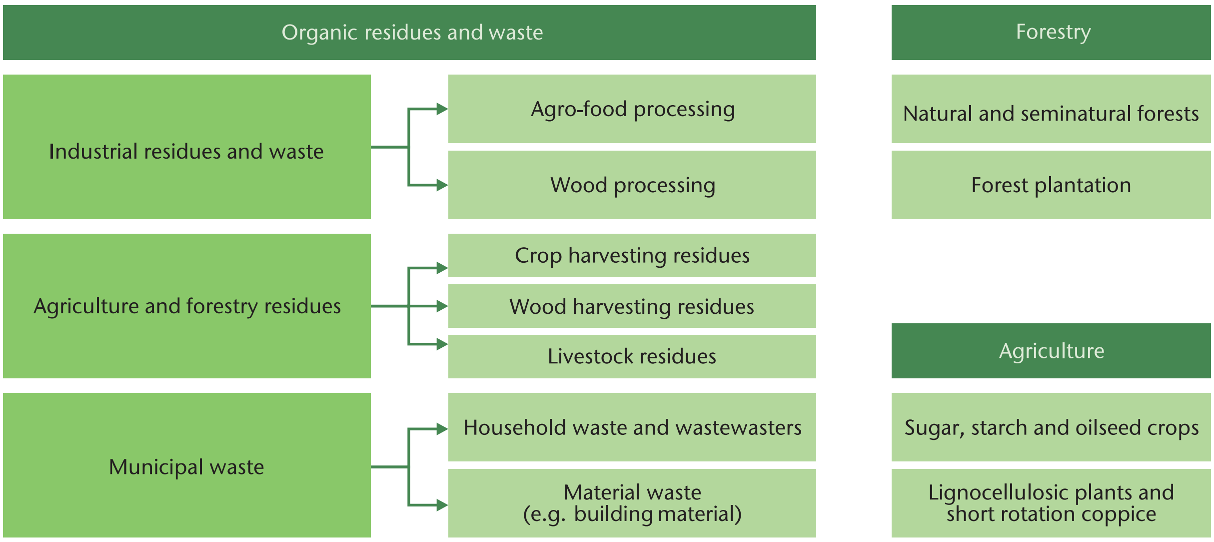
Sources of biomass

Biomass resources can be classified into three main groups, determined by their origin (Figure 5):

- *Residues and waste:* Biomass as a by-product, residue or waste of other activities and product streams
- *Forestry:* Biomass harvested from forestry
- *Crops and fast-growing grasses*: Biomass grown specifically for energy production.

Each type of biomass origin is discussed in detail below.

Figure 5: Biomass types according to origin



Source: adapted from FAO (2004), *Unified Bioenergy Terminology – UBET*, www.fao.org/docrep/007/j4504e/j4504e00.htm.

Residues and waste

The assessment of the biomass potential of residues and waste from agro-food and forestry supply chains, including residues of industrial processing, starts with the analysis of agricultural and forestry production and the identification of existing agro-food and wood processing industries to determine what residues are produced at each stage of the production process.[4]

4. For example, in rice mills residues will include rice husk, while sugar production facilities will generate sugar cane bagasse and molasses, if sugar cane is used as feedstock, or sugar beet pulp and molasses, if sugar beet is the feedstock. The identification of available residues is followed by analysis of the respective characteristics and the amount generated.

It is crucial to assess if and how residues are currently used and whether bioenergy might compete with existing uses. To ensure that the utilisation of residues will not have negative impacts on food security or the environment and will not undermine their use for other purposes, it is important to identify and quantify current uses as well as other potential non-energy uses. Crop and food processing residues are often used as animal feed, either directly or after further processing. Diversion from feed into the energy market may have detrimental effects on the feed market and directly or indirectly on food security (Maltsoglou et al., 2015).

An important consideration at this stage is the accessibility of residues. For harvesting residues, for example, it is important to know whether the crop residues are collected during harvesting or left spread in the field. In the case of livestock residues, farm size and feeding practices should be considered. The accessibility of residues has implications for the *technical potential* and also affects the economics of the *sustainable potential*. Information about the chemical and physical characteristics of the residues is used to calculate their energy potential and to identify suitable conversion technology (Vis and Van den Berg, 2010).

The biomass potential within an area is commonly expressed on an annual basis; however, it is important to consider seasonality and inter-annual variability. For instance, depending on the agricultural and crop production cycle, agro-food processing facilities may generate different types of residue during the year. In addition, climate and weather conditions, as well as changes in policy and market conditions, may affect agricultural production in the short and medium term, thereby also affecting residue generation.

The organic fraction of MSW and wastewater is also an important source of biomass suitable for energy generation. "Waste-to-energy" pathways can provide examples of good waste management practice contributing to the reduction of GHG emissions. A number of input parameters are key to assessing the technical and sustainable potential of waste or wastewater treatment and associated energy production facilities, and are equally important when designing such plants. To assess the energy potential of MSW, it is necessary to evaluate the composition of the waste's organic fraction. The technical potential is determined on the basis of the waste's characteristics and method of collection. It is important to know what proportion of the organic fraction of the MSW is, or can be, collected separately from the other waste fractions, and whether a separate waste collection system is in place or can be established. For municipal wastewater, the parameters to consider are the average amount of wastewater generated per inhabitant and the wastewater characteristics, such as total solids content, their organic share and degradability. Other key factors include: the existence of a wastewater collection system in the area assessed; the number of residential and industrial facilities that are connected to it; competition for wastewater from other sectors; and population density and stability in the assessed area. For example, the amount of waste and wastewater residue generated in tourist destinations may fluctuate considerably depending on the season.

Forestry

Forests are the oldest major source of biomass for energy production and a number of other material and ecosystem services, a role they continue to play today. When assessing the bioenergy potential of forests, it is important to consider their function, their sustainable management and the benefits a cascading use of wood brings (WBGU, 2010). Thus the assessment starts with evaluation of the forest stocks in the target area, any change in stocks over time, and their functions. In general, production forests are grown for the production of material and woodfuel, and these are the primary source of bioenergy feedstock. However, certain potential lies in protected forests, too. This includes residual wood cut for the purpose of maintaining the main function of the forest and its health. To identify the amount that can be harvested for energy production, it is necessary to identify the biomass quantities needed for material uses and the biomass quantities that can be used as woodfuel. When evaluating the *technical potential,* consideration should be given to tree species and the respective energy content, accessibility of forests, harvesting methods, and types of available forestry residue.[5] These factors will also have significant implications for the *sustainable potential*, where attention is given also to the preservation of ecosystem services.

Crops and fast-growing grasses

The potential for growing biomass specifically for energy production is assessed in ways similar to the potential for crop production. Factors to consider include the availability of land, its agro-ecological suitability for the selected crop and agricultural practice to be implemented, upon which the attainable yield and therefore the amount of biomass produced will depend. When considering crops as a source of biomass for energy, it is crucial to consider food security, the sustainable use of resources and potential socio-economic implications of production, as energy crops may directly compete with food crops for resources, such as land and water. Food security, sustainability and land tenure considerations should therefore already be incorporated in the assessment of theoretical and technical potentials. In practice this

5. Forestry residue types commonly used for bioenergy production include distorted wood, small round wood (SRW), branches, tops, bark, brash and others.

means that the type of crop should be carefully selected to avoid using important staple crops as energy crops, especially if the country is a net importer of staple foods.

The potential for sustainable increases in yield should be prioritised before considering expansion of arable land. A further important factor to consider is the characteristics of existing agricultural production in the country, including the type and size of agricultural holdings, agricultural practices and level of production, as well as market conditions. Considering the food security and sustainability criteria, biomass potential is calculated on the basis of potential crop production levels and subtraction of the part needed for non-bioenergy uses, primarily food, feed and material uses, but also exports if they bring greater socio-economic benefits to the country (FAO, 2014a). As with other biomass types, the economics of any project using energy crops as the feedstock will depend on the selected conversion technology, accessibility of biomass, policy and legislative frameworks and other prevailing constraints, such as technical and knowledge capacity and social acceptance.

Assessing available technologies and costs

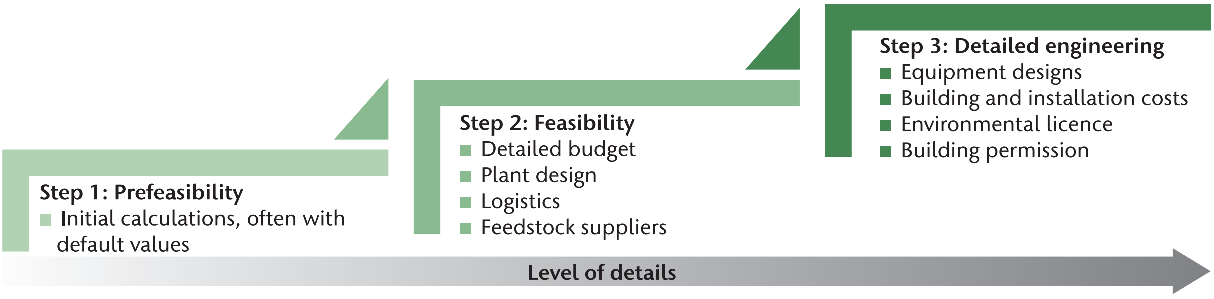
Following the assessment of biomass resources, the next step is to determine the requirements for and availability of technologies for converting the identified biomass resources. The thermochemical composition of biomass feedstocks differs markedly from solid fossil fuels due to typically higher oxygen, chlorine and alkaline content. This means that bioenergy technologies have to be specifically designed to match the properties of the feedstock. While some conversion processes are relatively straightforward (e.g. direct combustion of forest wood for heat production), a range of pre-treatment and upgrading technologies exist and are necessary to improve the characteristics of many biomass products, and in particular to enhance their energy density. In growing order of technology maturity, these include hydrothermal upgrading, torrefaction, pyrolysis and pelletisation.[6]

As shown in Figure 6, the design and engineering of bioenergy technology projects can be analysed in three steps that require growing levels of detail and information. The outcome of each step will determine whether or not it is worth continuing with the next one and finally with implementation:

- Step 1: Prefeasibility analysis where initial calculations are performed using default data and assumptions. Only the most critical process units are considered for calculation, and the operational regime (i.e. continuous or batch) is decided.
- Step 2: Feasibility study where more detailed information and process designs are required considering all types of operation involved in processing. Here it is also important to define other operational details, such as feedstock and reagent suppliers, and potential plant locations.
- Step 3: Detailed engineering study which considers precise calculations and designs of equipment, building sites, equipment installation, internal configuration, modes of operation, stabilisation times, building permissions and environmental licences, among other issues. Project implementation can begin after this stage.

6. Recognising that it would impractical to carry out here a comprehensive, comparative analysis of technology options for producing heat, power and transport fuels from each biomass type, for further insights readers may wish to examine the following publications (in chronological order): Douglas, 1988; Edgar, Himmelblau and Lasdon, 2001; Smith, 2005; IEA Bioenergy TCP, 2009; IEA, 2011a; IEA, 2012.

Figure 6: Steps in the planning and engineering of bioenergy technology projects



Source: adapted from Rincón, Hernández and Cardona (2014), "Analysis of technological schemes for the efficient production of added-value products from Colombian oleochemical feedstocks", *Process Biochemistry*, Vol. 49, No. 3; Rincón, Moncada and Cardona (2014), "Analysis of potential technological schemes for the development of oil palm industry in Colombia: A biorefinery point of view", *Industrial Crops and Products*, January, Vol. 52.

In addition to the analysis outlined above, certain overarching elements that need to be considered before implementing the project include:

- The availability of bioenergy technologies locally.
- The capacity to import and adapt bioenergy technologies.
- The availability of skilled human resources.

These initial considerations help to determine the country or region's technical capacity to pursue the bioenergy projects that are being considered for the roadmap. As the success of a roadmap heavily depends on these elements, it is important to identify and address potential gaps at an early stage. Where a skills gap is identified, the need for targeted training and certification programmes should be considered.

Other important aspects that are part of the technology assessment are system performance, process efficiency, the structure of the biomass supply chain, its viability over time, and logistical information. Operational parameters, such as the feedstock collection area, collection period and transport distances, may determine the optimal size of operations and/or how many bioenergy plants can operate with locally sourced feedstock and/or imported biomass products.

This information can help inform decisions on the location of bioenergy plants and whether all the biomass required to operate the plant exists locally or needs to be supplemented with external sources. It is also important to study the seasonality of biomass collection to define storage types and capacity.

Additionally, one should consider the costs of relevant technology components. For example, planning for a bioenergy co-generation project would require information on the upfront and ongoing costs of reciprocating engines and steam turbines, heat recovery equipment and thermal management systems, as well as communication and control equipment for grid integration, operation and management.

At this stage, production costs, financial profitability and capital investment relating to selected bioenergy pathways are analysed to understand how competitive biomass alternatives are compared to current market options, and how bioenergy prices might affect the choices made by final consumers. It is important to use the appropriate comparison price, considering the target market (e.g. rural, urban or industrial) and the potential alternative routes for biomass import or export.

Assessing sustainability

A range of environmental, social and economic factors may influence the final performance of the bioenergy supply chain. When developing the roadmap, it is therefore necessary to consider the sustainability of each part of the chain as well as the chain as a whole. This will result in the identification of the preferable biomass types, feedstock sourcing patterns and bioenergy technology options that can deliver the desired forms of energy in the country or region.

The production and use of bioenergy can provide multiple benefits, including economic and social development, climate change mitigation, and improved access to modern energy services. On the other hand, if unsuitable policies and practices are adopted, bioenergy development can also have risks, such as increased pressure on land and water resources, increased GHG emissions through land use change as well as biodiversity loss. The nature and magnitude of these benefits and risks depends on a number of factors, including:

- Environmental and socio-economic characteristics of the specific country, area or group of people considered.
- Regional, national and local policy environment.
- Types of bioenergy, feedstocks and processing technologies.
- Types of agricultural and forestry management approaches, systems and practices implemented in bioenergy feedstock production.
- Scale and ownership of production.
- Logistics of biomass transport, particularly the means of transport and distances.
- Types of business model found along the bioenergy supply chain.

At the national level, policy makers have implemented various approaches to assess, manage and monitor the sustainability of modern bioenergy development, particularly in response to public concerns that the GHG benefits of producing and using biomass can be reduced or negated by carbon emissions associated with direct or indirect land use change (LUC).[7] A sizeable literature exists on possible approaches and good practice that reduce LUC-related risks (including FAO, 2012b; LIIB, 2012; Wicke et al., 2015). Box 6 illustrates the approach taken by a leading biofuels-producing country, Brazil, to regulating and accounting for LUC.

Many countries have put in place mandatory sustainability criteria for biofuels. In EU countries, for instance, in order to be considered sustainable, biofuels must achieve GHG savings of at least 35% in comparison to fossil fuels (increasing to 50% in 2017 and, for new installations, to 60% in 2018). Furthermore, in order to qualify as sustainable, biofuels cannot be made from raw materials obtained (including through imports) from land with high biodiversity value and high carbon stock, such as wetlands, forests and highly biodiverse grasslands. Only biofuels that comply with these criteria can receive government support or count towards the EU targets of 10% of transport energy needs to come from renewable sources by 2020 (European Commission, 2015).[8]

Sustainability considerations are relevant throughout the whole roadmapping process. In particular, it is recommended that sustainability aspects are assessed during both planning and monitoring phases and at both national and project levels, taking into consideration the economic, social and environmental dimensions of sustainability (Figure 8).

7. Two different types of LUC have been identified in the context of bioenergy development: direct and indirect. Direct LUC occurs when land with high carbon sequestration potential is converted to cultivating biomass feedstock. Indirect LUC occurs when bioenergy feedstock production displaces, for instance, food production, which is subsequently relocated to areas with high carbon sequestration potential (Dehue, Cornelissen and Peters, 2011; IEA Bioenergy TCP, 2010b). In both cases, LUC can result in significant GHG emissions and in the loss or deterioration of biodiversity and ecosystem services.

8. This target was the subject of heated debate in the EU institutions over the sustainability of biofuels, focusing in particular on the difficulty of properly accounting in existing legislation for the potential impact of indirect LUC on biofuels' GHG balances along the whole supply chain. The debate triggered the introduction of a 7% cap on transport biofuel's eligibility to count towards the European Union's 2020 targets for renewable energy.

Box 6: Brazil's approach to assessing agricultural land as suitable for sugar cane production

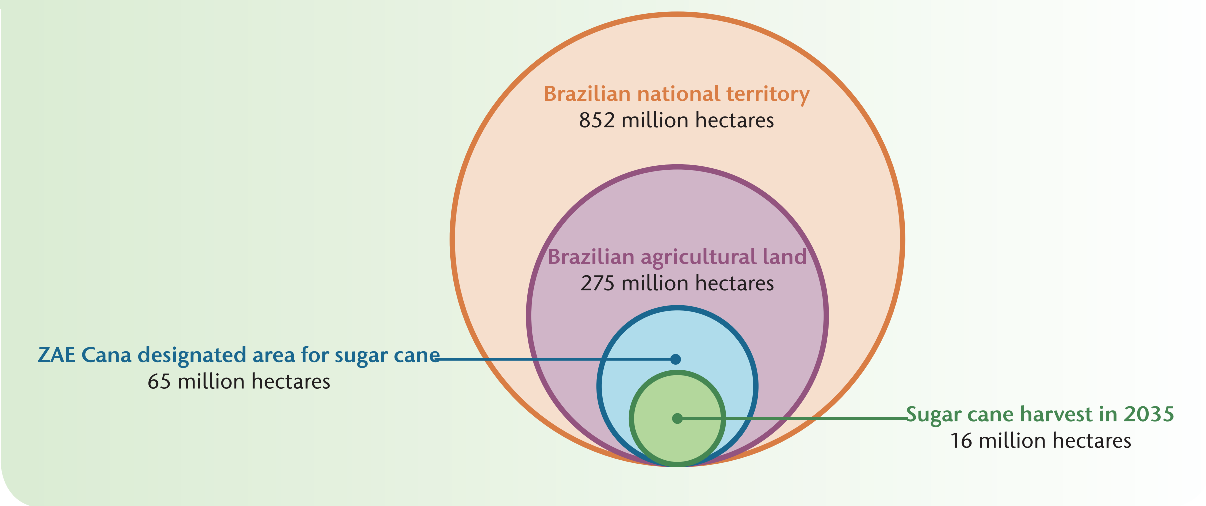
In response to concerns that increased biofuel production could displace other agricultural activities and contribute to deforestation, Brazil has become one of a handful of countries that have used Agro-Ecological Zoning (AEZ) techniques to identify suitable areas for bioenergy feedstock expansion, taking into account sustainability aspects and constraints.

The government's "ZAE Cana" programme has mapped suitable zones for growing sugar cane to ensure that sufficient suitable land remains to expand production in Brazil. The programme identifies underutilised pasture lands where sugar cane production could expand sustainably, for instance by increasing cattle densities on other pastures (Teixeira de Andrade and Miccolis, 2011). Under its guiding criteria, 7.5% of Brazil's national territory could be suitable for sugar cane production (Figure 7) and only 25% of this potential area is expected to be utilised for sugar cane in the next 20 years.

The programme is also enforced by limiting access to development funds for sugar cane growers and sugar mill/ethanol plant owners that do not comply with regulations. While the country's geography and climatic conditions might suggest that further expansion beyond the land identified in the ZAE Cana programme is possible, sustainable production is limited by the critical need to protect the Amazonian forests and other environmentally sensitive regions; expansion at the expense of protected areas could threaten exports to the United States and European Union, two of the three largest international markets for Brazilian biofuels.

Box 6: Brazil's approach to assessing agricultural land as suitable for sugar cane production (continued)

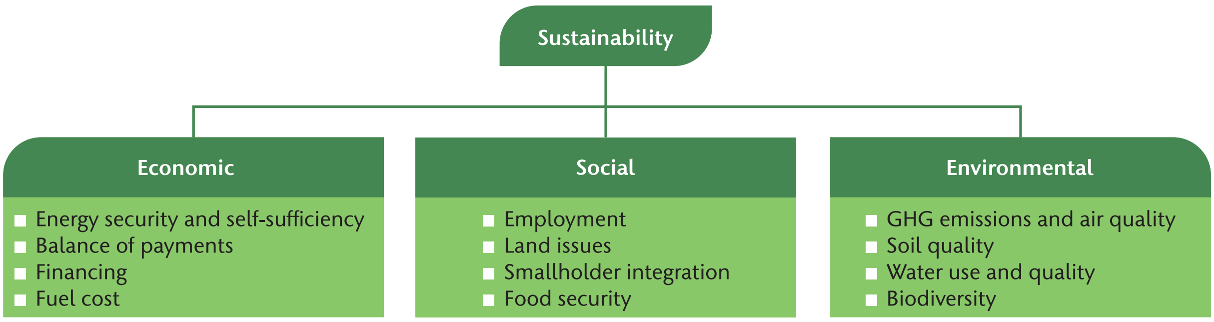
Figure 7: The ZAE Cana designation of land suitable for sugar cane production



Note: the ZAE Cana designated area is restricted to the total characterised by medium to high productivity; the sugar cane harvest includes both sugar cane for ethanol, based on IEA analysis, and sugar cane for sugar production, increasing by 1.7% per year.

Sources: IEA analysis drawing from information by the Brazilian Agricultural Research Corporation, Ministry of Agriculture, Livestock, and Food Supply (EMBRAPA); Teixeira de Andrade and Miccolis (2011), "Policies and institutional and legal frameworks in the expansion of Brazilian biofuels", Working Paper 71, Center for International Forestry Research, www.cifor.org/nc/online-library/browse/view-publication/publication/3509.html; IEA (2013), *World Energy Outlook 2013*; and presentation by Sandro Marschhausen at IEA/FAO workshop (Nov 2014).

Figure 8: Environmental, social and economic sustainability aspects of biofuel and bioenergy production



Source: adapted from IEA (2011a), *Technology Roadmap: Biofuels for Transport*.

Economic aspects of sustainability

The economic impacts (both short and long term) of bioenergy use should be evaluated to determine whether, under which conditions, and to what extent expanding bioenergy supply can produce a net economic benefit for the country or region. The competitiveness of bioenergy technologies should be evaluated against that of alternative energy sources and technologies, both fossil-based and renewable. In addition, the economics of using biomass for bioenergy should be compared to the economics of using it for other economic activities. For example, crop residues could be used for bioenergy but could also be used as animal feed in agricultural production.[9]

9. There is a rich and growing array of studies that analyse economic aspects of bioenergy projects and interactions along the biomass value chain, in some cases taking a combined approach inclusive of social and environmental aspects. Examples include the following: Cambero and Sowlati, 2014; Dale et al., 2013; Fazio and Barbanti, 2014; Vlysidis et al., 2011.

Expanding biomass production can have important implications beyond the biomass feedstock and downstream processing sectors. Bioenergy production can have positive multiplier or spillover effects for the rest of the economy, for example when intermediate inputs such as transport services are required to transport the biomass or biofuels to consumers or export markets. Growth in industries that support bioenergy can create new sources of income, which, if spent on consumer goods and services, creates a virtuous circle with additional demand for non-biofuel products.

Macroeconomic linkages may also play a role by stimulating overall economic growth. For example, in countries that are net exporters of biomass products, biofuel exports can relieve foreign exchange constraints, which often limit developing countries' ability to import the investment goods needed to expand production in other sectors. Together, these economic linkages can generate gains that are far larger than those generated within the bioenergy sector alone.

While there are potential economy-wide gains to be had from expanding bioenergy production, there are also potential costs for production and incomes elsewhere in the economy. Bioenergy production can require factor inputs, such as land and skilled labour, which are in limited supply in many countries. Allocating arable land to biomass feedstock may reduce the land available for other crops. Even where unused land is available to produce energy crops, a displacement of labour from sectors other than bioenergy may still occur, as workforce is drawn into biomass estates or plants, or as smallholder farmers reallocate their time to producing energy crops. As biomass production expands it may cause production in other sectors to fall, thus offsetting at least some of the economic gains mentioned above. Finally, biomass and biofuels producers may need tax incentives or supporting investments from the government that reduce public revenues for other activities, such as education, health and infrastructure (i.e. opportunity costs). This "fiscal displacement" may slow development in non-bioenergy sectors (FAO, 2010).

Social aspects of sustainability

In addition to economic benefits, expanding bioenergy production can provide a number of social and societal benefits, such as job creation, improved access to energy, rural development and, more generally, new opportunities associated with the development and diversification of biomass-related markets. Many of the social benefits derive from the spillover effects that bioenergy production can bring to other sectors of the economy – bioenergy production generates additional demand for a range of locally produced services (e.g. transport services), which may create new jobs and income opportunities for workers and households.

Conversely, bioenergy development may also have negative social impacts, for instance in cases of a mismatch between the existing local workforce and the specialised mix of labour skills required by an expanding bioenergy sector. Therefore, during the planning phase it is important to take into full account the possible social impacts of bioenergy development and consult with communities early in the process (discussed further in the following section on stakeholder identification). Specific attention must be paid to options for integrating smallholders in the bioenergy pathway(s), since their participation (or lack thereof) can also affect local communities' acceptance of bioenergy projects.

Within the social pillar of sustainability, the following issues are recognised as important – and to a certain extent are addressed under the main regulatory frameworks and voluntary standards for certification of sustainable bioenergy:

- education, training and capacity building
- employment
- food supply and access
- health and safety.

Environmental aspects of sustainability

For many countries, climate change mitigation is one of the main drivers and objectives of national bioenergy policies and strategies. Therefore, it is important to determine on what basis bioenergy can deliver GHG emission savings compared to using fossil fuels or other renewable energy sources. Given the increasing pressure on natural resources and ecosystems from the growing demand for biomass for food, feed, fibre and bio-based materials and chemicals, in addition to bioenergy, it is crucial to take environmental aspects into full account for the assessment of bioenergy sustainability.

The GHG impacts of bioenergy systems should be evaluated by looking at the whole life cycle of the bioenergy pathway(s) under consideration, including biomass production, biomass transport, bioenergy production, and final bioenergy end uses. Such a life cycle assessment (LCA) approach may also take into account the potential LUC (both direct and indirect) that can be triggered by the increased demand for biomass feedstocks.

LUC modelling and measurement are inevitably subject to uncertainties and assumptions; however, recent years have seen an intensification of research efforts to measure the exact order of magnitude of GHG emissions for direct and indirect LUC relating to various feedstock types, as well as strategies for mitigating these changes. For example, prioritising waste and residues as feedstock will not induce additional land demand if the residues are not otherwise used. Choosing high-yielding feedstocks, such as perennial energy crops, particularly on unproductive or unused soils, is also likely to reduce the risk of indirect LUC. Researchers in the Netherlands have developed a regional approach that aims to assess and quantify options to prevent indirect LUC, without diverting other crop production or expanding into high-carbon stock or other land with high environmental value (Brinkman et al., 2015).

Ultimately, regulatory schemes for sustainable land use management and voluntary standards for certification are both needed to ensure environmental sustainability of bioenergy production. Biofuels certification schemes are already used at an operational level and international certification schemes for solid biomass are being discussed. The relevant policy framework should consider the following aspects:

- air quality and lifecycle GHG emissions
- biodiversity, LUC and soil quality
- water quality, water use and efficiency.

A range of resources exists that can be of use in the assessment of economic, social and environmental aspects of sustainability. The Global Bioenergy Partnership (GBEP) has, with substantial input from both FAO and the IEA, produced a set of 24 indicators and related methodologies that aim to facilitate the assessment and monitoring of bioenergy sustainability at the national level (see Box 7 and Annex 2). As described further under Phase 4 of the *H2G.BIO* that considers *implementation, monitoring and revision* of the roadmap document, measured over time these indicators can show progress towards or away from the desired pathway of sustainable bioenergy development.

Box 7: GBEP Sustainability Indicators for Bioenergy

GBEP is an inter-governmental initiative that brings together 50 national governments and 26 international organisations. It was established to implement the commitments taken by the G8 in the 2005 Gleneagles Plan of Action to support "biomass and biofuels deployment, particularly in developing countries where biomass use is prevalent".

In order to facilitate the assessment and monitoring of bioenergy sustainability at a national level, GBEP produced a set of 24 indicators and related methodologies (FAO, 2011). These indicators, which are based on a series of relevant themes under the three pillars of sustainable development (Figure 8), address the production and use of liquid, solid and gaseous biofuels for heat and power and for transport. They are intended to inform policy makers about the environmental, social and economic sustainability aspects of the bioenergy sector in their country and guide them towards policies that foster sustainable development.

As of April 2015, the GBEP Sustainability Indicators for Bioenergy had been implemented in six countries and were in the process of being implemented in a further six. GBEP is considering how to use the lessons learnt from the implementation of the indicators to inform the development of an implementation guide. The full set of GBEP indicators is found at Annex 2.

Identifying bioenergy stakeholders

Given the cross-sectoral nature of bioenergy, an effective roadmapping process requires the participation of many diverse stakeholders. At the governmental level, several policy-making authorities need to co-ordinate amongst themselves, for example including ministries dealing with energy, transport, agriculture, environment and natural resources such as water and forestry. Social interest groups should also be involved in the bioenergy development process so that the full implications of the production chain are considered when determining public and private sector interventions.

Stakeholders may have different, even conflicting interests and views on policy and project developments, in some instances making collaboration and co-ordination a challenge. A cross-cutting and broad-based consultation which at the outset defines the stakes and priorities for bioenergy development can help promote collaboration throughout the bioenergy roadmapping phases (FAO and UNEP, 2010).

Useful governance frameworks at the national level include working groups to facilitate close inter-ministerial collaboration to define country priorities on issues of national importance, such as energy and food security. Such working groups may also include consultation with the private sector, financial institutions and civil society. Regional and municipal policy makers, industry associations as well as representatives of local communities should be given the opportunity to participate in the roadmapping process from early on, to ensure that the roadmap includes strategies to maximise the benefits of bioenergy for all parties. An example of stakeholder engagement is provided in Box 8.

Box 8: Stakeholder dialogue and set up on bioenergy in Sierra Leone

Sierra Leone, while a resource rich country, is classified as a low-income, food-deficit country, with 70% of the population below the poverty line and 35% undernourished. At the same time, less than 7% of the rural population have access to electricity networks and an estimated 90% of the population depend mainly on fuelwood for cooking and kerosene for lighting. In recent years private-sector investors have shown a growing interest in investing in bioenergy-related projects, but the country has had no policy on bioenergy. This has resulted in a lack of co-ordination among stakeholders from the various interests concerned and in relation to agriculture and energy policies.

As described above, given the multidisciplinary nature of bioenergy, stakeholder engagement and dialogue is one of the key elements in developing a feasible and implementable bioenergy roadmap. As a step in the bioenergy policy formulation process, in 2011 the government of Sierra Leone, in co-ordination with FAO, established a technical multidisciplinary working group, the Bioenergy and Food Security Working Group, with the primary objective of addressing bioenergy challenges and supporting dialogue on sustainable bioenergy development.

The Bioenergy and Food Security Working Group has brought together the many perspectives on bioenergy and the expertise to tackle sustainable bioenergy development given the country context, constraints and existing policies. The Bioenergy and Food Security Working Group is chaired by the Ministry of Energy and co-chaired by the Ministry of Agriculture, Food Security and Forestry, and also includes representatives from: the Ministry of Local Government and Rural Development; the Ministry of Land, Country Planning and Environment; the Ministry of Water Resources; the Ministry of Trade and Industry; the Ministry of Finance and Economic Development; the Sierra Leone Investment and Export Promotion Agency; the Ministry of Social Welfare, Gender, and Children's Affairs; the Ministry of Labour and Social Security; the Environmental Protection Agency of Sierra Leone; and the Human Rights Commission of Sierra Leone.

To date Sierra Leone has not been able to cover all steps of the roadmap process, but the outputs of the working group include a short- and longer-term strategy to respond to the pressing issues of investment requirements, identification of legislative gaps, and guidelines for agriculture and bioenergy investment.

Source: FAO (2012c), *BEFS Work in Sierra Leone*, www.fao.org/energy/befs/82341/en/.

Table 2: Stakeholders relevant to bioenergy policy and project development

Stakeholder type	*Overview of stakeholders*	*Role*
Government	National, regional or municipal departments (ministries) in charge of: ● Energy ● Transport ● Agriculture, livestock ● Forestry, environment, land use planning ● Food security ● Rural development, economic development ● Water resources ● Trade, industry, investment	Responsible and/or Accountable
Regulator or regulating body	Typically mandated by a governmental body, this includes entities responsible for: ● Operation of the electricity system ● Operation of thermal energy networks, in presence of district heating and/or cooling ● Setting, implementing and monitoring sustainability criteria, as well as standards and certification for biomass feedstock, biofuels and bioenergy technology ● Providing permits ● Regulating fuel standards and distribution ● Energy consumers' protection	Accountable
Industry and businesses	A wide range of stakeholders from the private sector may have an important role in the development and implementation of bioenergy roadmaps, including: ● Bioenergy project developers ● Farmers and land owners who take part in bioenergy projects ● Energy generators, both in distributed and centralised systems, including from sources alternative to bioenergy (e.g. other renewables, nuclear energy, fossil fuels) ● Energy retailers, i.e. the provider of electricity and heating services to households and industrial processes ● Forestry companies and land concessionaires ● Feedstock producers and processors ● Entities in charge of waste management ● Biomass transporters and traders ● Biofuel transporters and traders ● Equipment manufacturers and technology providers ● Companies providing planning, installation and maintenance services for bioenergy technologies ● Industry groups and associations	Accountable and/or Consulted

Stakeholder type	Overview of stakeholders	Role
Investors	Several types of investor are of interest to policy and decision makers when seeking to implement bioenergy strategies: ● Commercial banks ● Public financial institutions, including development banks ● International lenders and donors ● Private equity and venture capitalists ● Providers of microcredit	Consulted
Universities/ research organisations	This group typically includes experts from research centres and universities who can contribute to the roadmap development with valuable technical input, information and data	Consulted
Civil society	This includes groups whose role in the process may vary from central to negligible; their views must be considered in the roadmap process: ● Non-governmental organisations (NGOs), particularly those working on energy access, rural development, and environment ● Farmers and landowners (even if not taking part in bioenergy projects) ● Associations and groupings of energy consumers in the residential, services and industrial sectors ● Community-based organisations and groups ● Consumers	Consulted and/or Informed

Notes: Table 2 is organised by the hierarchy of roles; the list of stakeholders within each of the three types is not exhaustive and other parties may have a role depending on the institutional framework as well as on the scale and scope of the individual projects.

Not only is it important to identify these stakeholders prior to developing a roadmap, but it is also important to determine the role that each stakeholder could play in the process. Table 2, which is based on the "RACI" responsibility assignment matrix,[10] provides an overview of the types of stakeholders who should be consulted and included in bioenergy policy-making and project decisions, and their related functions.

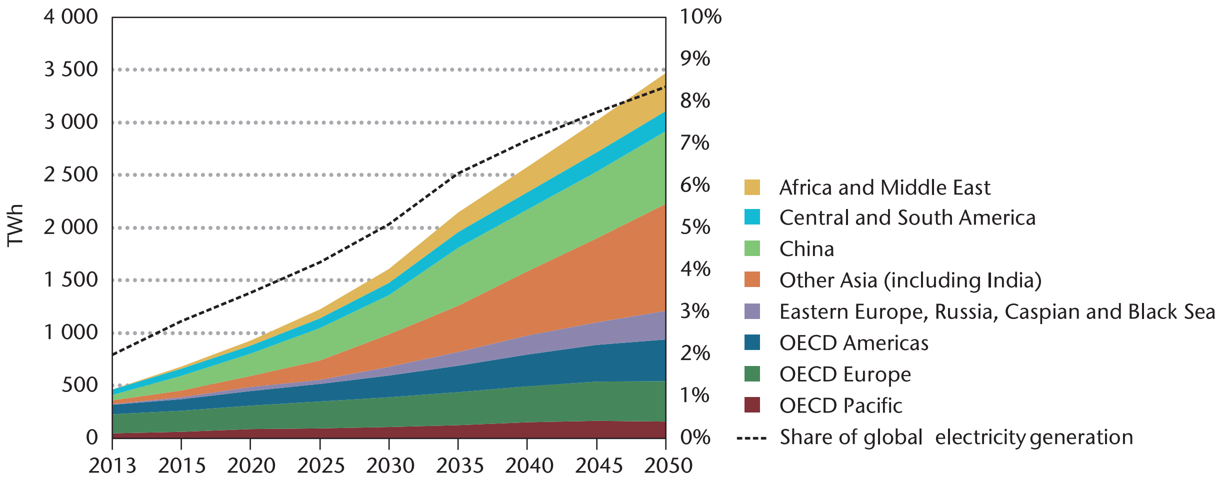
10. The "Responsible, Accountable, Consulted and Informed" (RACI) chart is a management tool used to define responsibilities among a group. It is a responsibility assignment matrix. More information is given in the *IEA Roadmap Guide* (IEA, 2014a).

At the conclusion of Phase 1, a range of information will have been gathered and all relevant stakeholders will have been identified. From this point, the process of defining the needs and objectives for deploying bioenergy can begin (be it energy security, reducing GHG emissions, mitigating and adapting to climate change, poverty reduction and increasing rural income, local environmental protection, or other aims). *Visioning*, the next phase in the roadmapping process, focuses on identifying the drivers of a bioenergy strategy, and articulating them in the form of a coherent vision.

Phase 2: Visioning

The second phase in the roadmapping process should outline a vision for bioenergy deployment in the country or region within a given timeframe. A good roadmap ought to include a clear statement of the desired outcome, accompanied by a specific course of actions for reaching it. This will serve as the mission statement, framing what the roadmap will aim to achieve in broad terms. This phase may include modelling and scenario analysis used to define possible future outcomes. Figure 9 provides an illustration of the possible outcome of the *Visioning* phase, drawing from the IEA's long-term global vision of biomass for electricity generation.

Figure 9: Global vision of biomass for electricity generation



Source: IEA analysis based on data from the *Energy Technology Perspectives* (ETP) 2°C Scenario (2DS) (IEA, 2016c).

Note: this example is particularly interesting in that it sets a global target over 8% of electricity generation from bioenergy by 2050 and it provides a breakdown for key world regions, in line with IEA models that integrate the technical and economic characteristics of existing technologies and aspects specific to each market. The underlying approach can be used at national or regional level to determine the cost-effective mix of biomass resource and technologies in the bioenergy roadmap.

Climate-related international collaboration mechanisms have become increasingly relevant to the *Visioning* phase in recent years, specifically in the form of roadmapping processes for low-carbon technologies. The pledges – or Nationally Determined Contributions (NDCs) – for climate change mitigation submitted by individual countries for the 21st UN Conference of the Parties (COP21) in December 2015 can serve as a frame for the wider decarbonisation vision that should guide individual countries' roadmaps for bioenergy deployment.

As shown in Figure 10, this section of the *H2G.BIO* focuses on the process of defining the pathway(s) and milestones for bioenergy technology deployment. Two components are particularly important in this process and will be examined here: understanding the drivers and expected benefits of bioenergy, and setting targets for bioenergy deployment. Both are prerequisites to defining a clear vision for the roadmap.

Figure 10: Visioning phase

Notes: in this figure each arrow represents a substep in one of the four phases of the roadmap process set out in the IEA *Roadmap Guide* and in Figure 1 of this report; green-shaded arrows indicate substeps that are also discussed in this *H2G.BIO*; for further information on the steps in blue, see the IEA *Roadmap Guide* (IEA, 2014a).

Drivers for bioenergy

The identification of drivers for deploying bioenergy technologies is a key step in developing the vision and long-term goals of the roadmap. Significant variation exists across countries and regions in the drivers for deploying bioenergy, as well as in the relative importance of each. Based on research and experiences captured through the series of expert workshops undertaken to source information for this publication (see Box 1), the major drivers for bioenergy technology deployment can be grouped into three categories, as detailed further in Table 3:

- economic development and employment
- energy security
- reduction of pollution and GHG emissions.

Table 3: Overview of typical drivers for bioenergy deployment

Categories	***Possible drivers***	***Expected benefits***	***Examples of countries the driver is applicable to****
Energy security	• Reduce reliance on imported fossil fuels • Diversify energy supply mix • Increase dispatchable renewable capacity	• Reduced demand for imported fossil fuels • Diversification of the energy supply with positive impact on prices and price volatility • Improved balance of payments	Countries that are net energy importers. • IEA member countries such as Germany, Italy, Japan, Korea, United States • IEA partner countries such as Brazil, Chile, China, Tanzania, Thailand
Economic development and employment	• Generate new sources of income from indigenous biomass resources • Create jobs • Foster rural development • Increase energy access	• Economic growth • Benefits from expanded market for biomass resources and services • Rural development may lead to increased disposable income which can have positive macroeconomic impacts • Increased employment may generate higher income tax revenues, hence positive impact for the public budget	Countries with significant bioenergy generation capacity. • IEA member countries such as Canada, Denmark, Estonia, the Netherlands, Poland, Sweden. • IEA partner countries such as Botswana, Cambodia, Indonesia, Mozambique, the Philippines, South Africa, Zimbabwe, Viet Nam
Environmental benefits	• Reduce GHG emissions, particularly CO_2 and CH4 • Improve air quality and mitigate environmental pollution locally	• For forestry residues specifically, improved forest site conditions for planting** • Use of organic waste and agricultural residues that would otherwise be discarded • Lignocellulosic crops that could be grown on a wide spectrum of land types may mitigate land and water demand and reduce competition with food	Countries that set ambitious GHG reduction goals. • IEA member countries such as the EU countries, Switzerland, Norway, United States. • IEA partner countries such as: Brazil, China, Malaysia, the Philippines, South Africa.

* For each category of drivers, the examples of countries provided in Table 3 include at least five IEA member countries and five IEA non-member countries whose representatives participated in the expert workshops for the *H2G.BIO* (see Box 1). The examples are based on information in the IEA databases of energy statistics, policies and measures as well as on information gathered at the *H2G.BIO* expert workshops.

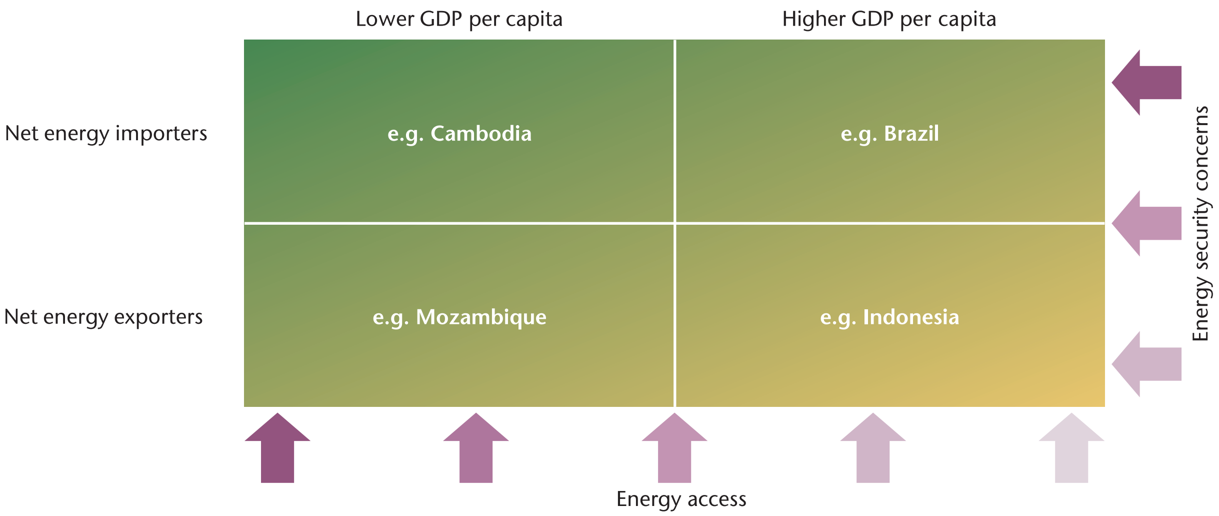
** Thinning from harvesting may lead to improved growth and productivity of the remaining stand, and removal of biomass from over dense stands can reduce the risk of wildfires (see also IEA Bioenergy TCP [2009]).

Each country taking steps towards bioenergy deployment will have unique priorities and will need to adapt the approach to its particular national or regional context. While some countries may identify several drivers for deploying bioenergy, others may choose to craft their mission statement around one or two main drivers. Decision makers should consider that including multiple drivers in the roadmap vision may influence the targets, data requirements and resources evaluation. In the absence of well-thought-out analysis of the value of bioenergy to the public sector, the private sector and civil society at large, it will be difficult for policy and decision makers to design a strategy that maximises the benefits of higher shares of bioenergy deployment, not least in periods of tight budgetary constraint.

The analysis of current and projected energy end uses in the buildings, industrial and transport sectors can help narrow down the focus of the bioenergy roadmap vision. Country-specific resource assessment and sustainability considerations explored under *Phase 1: Planning and preparation* of the *H2G.BIO* should inform decisions relating to the *Visioning* phase.

Figure 11 is a simple illustration of how different economic circumstances and energy security concerns can determine the drivers of bioenergy deployment, sometimes simultaneously. IEA research has shown that countries that are net energy importers tend to be driven more strongly to deploy bioenergy for energy security reasons. In net energy exporters, energy access can be an additional driver to pursue increased levels of bioenergy in the supply mix. In the case of Cambodia, as a net energy importer with a relatively lower GDP per capita, both energy security concerns and improving energy access may be key drivers for bioenergy deployment.

Figure 11: Typology of country clusters by strategic bioenergy policy drivers



Sources: based on data from IEA (2016d), *World Energy Balances*, and adapted from IEA (2011b), *Policies for Deploying Renewables*.

Note: the arrows are shaded to illustrate the expected likelihood that energy access and energy security concerns respectively will influence bioenergy strategies. A darker arrow suggests a greater likelihood that a bioenergy strategy will be influenced by energy access and/or security concerns. IEA analysis that explored the correlation between energy balances and increases in the share of biofuels in the transport sector in the timeframe 1990-2009, suggests that net oil importers have statistically significant higher increases in biofuels' share of the overall fuel mix (IEA, 2011a). The case of Indonesia, which attained a greater share for biofuels at a moderate gross domestic product (GDP), and which is also an exporting country, points to the importance of other drivers for investing in biofuel development, such as catalysing economic growth and alleviating poverty in rural areas (IEA, 2015b).

Deployment targets

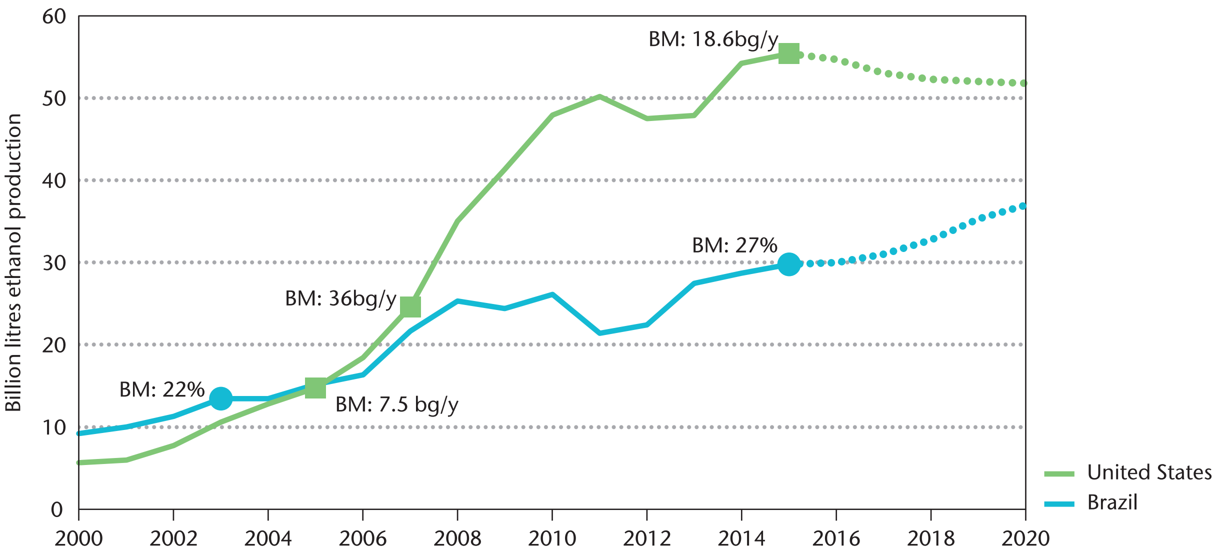
Individual countries differ in their existing energy infrastructure, energy demand profiles and the sustainable sources of biomass feedstock that are accessible and cost effective. Therefore, different drivers and related policy goals lead to the prioritising of different biomass options, bioenergy pathways and deployment targets. Bioenergy targets should be set in relation to country-specific analysis that illustrates the viability of bioenergy pathways and the end uses of the heat, power or transport fuels designated for domestic and/or international markets.

Setting a clear vision with credible targets will help effectively implement the roadmap, particularly when targets are mandatory rather than aspirational. An example of how mandatory targets have driven bioenergy deployment is the application of biofuel blending mandates in the transport sector. The IEA estimates that the adoption of blending targets or mandates, which define the proportion of biofuel (on a volume or energy basis) that must be used in road transport fuels, played a decisive role – in combination with other policies and drivers – in the eight-fold growth in global biofuel production that has taken place over 2000-15 (IEA, 2015f).

In 2005, the United States introduced the Renewable Fuel Standard (RFS) programme, which included a mandatory requirement for transport fuels to contain a minimum volume of renewable fuels. Initially, a target was set of 7.5 billion gallons of renewable fuel to be blended annually into gasoline by 2012. In 2007, the RFS was expanded under the Energy Independence and Security Act, increasing the long-term goal for volumes of renewable fuels to 36 billion gallons per year by 2022. By 2010, the United States had become a net exporter of biofuels and later became the world's largest ethanol exporter. Brazil provides a further successful example of government policies and targets shaping trends in biofuel production and use. The initial spur in 2003 was an ambitious blending mandate that aimed to incentivise the replacement of oil as transport fuel by ethanol produced from sugar cane, but that also supported large-scale transition to a vehicle fleet capable of running either on gasoline, ethanol, or a mixture of the two (Box 9).

Figure 12 shows how bio-ethanol production expanded significantly in both the United States and Brazil following the introduction of transport fuel blending mandates. Figure 13 illustrates that mandates produced comparable results in biodiesel production in Germany and the Netherlands.

Figure 12: Blending mandates and ethanol production in Brazil and the United States



Notes: the following acronyms stand for: BM = blending mandate for biofuels; bg/y = billion gallons per year; the following symbols in the line chart stand for: United States = ■ 2005; the RFS programme introduces the requirement for transport fuels to contain a minimum volume of renewable fuels with an initial target of 7.5 billion gallons of renewable fuel blended into gasoline by 2012; ■ 2007: RFS expanded, increasing the long-term goal for volumes of renewable fuels to 36 billion gallons by 2022; ■ 2015: the intermediary target for 2016 is set at 18.6 billion gallons; Brazil = ● 2003: the ambitious ethanol blending mandate of 22% pushes the market to make a breakthrough in flexible-fuel vehicles that can run on any proportion of gasoline (E20-E25 blend) and hydrous ethanol (E100); ● 2015: Brazilian ethanol blending mandate increased to 27%.

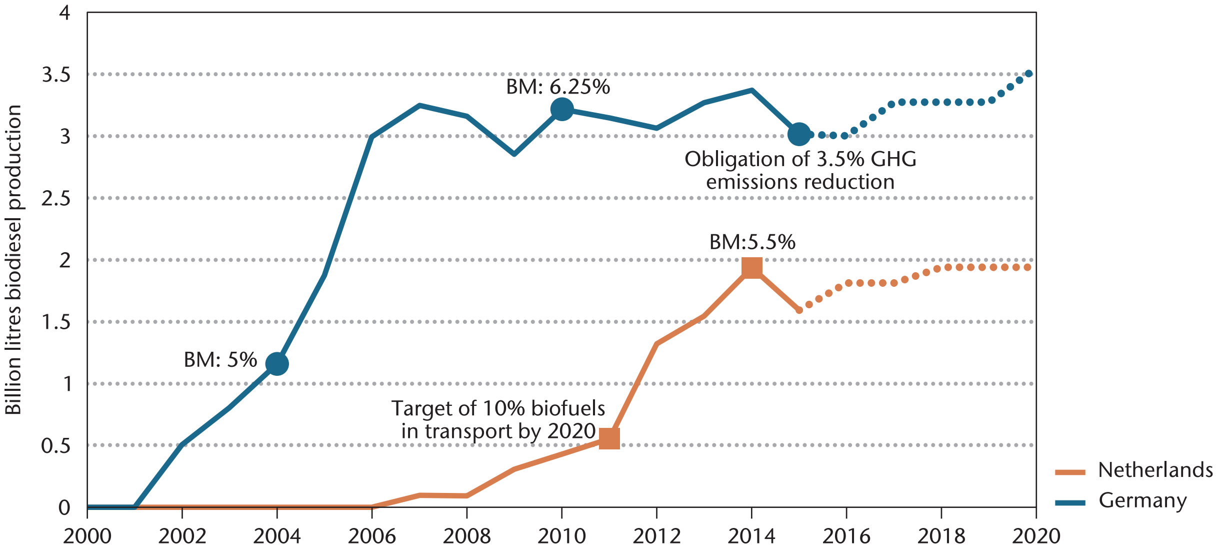
Source: IEA (2016a), *Medium-Term Oil Market Report 2016* and analysis based on the IEA/IRENA *Joint Renewable Energy Policies and Measures Database*, www.iea.org/policiesandmeasures/renewableenergy/.

Within biofuel blending mandates, mandatory quotas for specific types of biofuel may be an effective policy solution to support market penetration of innovative bioenergy technologies, particularly advanced biofuels that hold considerably higher potential for emission savings, but which currently present higher production costs and complexity.[11] In 2009, the United States introduced a quota within the RFS, requiring a certain percentage of renewable fuels in the mandate to be produced from lignocellulosic feedstocks. This quota is set at 16 billion gallons for the year 2022, representing 45% of the 36 billion gallons of renewable fuels mandated under the RFS.

Clear and reliable targets are an important component of the vision that guides a national or regional bioenergy roadmap. It should be noted, however, that technological advancements will also affect the market penetration of bioenergy, and while region-specific factors may influence bioenergy deployment, technological progress will largely follow global trends. The results of the sustainability assessment should feed into stakeholder dialogue and inform the definition of bioenergy policies. These will aim to ensure sustainable and efficient use of natural resources and serve the strategic objectives of the country, such as energy supply, job creation, rural development and improved agricultural production, among other factors. Policy makers need to adopt a dynamic approach to policy implementation, as highlighted in Box 9 and examined in the section of the *BIO.H2G* dedicated to the fourth phase of the roadmapping process: *Implementation, monitoring and revision.*

11. As a result of policy uncertainties, in past years some markets have struggled to attract investment in commercial-scale advanced biofuel projects. The United States and Italy are among the few countries that took the important step of introducing specific quotas for advanced biofuels.

Figure 13: Biofuel policies and biodiesel production in the Netherlands and Germany



Notes: the following acronyms stand for: BM = blending mandate for biofuels; the following symbols in the line chart stand for: Germany = ● 2004: biofuels blending regulation comes into force and sets B5 blending mandate; ● 2010: biofuels quota obligation of 6.25% (by energy) of total distributed fuel in Germany adopted; the minimum requirement for biodiesel is 4.4%; ● 2015: Climate Protection Quota replaces biofuel quota obligation, requiring the mineral oil industry to reduce their products' GHG emissions by 3.5%, rising to 4% in 2017 and 6% in 2020; Netherlands = ■ 2011: adoption of the EU Renewable Energy Directive and EU Fuel Quality Directive within national legislation including the Netherlands' target to reach 10% of transport energy consumption to be sourced from renewables by 2020; ■ 2014: minimum percentage of biofuels in total fuel use established at 5.5%.

Source: IEA (2016a), *Medium-Term Oil Market Report 2016* and analysis based on the IEA/IRENA *Joint Renewable Energy Policies and Measures Database*, www.iea.org/policiesandmeasures/renewableenergy/.

Box 9: The biofuels integration challenge: Brazil's experience with "flexible fuel" vehicles

There is a limit, generally referred to as the "blending wall", to the extent that conventional biofuels such as ethanol and biodiesel are compatible with existing vehicle fleets. Most commercial road vehicles are not designed to run on a level of ethanol in gasoline exceeding 10-20%.

This constraint may hamper biofuel growth in both established and emerging economies. Brazil, the world's second-largest biofuel producer, has sought to overcome this barrier by supporting the market uptake of flexible-fuel vehicles (FFVs) that are designed to run on gasoline or gasoline-ethanol blends generally of up to 85% ethanol (E85). In 2003 the introduction of FFVs, capable of running on any given blend of ethanol and petrol, gave a new boost to the ethanol sector. According to reports by the regional daily newspaper, O Estado de S. Paulo, in 2009 nearly two-thirds of all registered FFVs regularly used ethanol fuel, with a figure of around 93% in the São Paulo state, which hosts numerous production plants. As drivers are able to use both gasoline and ethanol (and in some cases, also compressed natural gas), demand for these fuels has become very sensitive to their relative prices.

Regardless of biofuel market trends, it is worth highlighting that enabling frameworks, such as those related to FFVs, need to be initiated in advance of limits for market deployment being reached, and such changes may need to be encouraged via policy and regulation – for example by requiring retailers to provide high-concentration biofuel blends such as E85, by encouraging the development of suitable infrastructure, by providing tax incentives for FFVs, and by negotiating with vehicle suppliers to extend vehicle warranties to provide cover when high biofuel blends are used.

Sources: data from Brazil's National Industry Association of Automobile Manufacturers (ANFAVEA); O Estado de S. Paulo (2013), "Etanol é usado hoje em apenas 23% dos carros" [Today just 23% of flex-fuel cars are using ethanol] (in Portuguese) (14 November) Revista Veja, http://info.abril.com.br/noticias/tecnologias-verdes/2013/11/etanol-e-usado-hoje-em-apenas-23-dos-carros.shtml (accessed 16 November 2015).

Phase 3: Roadmap development

Once a vision is established, the third phase in the roadmapping process begins with the preparation and review of the draft roadmap document itself. As shown in Figure 14, the content of the roadmap is usually discussed and determined through a number of expert workshops aimed at identifying existing barriers to bioenergy deployment within the country or region and possible actions that decision makers could undertake to overcome these obstacles.[12] Expert judgment will also be useful for setting a realistic timeline and milestones for the implementation of the bioenergy roadmap, in collaboration with responsible stakeholders.

This section of the *Bio.H2G* explores a range of possible barriers that can hinder deployment of bioenergy, and it provides an overview of relevant action options and information sources available to policy and decision makers. While many barriers are common across regions, specific barriers may apply at a local level, depending on the types of biomass resource available as well as on the dynamic relationship with the economic and social context of the region. Different bioenergy feedstocks also have different implications for technology requirements, environmental impact and bioenergy pathway configuration. As a result, it is crucial that responses and policy measures to support bioenergy deployment are tailored to the specific, local conditions of the area where bioenergy projects are expected.

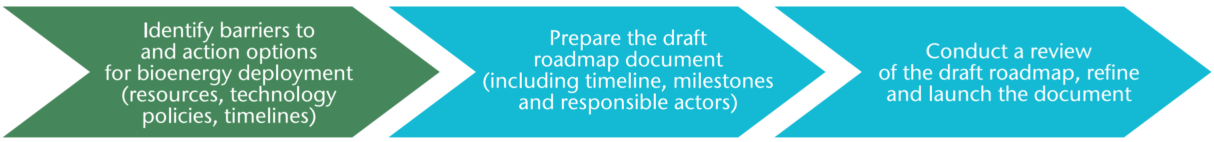
While every effort has been taken to identify a comprehensive set of potential barriers and responsive actions, the list is not exhaustive. Barrier types and action options are categorised as follows:

- biomass resource planning
- technology (bioenergy plants and conversion)
- energy infrastructure (electricity and heat markets)
- financial and economic considerations.

The occurrence of barriers and the associated action options vary for each country; however, certain recurring elements can be identified and are summarised in Tables 4 to 7, with a description of the issue as well as a number of strategies or action options that could enable obstacles to bioenergy deployment to be overcome.

12. For suggestions and guidance on holding a successful roadmap workshop, see the IEA *Roadmap Guide* (2014a). The Sustainable Energy Authority of Ireland's *Bioenergy Roadmap* (2010) and the Department of Energy and Climate Change's *UK Bioenergy Strategy* (2012) provide illustrations of what a country-specific, final roadmap document can look like.

Figure 14: Roadmap development phase



Notes: in this figure each arrow represents a substep in one of the four phases of the roadmap process set out in the IEA *Roadmap Guide* and in Figure 1 of this report; green-shaded arrows indicate substeps that are also discussed in this *H2G.BIO*; for further information on the steps in blue, see the IEA *Roadmap Guide* (IEA, 2014a).

Considerations for biomass resource planning

As discussed earlier under Phase 1, policy and decision makers require information about the potential of each of the three main types of biomass resource so as to undertake effective planning for bioenergy deployment. The three types of resource are i) residues and waste, ii) forestry, and iii) crops and fast-growing grasses.

The availability of feedstock is generally a function of land use, water availability, climate, food demand/supply cycles and a number of other socio-economic considerations. Competition with other local economic activities may represent a major barrier to bioenergy development. Location-specific factors could undermine the sustainability or profitability of bioenergy projects, even those relying on business models that worked well in other places.

Certain potential feedstocks pose logistical challenges relating to, for instance, the need to provide storage in response to the seasonal availability of biomass resources. Feedstocks that require short, season-bound harvest periods call for diversification strategies that can ensure stable feedstock supply for continuing bioenergy generation.

In many emerging and developing economies, the collection of feedstocks continues to pose the largest barrier, since agricultural production is mostly small in scale and geographically scattered. Due to inadequate infrastructure and logistical limitations, in these countries the economically feasible transport range is generally limited to a 25-75 kilometre (km) radius around the conversion plant (Van Sambeek et al., 2012). Table 4 provides an overview of common barriers and possible responses, as well as resources available to policy and decision makers.

Table 4: Overview of barriers and action options relating to biomass resource planning

Barrier	Instances	Action options
Competition with other socio-economic activities	Poorly managed bioenergy expansion can trigger negative effects such as compromising local access to land and food security. Availability of certain feedstocks may be limited due to competition with other biomass uses (e.g. animal feed).	• Prioritise land use for food production until local demand is fulfilled. • Promote integrated biomass supply chain for food, energy, and non-energy products – e.g. consider developing biorefineries (see Box 11). • Encourage the cascading use of biomass, e.g. by introducing regulation that aims to exploit synergies with other sectors (e.g. construction). • Ensure local communities can benefit from bioenergy developments, e.g. by establishing smallholder co-operatives. • Encourage local employment in the feedstock production and distribution chain. • Create a specialised body to manage conflicts and resolve disputes between developers and local population.
Logistical constraints to biomass supply chain*	Inadequate infrastructure and low energy density of certain feedstocks can make transporting feedstock difficult and costly. This can limit the area within which it is possible to economically source or import biomass. Some forestry resources are available in remote locations, with prohibitive collection/transport costs. Inadequate port infrastructure (e.g. biomass storage and handling facilities) might prevent international biomass trading.	• Transport costs can be decreased by reducing the high initial moisture content of many biomass feedstocks. Encourage biomass pre-treatment and upgrading processes, from the most basic drying, to torrefaction, steam treatment, pelletisation and pyrolysis. • Consider the whole range of possible biomass feedstocks, including dispersed residues and organic wastes, as well as possibilities for drying and storage facilities in the planning and positioning of the conversion plants. • Consider investment in infrastructure (road network, railways and water transport).**

* These factors also influence the economics of bioenergy projects. A more detailed discussion can be found in Table 7 relating to finance and economic aspects.

** In terms of both costs and energy requirements, transport by train or boat is generally superior to road vehicles over long distances. In Brazil there are also examples of logistical co-operation between various producers, with a privately financed pipeline from the major sugar cane growing area of Ribeirão Preto in São Paulo state to the Petrobras refinery in Paulinia that started operation in 2013.

Table 4: Overview of barriers and action options relating to biomass resource planning (continued)

Barrier	Instances	Action options
Environmental concerns	Overuse of national resources through deforestation and soil degradation. Threat to biodiversity conservation. Some practices that seek to improve feedstock yields may lead to negative impacts such as euthrophication, or degradation of soil and water resources.	• Adopt sound sustainability certification schemes for biomass. • Establish procedures that systematically consider whether it is possible to valorise organic wastes and agricultural/ animal residues for bioenergy production. • Develop spatial development plans that mitigate the risk of LUC (direct and indirect) and ensure strict application. • Regulate the use of fertilisers and irrigation practices consistent with sustainable cultivation and water management techniques. • Use an LCA approach to assess the net GHG emission of bioenergy developments.

Examples of tools and resources relating to biomass resource planning (in alphabetical order)

- **FAO: *BEFS Approach: Implementation Guide* (FAO, 2014b). See Box 3.**
- **FAO/BEFS: *A Compilation of Tools and Methodologies to Assess the Sustainability of Modern Bioenergy* (FAO, 2012a).** Compilation of tools to assess impact of bioenergy sustainability on socio-economic, and environmental issues, as well as gender issues.
- **FAO/BEFS: *Bioenergy and Food Security: The BEFS Analytical Framework* (FAO, 2014c).** Guidance document on the analytical approach for assessment of sustainable bioenergy potential.
- **FAO/BEFS: *Assessing the Water Energy Food Nexus* (FAO, 2014d).** Insightful analysis of the interrelations among the three sectors.
- **FAO/IFES: *Evidence-Based Assessment of the Sustainability and Replicability of Integrated Food - Energy Systems – A Guidance Document* (FAO, 2014e).** Guidance document concerning existing integrated food energy systems.
- **FAO: *Biomass Resource Mapping in Pakistan* (Kojakovic and Maltsoglou, 2014).** Lessons learnt from overcoming barriers related to limited feedstock availability.
- **IEA Bioenergy TCP: *Bioenergy, Land Use and Climate Change Mitigation*, (IEA Bioenergy TCP, 2010b)**.
- **IEA: *Bioenergy for Heat and Power: Technology Roadmap* (IEA, 2012).** The roadmap identifies priorities for expanding use of biomass for electricity and heat generation, and sets out milestones for technology development in order to achieve a doubling of global bioenergy supply by 2050.
- **IEA: *Biofuels Technology Roadmap* (IEA, 2011a).** The roadmap identifies priorities for expanding use of biofuels, and sets out milestones for technology development to achieve a share of 27% of total transport fuel by 2050.
- **Netherlands Enterprise Agency: *Sustainable Biomass Production and Use: Lessons Learned from the Netherlands Programme Sustainable Biomass 2009-13* (Netherlands Enterprise Agency, 2014).** Parts 3 and 4 provide assessment tools to predict the interplay among bioenergy, food production, land and water use, and GHG emissions.
- **UN Energy: *Sustainable Bioenergy, A Framework for Decision Makers* (UN- Energy, 2007).** It broadly explores the intersection of bioenergy and other topics, notably addressing gender issues in Section 4.
- **World Bank: *Fuel Supply Handbook for Biomass - Fired Projects* (World Bank, 2010).** Analysis of the supply chains for various biomass feedstocks, including consideration of storage and other logistical aspects.

Considerations for bioenergy plants and conversion technologies

As outlined earlier in this publication, a variety of technologies can be used to convert biomass feedstocks to heat, electricity and a range of solid, liquid and gaseous fuels, including direct combustion, co-firing, gasification, pyrolysis, extraction, fermentation and anaerobic digestion. However, in many countries a major barrier to market uptake of advanced technologies is a lack of information about the range of technology options, how they perform under local conditions and the scope for optimising conversion efficiencies and overall system design.

In most OECD markets, the primary barrier to expanding bioenergy use is not one related to technological readiness and applicability, but rather to obtaining an adequate (both in terms of quality and quantity) and cost-competitive supply of biomass. For bioenergy plants, scale of operations is a very important factor, with significant potential for reducing unit production costs and operating costs with increasing scale (IEA, 2012).

The scale of the bioenergy plant or installation (heat, electricity or biofuel) is typically related to the choice between local, relatively small-scale conversion of biomass at one end of the spectrum, and larger-scale conversion to supply regional, national or even international markets at the other. The choice of bioenergy technology and of plant scale depends on the availability and economics of the biomass supply; however, it is also influenced by the type of final energy demand. Where a market exists for both electricity and thermal energy, maximum combined heat and power production by co-generation is preferable. However, depending on the climatic conditions, possibilities for co-generation year round may be limited to industrial processes. Another option for enhancing the attractiveness and profitability of bioenergy plants is to expand the spectrum of outputs that can be produced by the same biomass conversion plant. This concept is embedded in biorefineries, which are briefly explored in Box 10.

From the collection of biomass to the transformation into a bioenergy product, a range of technical competencies is needed for operating different generation technologies. The lack of a skilled workforce to effectively operate bioenergy technologies may severely hamper the potential to expand bioenergy deployment or lead to poor quality installations that damage consumer confidence. Particularly in emerging and developing economies, it is important to ensure an appropriate workforce that can plan, engineer, operate and maintain a biomass-to-energy plant.

Box 10: Biorefineries

The biorefinery concept is to produce a variety of products, fuels, and energy from a certain feedstock. The economic competitiveness of the operation is based on the production of high-value, low-volume co-products in addition to comparably low-value biofuels. Biorefineries can process different biomass feedstocks into energy and a spectrum of both intermediate and final marketable products, such as food, feed materials and chemicals (de Jong and Van Ree, 2009). Two main categories can be defined: energy-driven biorefineries, which include biofuel plants, and product-driven biorefineries, which focus on producing food, feed, chemicals and other materials and might create power or heat as a co-product (de Jong and Jungmeier, 2015).

A biorefinery can consist of a single unit, for instance a paper mill that produces pulp and paper and generates electricity from processing residues. It can also be formed by a cluster of single facilities that process by-products or wastes of neighbouring facilities. Biorefineries can potentially make use of a broader variety of biomass feedstocks and allow for a more efficient use of resources than current biofuel production units, and reduce competition among different uses of biomass. Several innovative biorefinery concepts are currently being developed and implemented. Some of these biorefinery concepts have reached high degrees of complexity, simultaneously using different feedstocks (e.g. algae, miscanthus and wood chips from short rotation) to co-produce a broad spectrum of different products (e.g. ethanol,

Box 10: Biorefineries (continued)

phenol, omega-3 fatty acids, biodiesel). It can be difficult for industry, policy makers, and investors to decide which configuration is conducive to the most valuable outputs in the short, medium and long term, and to assess the technological and economic risks.

A range of valuable studies has been carried out by the IEA Technology Collaboration Programme on Bioenergy under Task 42 that provide an overview of a range of operating biorefineries, identify critical factors for increasing cross-sector collaboration and expanding market penetration of biorefineries, and even introduce a "Biorefinery Complexity Index" (BCI).

Sources: de Jong and Van Ree (2009), Biorefineries: adding value to the sustainable utilisation of biomass, www.ieabioenergy.com; IEA (2011a), Technology Roadmap: Biofuels for Transport; de Jong and Jungmeier, (2015), "Chapter 1 - Biorefinery Concepts in Comparison to Petrochemical Refineries", Industrial Biorefineries & White Biotechnology, pp. 3-33, http://dx.doi.org/10.1016/B978 - 0 - 444 - 63453 - 5.00001 - X.

Table 5: Overview of barriers and action options relating to bioenergy plants and conversion technology

Barrier	*Instances*	*Action options*
Inadequate supply of biomass	Low-quality biomass types such as chicken manure, straw and grasses pose a challenge for thermal conversion processes, specifically due to ash melting behaviour and presence of halogens and sulphur. Such ashes increase the risks of corrosion, erosion and clogging in furnace, necessitating boiler and flue gas cleaning, and require dedicated and adapted conversion processes, e.g. cigar furnaces for straw. Variability in the volumes of feedstock supply may limit the choice of viable conversion technology options.	• Build in a pre-treatment process to reduce ash content and produce higher-quality fuel, e.g. through pyrolysis, gasification, torrefaction with associated washing of the torrified material. • Biomass gasification should also be considered as one of the technology choices for converting distributed and low-value lignocellulosic biomass to gaseous fuel for generating electricity and/or co-generation. • Support investment in feedstock flexibility, thereby allowing for use of a broader feedstock base for each conversion plant, depending on availability and economics.
Operational aspects and siting*	Limited scale of operations (for thermal plants at capacities less than 10 megawatts [MW]) may result in relatively lower generation efficiencies.** Data on feedstock availability are inaccurate or unavailable. Opposition of local population affected by the new bioenergy plant. Concerns that bioenergy plant operations may interfere with the ecology of the surrounding environment. Lack of knowledge about how technologies perform under local conditions.	• Encourage flexible (or scalable) capacity and geographic distribution of bioenergy plants as a function of current and planned feedstock availability. • Undertake comprehensive assessment of natural resources and spatial development plans. • Raise awareness among local population of the benefits of bioenergy (GHG reduction, employment opportunity, energy access). • Establish standards for negative externalities (e.g. noise, waste disposal) and ensure enforcement. • Test performance of technologies under local conditions.

* See also Table 4 for aspects relating to logistical constraints of biomass supply chains.

** It should be noted that plant capacity is only one of many factors that may influence generation efficiency. Other important factors include biomass feedstock, the technology used, the process engineering, and how the plant is operated and maintained. For additional considerations on economic and financial issues, see also Table 7.

Barrier	Instances	Action options
Shortage of qualified workforce	Shortage of local experts in modern biomass conversion technologies may limit the choice of bioenergy projects that can be developed. High cost for operations and maintenance (O&M) due to local lack of qualified personnel.	• Develop higher education curricula and training to meet the whole set of skill requirements and professional profiles of the bioenergy sector. • Encourage technology and knowledge exchange with mature bioenergy markets. • Support public- and private-sector investment in local capacity building. • Consider adopting bioenergy technologies with a track record of deployment elsewhere and that either do not require tacit skills for operation, or that are supplied with all know-how necessary for operation in the recipient country context.
Information asymmetry/ shortage	Technologies and components are not standardised leading to perceived risks for deployment/performance. Lack of knowledge about technological options available internationally.	• Participate in international collaboration on standards. • Build capacity through international collaboration for bioenergy technology.

Examples of tools and resources relating to bioenergy plants and conversion technology (in alphabetical order)

- **IEA Bioenergy TCP: *Better Use of Biomass for Energy Background Report* (IEA Bioenergy TCP,** 2010a**):** The report aims to provide guidance on the issue of biomass energy policies in OECD member countries, regarding options for improving supply, production, conversion, end use and policies.
- **IEA Bioenergy TCP: *Bioenergy – A Sustainable and Reliable Energy Source* (IEA Bioenergy TCP, 2009):** This review provides an overview of potential for bioenergy and the challenges associated with its increased deployment; a whole section of the publication focuses on bioenergy routes and conversion technologies.
- **IEA: *Bioenergy for heat and power: Technology Roadmap* (IEA, 2012):** The roadmap identifies technology goals and defines key actions that governments and other stakeholders must undertake to expand the sustainable production and use of bioenergy.
- **IEA: *Biofuels Technology Roadmap* (IEA, 2011a):** The roadmap identifies technology goals and defines key actions that stakeholders must undertake to expand biofuel production and use sustainably.
- **Netherlands Enterprise Agency: *Sustainable Biomass Production and Use: Lessons Learned from the Netherlands Programme Sustainable Biomass 2009-13* (Netherlands Enterprise Agency, 2014):** The report compiles the overall lessons learnt from the programme to promote the sustainable production of biomass for export and local use; the report has a specific section dedicated to technologies, applicability of feedstock and innovations in conversion.
- More broadly, there is a large and growing body of **academic education and vocational training** courses concerned with both biomass technology and bioenergy processes. Canvas Network and Coursera are among a number of institutions that provide the opportunity for distance learning.

Considerations for energy infrastructure (electricity, heat and transport markets)

While centralised production remains the core of most energy systems worldwide, IEA analysis suggests that globally the share of distributed, variable renewable energy (VRE) generation systems is increasing (IEA, 2014c; IEA, 2014f). As greater shares of VRE are integrated into the energy system, networks face the challenge of effectively balancing supply and demand in light of the uncertainty of output from these sources. The IEA *How2Guide for Smart Grids in Distribution Networks* (IEA, 2015c) offers specific guidance to national or regional roadmapping efforts on system integration and deployment of smarter electricity distribution networks.

Bioenergy generally provides dispatchable electricity. Depending on the flexibility embedded in any given plant, bioenergy power plants can adapt to the daily patterns of electricity supply and demand. Several plant types can react to load variations at fairly short notice and therefore provide valuable flexibility to the power system.

In certain emerging and developing economies, electricity networks are underdeveloped or ageing, particularly in rural areas, restricting these populations' access to the grid. This lack of electricity infrastructure can prevent new bioenergy generators from accessing these markets, which can be a barrier to large-scale deployment of modern bioenergy. Conversely, in some cases, lack of grid access can be a driver for small-scale bioenergy projects, allowing bioenergy-supplied mini-grids to emerge, which service rural communities with a good source of biomass but without access to the main electricity grid.[13] Even in emerging economies with relatively better infrastructure, such as South Africa, the reluctance of public utilities to purchase energy from distributed biomass plants may prove a critical barrier, as illustrated in the case study under Box 11.

Incorporating bioenergy into the energy system in an integrated way, linking the transport, heat and electricity sectors, can help to reduce inefficiencies. Co-generation and district energy networks are an important component of such integrated energy systems (IEA, 2014d). Insufficient development of biofuel infrastructure, particularly at the end use, can represent a significant barrier to scaling up the use of bioenergy in the transport sector. Table 6 provides an overview of barriers and action options relating to the energy markets and network operators.

13. For example, in rural India, Husk Power Systems has established a business model based on constructing bioenergy-supplied mini-grids for rural communities without access to the main grid but within 10 km of rice husk or other agricultural residues. See: www.ashden.org/files/Husk%20winner.pdf.

Box 11: South African examples of modern bioenergy power projects

South Africa has, by far, more installed grid-based capacity (46 gigawatt [GW]) than any other country in Sub-Saharan Africa (IEA, 2014e). Despite the considerable biomass potential that exists in the country, Eskom, the South African public electricity utility and grid operator, does not use biomass for electricity production and relies on coal-fired power plants for 85% of its capacity.

The sugar and the pulp industries have expressed an interest in using biomass as a source, installing generation capacity for about 245 MW_e (bagasse) and 170 MW_e (sawdust) to supply energy for the respective industrial processes. South Africa has a sizeable agricultural and forestry sector; however wood pellets are mostly exported to European markets due to lack of local demand.

Against this backdrop, the government has sought to support renewable energy deployment by creating incentives, such as the Renewable Energy Feed-In Tariff (REFIT), and a dedicated programme for Renewable Energy Independent Power Producers (REIPP), which aims for 35 MW_e of bioenergy installed capacity by 2020 (of which 16 MW from biogas and 18 MW from waste-to-energy).

The South African system for renewable energy procurement requires that developers apply for a series of licences, permits and quotes. This requires direct engagement with Eskom, the Department of Energy, the Department of Agriculture, Forestry and Fisheries, and the National Energy Regulator.

A number of attempts have been made in the past decade to set up bioenergy plants producing wood pellets as biomass fuel, which did not succeed because of failure to secure a favourable power purchasing agreement (PPA) from Eskom for the surplus electricity. The Howick plant commissioned by Biotech Fuels in 2006 in KwaZulu Natal region and the Tsitsikamma biomass plant commissioned in 2005 in Western Cape provide instructive case studies.

Conversely, experiences exist of how early-stage collaboration with energy stakeholders, optimised agricultural practices and close involvement of local communities have allowed bioenergy production and at the same time reduced environmental degradation. The "Beema Bamboo to Energy Project" (BBEP), started in November 2013 by Green Grid Energy (Pty) Ltd in the Ilembe District, entails the cultivation of 500 hectares of beema bamboo, initially used to fuel a small-scale gasifier (3.6 MW_e) in Mandeni. The project developer currently aims to scale up production and supply fuel for a range of uses, including co-firing in a thermal power plant operated by Eskom.

The Bronkhorstspruit Biogas Plant (BBP) in the Gauteng province provides another example of a commercially viable bioenergy project that is breaking new ground in South Africa. With expected electricity generation capacity of 4 MW when the plant is operating at full scale, the project's business model rests on a PPA agreed by the project developer Bio2Watt directly with one industrial customer, thereby displacing consumption of (mostly fossil fuel based) electricity from the national power system generator and network operator.

Although it is certainly too early to assess the impact of these projects, if successful the BBEP and BBP initiatives will provide, respectively, an interesting example of what is possible in a community-based enterprise that aims to generate sustainable energy, valorise degraded land and realise direct employment for local population, and an innovative case study of business-to-business PPA. What is still needed for these pilot initiatives to flourish are the market conditions to allow replication at national scale of a facility selling energy to local industry and the surplus to the electricity grid on profitable terms.

Sources: Petrie (2014), *South Africa: A Case for Biomass?*; Naidoo (2014), "Green Grid Energy: Bamboo to energy project", presentation, April; Kwant (2014), "Key lessons for bioenergy technology deployment, experiences with pilot projects in Southern Africa", presentation, April.

Table 6: Overview of barriers and action options relating to energy infrastructure (electricity, heat and transport markets)

Barrier	Instances	Action options
Constraints on connecting to the electricity grid	Transmission system operator (TSO) and distribution system operator (DSO) may lack capacity to enable grid connection (or have no interest in doing so). Transmission grid does not reach areas with abundant biomass resources. Non-transparent, burdensome interconnection procedure. Connection fees and back-up charges may be prohibitive. Market conditions and energy prices failing to reward efficiency and flexibility. Point of connection and rights of way may be disputed, particularly in case of long distance between plant site and grid node. Transmission and distribution infrastructure is outdated.	• Assess the adequacy of the national electricity transmission and distribution networks to allow for decentralised and distributed energy generation. • Enable independent power producers to readily access the grid, if needed revising regulation of system operators (TSOs and DSOs). • Encourage TSOs and DSOs to adopt international best practices and support uptake of "smart" control and communication technology. • Encourage holistic planning of bioenergy, conventional power plants and other plants generating VRE, seeking to manage correlation of outputs to enhance stability. • Consider unbundling vertically integrated utilities (generation, transmission and system functions) or other regulatory measure to enhance market competitiveness. • Periodically assess the adequacy of connection fees and rates to market conditions, distinguishing connection costs from grid reinforcement costs.

Table 6: Overview of barriers and action options relating to energy infrastructure (electricity, heat and transport markets) (continued)

Barrier	*Instances*	*Action options*
Lack of or inadequate market for bioenergy heat	District heating pipework has high capital costs and heat cannot be efficiently transported over long distances. This can limit the area within which it is possible to site bioenergy co-generation plants. Local energy market conditions may fail to ensure viable energy prices for heat sale. Lack of enabling framework and/or awareness to use waste heat* as by-product of biomass power generation.	• Develop strategic local, regional and national heating and cooling planning based on mapping of thermal energy demand and biomass supply potential. • Consider investments in local heat (and cold) networks, connected to bioenergy plants. • Identify cost-effective opportunities for co-generation, aiming to maximise the exergy** output (heat-to-power ratio). • Plan for geographic distribution of bioenergy plants taking into account possible heat customers, including various demand profiles. • A reasonable price for CO_2 emissions can stimulate the use of biomass for industrial heat.
Issues related to biofuel transport, distribution and usage	Risk of stress corrosion cracking (SCC) of ethanol pipelines and storage tanks. Existing pipeline infrastructure may have residues that could contaminate ethanol. Transporting biofuels from refineries to blending terminals may require large numbers of freight vehicles and hazardous material drivers. The vehicle stock in the domestic market requires a relatively low ethanol "blending wall"***. This may pose severe limitations to the market for blended fuels at higher ratios (e.g. above E15).	• Consider a risk management strategy to address integrity threats to biofuel pipelines and storage tanks. • Investigate use of advanced materials for new ethanol pipelines. For existing pipelines, consider using additives that may reduce risk of SCC of steel. • Plan for vocational training for service providers and professionals in the transport of biofuels and hazardous material. • Consider incentives to increase the market uptake of flex-fuel vehicles. • Consider policy measures that mandate minimum levels of blended fuels, with progressive increases over time.

Examples of tools and resources relating to bioenergy infrastructure and markets (in alphabetical order)

- **DNV: *Bioenergy Infrastructure: Managing in an Uncertain Future* (DNV, 2010)**. This publication explores some of the potential risks associated with, and mitigation strategies for, transporting biofuels (particularly ethanol).
- **IEA: *Bioenergy for Heat and Power: Technology Roadmap* (IEA, 2012).** The roadmap identifies key priorities for expanding use of biomass for electricity and heat generation, and sets out milestones for technology development to achieve a doubling of global bioenergy supply by 2050.
- **IEA: *How2Guide for Smart Grids in Distribution Networks* (IEA, 2015c).** This offers specific guidance to national or regional roadmapping efforts on system integration and deployment of smarter electricity distribution networks.
- **IEA: *Linking Heat and Electricity Systems: Co-Generation and District Heating and Cooling for a* Clean Energy Future (IEA, 2014d).** This publication examines some of the reasons behind the slow progress of co-generation and advanced district heating technologies, and provides policy recommendations applicable to biomass heat and/or power systems.
- **IEA: *The Power of Transformation* (IEA, 2014c).** A detailed economic assessment of the flexible resources (flexible generation, grid infrastructure, electricity storage, demand-side integration) that can facilitate VRE system and market integration.
- **World Bank/ESMAP: *Model for Electricity Technology Assessment (META)* (World Bank, 2015).** Facilitates the comparative assessment of the economic costs of more than 50 electricity generation technologies, incorporating the costs associated with externalities in power generation.

* Waste or surplus heat refers to heat contained in side streams, product or waste streams produced as part of the industrial processes, including normal operation of biomass power plants. This heat, unless recovered, is dissipated in the environment e.g. through cooling towers.

** Exergy is a measure to indicate the extent to which a form of energy is convertible to other forms of energy.

*** The limiting of ethanol in gasoline to 10-15% because of vehicle compatibility constraints is one example of an infrastructure bottleneck that has hindered biofuel growth in key markets worldwide.

Financial and economic considerations

Many bioenergy technologies are already mature and can provide transport fuels, electricity and/or heat at costs competitive with fossil fuel-based generation in an increasing number of circumstances, particularly in markets where GHG emitters are requested to offset the negative externalities of conventional generation.

Numerous factors may influence the economic viability of bioenergy projects and need to be examined by the party undertaking the roadmapping process. Of prominent importance are feedstock availability and price over time, the scale of operations, the supply chain's organisation and structure, and the extent to which the markets for electricity, heat and biofuels can absorb bioenergy supply. In this respect, it is useful to highlight that in certain markets the lack of heat sinks (district heating, demand from industrial processes) deprives developers of one potentially considerable revenue stream, and therefore may be a key limiting factor to the further deployment of bioenergy in OECD member countries and non-OECD countries alike.

Bioenergy production depends on feedstock availability and accessibility, which can vary seasonally. To mitigate the economic risks associated with feedstock availability and accessibility, systems should be in place so that plants can source from alternative providers or feedstocks in times of shortage. Moreover, the variety of bioenergy technologies in the power sector results in a great disparity of investment and generation cost values (Box 12). Even when considering the same bioenergy technology, investment and generation costs span a wide range at a global level, depending on capacity (e.g. linked to economies of scale), level of technical sophistication and locational factors, such as the cost of capital and applicable regulatory regimes. Furthermore, for co-generation plants the pattern of heat offtake demand will also affect generation costs. Conversely, for those technologies with more uniform capital and fuel costs, such as small-scale co-firing or landfill gas plants, less variation in generation costs is observed.

Box 12: Regional variations in bioenergy investment and operating costs

While there are variations in investment costs for a given technology between regions, for example investment costs for biogas plants in China and India can be half of those in Europe, it is also important to consider that the technologies are often not comparable on a like-for-like basis. Higher investment costs in certain regions are generally linked to more advanced bioenergy technologies that may offer higher performance and efficiency as well as reduced O&M requirements, all of which favourably affect generation costs, as well as improved emissions control. Generally, and especially at larger capacities, project costs are bespoke according to the specifics of the plant and fuel/feedstock used (IEA, 2012).

In the power sector, notable downward trends in generation costs for onshore wind and solar photovoltaic (PV) technologies, coupled with the transition towards auctions and competitive bidding for renewable energy support in many countries, are likely to favour those bioenergy technologies in the power sector which benefit from lower investment costs, competitively priced fuel supply and which also contribute to wider policy objectives. Examples of these include rural development, improved waste management or operational flexibility within power systems with high shares of VRE technologies. It should be noted that since levelised cost of electricity (LCOE) results do not take into account the value of electricity produced (determined according to the time and location of generation) there are limitations in making direct LCOE comparisons between VRE and bioenergy technologies.

Box 13: Renewable Energy Guidelines on Biomass/Biogas Power Project Development in Indonesia

In June 2014, the Indonesian Ministry of Energy and Mineral Resources, through its Directorate General for New, Renewable Energy and Energy Conservation (DG NREEC), launched the first edition of the *Renewable Energy Guidelines on Biomass/Biogas Power Project Development in Indonesia*.

The guidelines describe the administrative procedures for developing a biomass/biogas power plant in Indonesia and focus on the needs of project developers, investors and other actors involved in the development of RE power projects as independent power producers (IPPs).

More precisely, the guidelines:

- Highlight administrative procedures, including requirements for project developers and/or investors.
- List legal and regulatory provisions, as well as necessary permits.
- Identify country-specific challenges for project development.
- Give information on how to obtain financial closure.

The guidelines promote transparency and clarity in the renewable energy project's pathway. They walk users through the relevant administrative procedures and help them identify the related risks, so that proper mitigation measures can be designed and implemented.

The development of the guidelines for Indonesia was supported by the GIZ Renewable Energy Programme Indonesia/ASEAN, through the Renewable Energy Support Programme for ASEAN (ASEAN-RESP), the Project Development Programme Indonesia (PDP), and the Promotion of Least Cost Renewables Project (LCORE).

Source: ASEAN-RESP (2014), *About RE Guidelines*, www.re-guidelines.info (accessed 4 September 2015).

The market frameworks under which different energy technologies compete can have a significant impact on projects' bankability (IEA, 2015d; IEA, 2014c). In mature markets with stable policy frameworks, secure access to biomass resources, good financing conditions and rising demand, utility-scale bioenergy plants are able to compete with wholesale electricity prices.[14] An assessment of the complex relationship between feedstock supply, energy demand and biomass technology costs is beyond the scope of the *BIO.H2G*; however, it is worth noting that support for new bioenergy generation capacity needs to be accompanied by an enabling framework that allows investors to see a secure and predictable income over the lifetime of the project. This is likely to mitigate risks, thereby reducing financing costs and ultimately generation costs. Box 13 provides an example of such frameworks, through the use of guidelines for bioenergy development in Indonesia.

Table 7 provides a summary of potential economic and financial barriers to investment in bioenergy deployment, and outlines a selection of measures that can be considered to overcome the barriers. In addition to blending mandates for biofuels that were discussed in *Phase 2: Visioning*, a range of support mechanisms is available that can be considered to support bioenergy roadmap implementation (Table 8).

14. A more detailed discussion on conceptual approaches to the analysis of the LCOE can be found in the IEA *Medium-Term Renewable Energy Market Report* 2015 (IEA, 2015f), as well as in the recent study *Projected Costs of Generating Electricity* (NEA/IEA, 2015).

Table 7: Overview of financial and economic barriers and action options

Barrier	Instances	Action options
High upfront investment costs	Certain advanced bioenergy technologies may require higher upfront capital investment (USD per kilowatt [kW]) than conventional power plants, particularly if associated with co-generation or tri-generation. This barrier is also applicable to gasification and pyrolysis technologies. Inadequate infrastructure is likely to affect the project economics.	• Consider capital grants, loan guarantees and tax incentives, and ensure a predictable policy framework (i.e. by including in the roadmap clear indications about procedures for revising the incentives as the market scale grows). • Support investment in energy infrastructure (electricity grid and heat networks) to allow project developers the possibility to satisfy multiple demand profiles. Invest in transport infrastructure, thereby expanding the options for feedstock supply. • Encourage the establishment of public-private partnerships as a vehicle for raising finance at lower cost.
High real (or perceived) risk	"Stop-and go" policy approaches or retroactive changes have undermined investor confidence. Lack of accurate data on feedstock availability and energy demand. Asymmetry of information affects investor understanding of bioenergy markets. Concerns that local stakeholders or communities might oppose a new bioenergy project, including on environmental grounds. Burdensome procedures to obtaining project permissions, involving multiple and potentially conflicting levels of authorisation. Bioenergy project developers may underestimate the time needed to bring a project to completion, creating unrealistic expectations in investors, business counterparts, public authorities, and ultimately public opinion.	• Phase out fossil fuel subsidies that create inefficiencies and market distortions. • Consider approaches to reducing the risk of bioenergy projects, in particular by guaranteeing certain levels of remuneration (e.g. feed-in tariffs [FITs]) for an adequate timeframe (e.g. through long-term power-purchasing agreements). • Set up policy frameworks that enable fair sharing of risks and benefits among all stakeholders. • Consider whether the design of power, heat or transport markets needs to be revised to enhance transparency and foster competition. • Seek to mitigate risk and reduce asymmetry of information by creating atlases of biomass and natural resources (to be periodically revised) and use geographic information system (GIS)-based tools. • Generate and disseminate knowledge about the benefits of bioenergy, including through communication campaigns. • Regularly monitor compliance of projects to regulations, to deter "moral hazard" type behaviour among investors.
Lack of private investors	Even though many bioenergy technologies are now mature and have established economics, uncertainty about the long-term market outlook and policy framework may severely limit the extent of private finance available to project developers, and/or act as deterrent for developers to seek funding on equity markets.	• Policy makers should facilitate private investment in bioenergy projects by setting up a diverse portfolio of incentives based on technology and market maturity. These may include both price-based mechanisms (such as FITs, market premiums and tax incentives) and quantity-based instruments (such as quotas with tradable certificates, blending mandates and procurement via auctions).

Table 7: Overview of financial and economic barriers and action options (continued)

Barrier	Instances	Action options
Lack of private investors (continued)	In the buildings sector, those who pay for energy services may not be the decision makers on new supply-side investments e.g. on biomass heat technology.	• Monitor market trends at global, regional and local level and plan for policy frameworks to be responsive to exogenous changes according to a predictable pattern. • Increase awareness at national and international level, including through collaboration with international organisations and partnerships, of the opportunities for investing in bioenergy projects in the roadmap target region. • Consider strategies to overcome the "owner-tenant dilemma", including through policy measures such as renewable heat obligations.

Examples of tools and resources relating to financial and economic barriers (in alphabetical order)

- **J. Giersdorf/DBFZ: *Politics and Economics of Ethanol and Biodiesel Consumption in Brazil (Giersdorf, 2013).*** Well-thought-out analysis of how biodiesel and ethanol policies affected biofuel market development in Brazil.
- **IEA: *Energy Technology Perspectives* (IEA, 2015a; IEA, 2016c).** Achieving widespread deployment of innovative technologies requires strategic, parallel action in technology development and market creation to close the cost gap inherent in their application.
- **IRGC: *Risk Governance Guidelines for Bioenergy Policies* (IRGC, 2008).** This policy brief identifies ways to deal with the risks involved in the development of bioenergy projects and offers an assessment of supportive policy options.
- **OECD: *Biofuels Support Policies* (OECD, 2008).** Thorough analysis of policy tools that can accelerate bioenergy technology deployment, including examples and case studies from OECD member countries as well as non-OECD countries.
- **SNV REDD+: *Biomass Waste to Energy Toolkit for Development Practitioners* (SNV, 2014).** A toolkit for project developers that includes an overview of policies relevant to regulation and financing.

As illustrated in Table 8, a number of different policy and regulatory instruments can be applied to mitigate financial and economic barriers to bioenergy deployment. Each measure should be considered in the framework of the wider policy environment that will affect its applicability and effectiveness. A range of technical, environmental, infrastructural and societal factors that differ according to national and regional circumstances may accelerate, or hinder, the successful implementation of these policy measures and the creation of an attractive investment climate.

A detailed description of each policy instrument and its applicability to bioenergy promotion is provided under Annex 1. Case studies throughout the *H2G.BIO* provide more nuanced and country-specific information on how policy instruments have been used to overcome challenges within particular contexts. Tables 9 and 10 supplement this conceptual framework with an overview of support measures for biomass electricity and biomass heat respectively, currently applied in a range of IEA member and partner countries. Annex 3 provides an overview of blending targets and mandates by country.

Table 8: Correlation of selected bioenergy barriers with relevant policy and regulatory measures

	REGULATORY SUPPORT			ECONOMIC SUPPORT						
Barrier	***Renewable energy laws/targets***	***Quotas / RPS***	***Certification schemes***	***FIT / FIP***	***Capital grants/subsidies***	***Soft loans***	***Tax relief***	***Tradable green certificates***	***Carbon pricing***	***Auction schemes***
Lack of or inadequate market for bioenergy heat	■	■		■	■	■	■	■	■	
High upfront investment costs				■	■	■				
High real (or perceived) investment risk		■	■	■	■	■	■	■		■
Lack of private investors		■		■	■	■	■	■		■
Cost-competitiveness of bioenergy and biofuels projects				■			■	■	■	■
Competition with other socio-economic activities	■	■	■							
Environmental concerns			■							
Inadequate supply of feedstock/ high cost of feedstock				■	■	■	■			■

Note: highlighted cell indicates that policy instrument is relevant; FIP = feed-in premium; RPS = renewable portfolio standards.

Table 9: Overview of regulatory and economic support measures for biomass power in selected countries

Country:	*Renewable energy laws/targets*	*Certification schemes*	*Quotas/RPS*	*FIT/FIP*	*Capital grants and subsidies*	*Soft loans*	*Tax relief*	*Tradable green certificates*	*Carbon pricing*	*Auction schemes*
	REGULATORY SUPPORT			**ECONOMIC SUPPORT**						
Major generation countries for biomass power										
Brazil	national				national	national	national			national
Canada	state/provincial		state/provincial	state/provincial	national	national	national			national
China	national			national	national				state/provincial	
Finland	national			national	national					
Germany	national			national	national	national	national			
Italy	national		national	national			national	national		national
Japan	national		national	national			national			national
Sweden	national		national		national		national	national	national	
United Kingdom	national		national	national		national	national			national
United States	state/provincial		state/provincial	state/provincial	national	national	national	state/provincial	state/provincial	state/provincial
Other selected countries that took part in *BIO.H2G* expert workshops										
Chile	national		national		national					national
Indonesia	national			national			national			
Lao PDR	national						national			
Malaysia	national			national		national	national			national
Netherlands	national			national				national		national
Philippines	national			national			national			
South Africa	national					national	national			national
Tanzania				national	national	national				
Thailand	national			national	national		national			
Viet Nam	national			national		national	national			

Notes: [light green] = national level policy; [dark green] = state/provincial level policy; this table is the result of IEA stock taking, and does not necessarily include all existing policy measures for biomass power; scale of support schemes varies widely and is not reflected in the table.

Source: IEA, 2015f and analysis based on the IEA/IRENA *Joint Renewable Energy Policies and Measures Database*, www.iea.org/policiesandmeasures/renewableenergy/.

Table 10: Overview of regulatory and economic support measures for biomass heat in selected countries

Country:	REGULATORY SUPPORT: Renewable energy laws/targets	REGULATORY SUPPORT: Certification schemes	REGULATORY SUPPORT: Renewable heat obligations	ECONOMIC SUPPORT: FIT/FIP	ECONOMIC SUPPORT: Capital grants and subsidies	ECONOMIC SUPPORT: Soft loans	ECONOMIC SUPPORT: Tax incentives	ECONOMIC SUPPORT: Installers certification	ECONOMIC SUPPORT: Co-generation incentives
Selected major world markets for biomass heat									
Austria	national		national		national				national
Brazil									national
Canada					state/provincial		national		
China	national								
Denmark	national		national	national			national		national
Finland	national		national	national	national			national	national
Germany	national		national		national	national		national	national
India			state/provincial		national				
Netherlands	national		national	national					national
Sweden	national		national				national		
United States	state/provincial	national	national	national	state/provincial	state/provincial	state/provincial	national	state/provincial

Notes: [light green] = national level policy; [dark green] = state/provincial level policy; this table is the result of IEA stock taking, and does not necessarily include all existing policy measures for biomass heat; scale of support schemes varies widely and is not reflected in the table.

Source: IEA, 2015f and analysis based on the IEA/IRENA *Joint Renewable Energy Policies and Measures Database*: www.iea.org/policiesandmeasures/renewableenergy/.

Phase 4: Implementation, monitoring and revision

Roadmap implementation in the fourth and final phase includes the key steps of monitoring the roadmap's impacts and determining whether and how it may require revision. This is a continuous process, with tracking and monitoring occurring on a regular basis, as shown in Figure 15. This section of the *H2G.BIO* provides suggested indicators to measure progress in implementing a bioenergy roadmap.

Figure 15: Implementation, monitoring and revision phase

Note: in this figure each arrow represents a substep in one of the four phases of the roadmap process set out in the IEA *Roadmap Guide* and in Figure 1 of this report; green-shaded arrows indicate substeps that are also discussed in this *H2G.BIO*; for further information on the steps in blue, see the IEA *Roadmap Guide* (IEA, 2014a).

Monitoring roadmap implementation

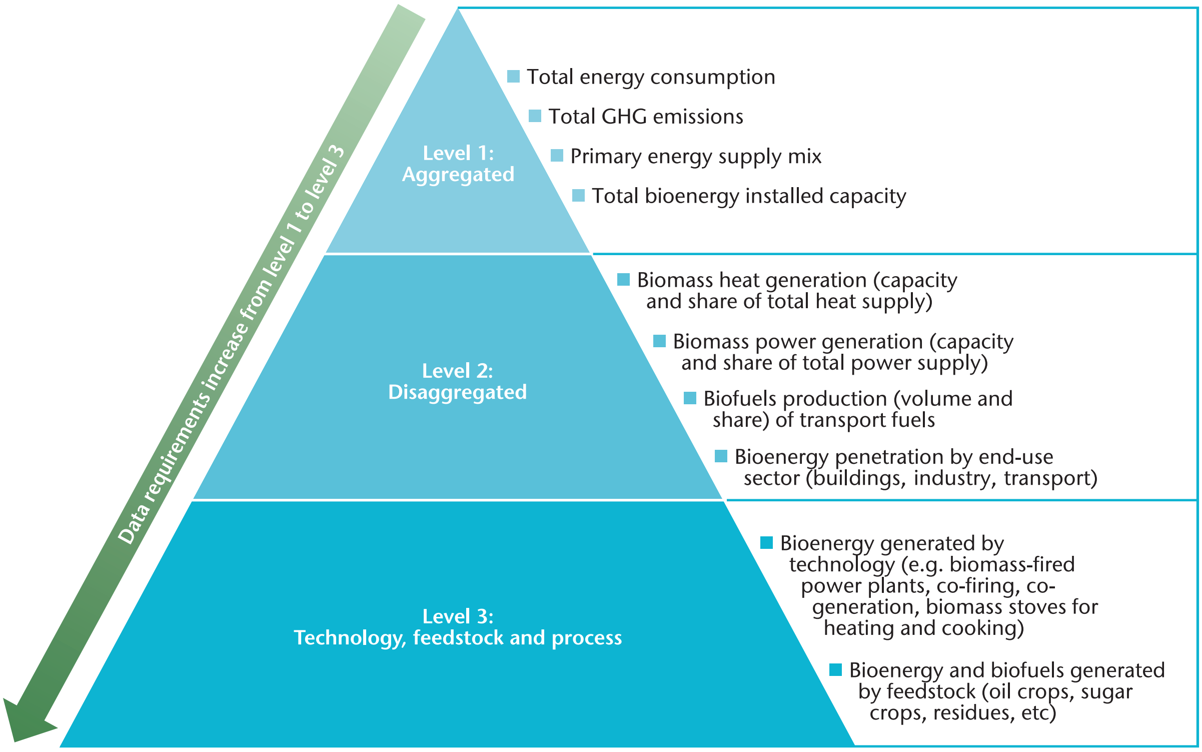
Monitoring is a critical part of the roadmapping process. It is at the foundation of the IEA and FAO analytical work to inform policy makers whether current policies and settings are effective in driving efforts to achieve energy and food security.[15] Once the bioenergy technology roadmap is in place, it is important to monitor the deployment of modern bioenergy technologies in the relevant country or region, and to consider whether the roadmap itself needs adjusting in light of experiences gained through its implementation.

Establishing metrics that capture the roadmap's impact (on the energy mix, economy, technology uptake, etc.) is very important, providing governments with quantitative and qualitative information about the roadmap's successes and shortcomings. These data can then be used to improve policy settings, tweak targets, or adjust institutional frameworks if needed. In addition to monitoring the roadmap's impacts, metrics can be established to capture changes in drivers for bioenergy deployment over time. The most appropriate set of metrics (or indicators) will depend on the country's primary drivers for implementing a roadmap, as well as on local conditions, energy use trends, data availability and national targets (IEA, 2015a). While certain metrics are more comprehensive for each energy demand profile and bioenergy technology, it is important to underline that no single metric can fully portray a country's progress towards bioenergy integration.

It is useful to establish a hierarchy of metrics to measure the roadmap's impacts at a range of levels. For example, high-level metrics could measure reductions in national GHG emissions, or the share of bioenergy in the supply mix. At a disaggregated level, metrics could track how the roadmap is influencing energy end uses (power, heat or transport fuel) as well as end-use sectors (buildings, industry or transport). Metrics established at a higher level of detail measure bioenergy penetration by bioenergy pathway (e.g. pelletisation for biomass combustion or anaerobic digestion for biogas production), conversion technology (e.g. biomass-fired power plants, small-scale co-generation, biomass stoves for heating and cooking, etc.) and by feedstock (e.g. woody biomass, sugar and starch crops, organic residues and waste, etc.). Figure 16 illustrates the different levels of metric, showing indicators from most aggregated (level 1) to least aggregated (level 3), which require significant data collection.

15. Published regularly as part of each edition of the IEA *Energy Technology Perspectives* (*ETP*), *Tracking Clean Energy Progress* (*TCEP*) examines whether the actions needed to decarbonise the energy sector over the coming ten years are progressing as required to achieve the IEA 2°C Scenario (2DS) by 2050. It also highlights areas that need additional stimulus and identifies key actions that energy ministers and their governments can take to scale up technology deployment, while also demonstrating the potential to save energy and reduce emissions.

Figure 16: Hierarchy of indicators for tracking progress of bioenergy roadmap implementation



Notes: these metrics are intended for illustrative purposes and not to be a definitive list; levels do not indicate importance of a given metric.

Source: adapted from IEA (2015a), *Energy Technology Perspectives 2015*.

While indicators are not used until Phase 4, it is useful to identify metrics early on in the roadmapping process, through engagement with diverse stakeholder groups, to establish what information would be most useful to capture during the monitoring phase (see Table 2).

Table 11 provides a series of qualitative and quantitative metrics grouped by indicator type (technology, financial, policy and sustainability) that decision makers can use to measure the impacts of a bioenergy roadmap and evaluate whether policies to promote bioenergy uptake are delivering the desired outcomes. There is a strong complementarity between the metrics and indicators provided in Table 11, allowing measurement of progress against the specific roadmap milestones, and the GBEP indicators presented in Phase 1 (Box 7 and Annex 2), which aim to assess bioenergy sustainability across environmental, social and economic dimensions.

Table 11: Qualitative and quantitative indicators and metrics for monitoring progress towards the implementation of a bioenergy roadmap

Indicator type	Description	Metrics
Bioenergy technology deployment	• Availability of biomass produced or collected for energy generation • Bioenergy projects implemented • New bioenergy capacity installed for electricity generation • Share of bioenergy (percentage) in the total installed power capacity • New bioenergy installed capacity for heat generation • Share of bioenergy (percentage) in the total heat supply • Total biofuel production and contribution by type (biodiesel, ethanol and advanced biofuels) to total fuel consumption in the transport sector	• Biomass feedstock volume or weight • Number of bioenergy installations (by type) • Bioenergy installed capacity (GW) • MWh or GWh of electricity generated • MJ or BTU of heat generated • Billion or million litres of biofuel produced
Financial	• Availability and effectiveness of grants and incentives, and other policy measures that may affect the remuneration framework for bioenergy projects (e.g. FITs; capital grants and subsidies; tax incentives; auction schemes, etc.) • The availability and cost of finance, which will affect the LCOE of each bioenergy project type • Value of tradable green certificates and other measures relating to carbon pricing • Market expansion for bioenergy technologies • Project financing supported by financial institutions	• Total asset value of bioenergy projects in the reference currency (e.g. USD) • Total turnover associated with bioenergy projects in the reference currency (e.g. USD) • Discount rate (% real) • Typical system cost in the reference currency (e.g. USD/kW) • Value of lending by financial institutions for bioenergy projects in the reference currency (e.g. USD) • Value of biomass trade in the reference currency (e.g. USD) • Capital expenditure (CAPEX) and operating expenditure (OPEX) in the reference currency (e.g. USD)
Sustainability	• Socio-economic: impact on employment; access to energy; rural development; food security; poverty reduction; contribution of the bioenergy industry to GDP • Environmental: GHG emission reductions; improvements in agricultural practices	• Number of jobs created, by education level • Percentage of population connected to the electricity grid • Number of people with access to modern bioenergy (e.g. clean cook stoves) • Value of public and private investments in infrastructure associate with bioenergy projects • Value of emissions reductions expressed in tonnes of CO_2 equivalent

Indicator type	Description	Metrics
Policy and processes	• Improvements to policy framework for bioenergy • Effectiveness of stakeholder consultation • Effectiveness of awareness raising/ campaigns organised • Measures being taken to remove non-economic barriers (e.g. installers certification) • Improvements to the bioenergy permitting procedures • Support available to project developers along the biomass supply chain • Compliance with non-mandatory regulatory measures (e.g. biofuels blending targets; bioenergy targets) • Milestones specific to sectoral strategies	• Number of stakeholder workshops organised • Number of useful new institutions created, or institutions reformed • Number of stakeholders reached by communication campaigns; qualitative assessment of stakeholder acceptance • Average time to market of bioenergy projects (by type, taking into account permitting procedures) • Number of new support policy measures adopted • Duration and success rate within the permitting process • Qualitative assessment of policy makers' actions • Number of sectoral milestones being met

Notes: BTU = British thermal unit; GWh = gigawatt hour; MJ = megajoule; MWh = megawatt hour.

For each indicator, robust data and transparent analysis will be important. This may be challenging where new metrics are created and data series are short. Specific resources may need to be allocated to bolster data collection and verification. The collection of such data must take account of commercial sensitivities and can be anonymous, although increased transparency for publicly subsidised projects may yield both greater accountability and faster learning curves for the entire industry.

Analysing the metrics above allows for the tracking of absolute and relative progress in the implementation of the bioenergy roadmap, or of a combination of bioenergy technologies and pathways. They also allow for the comparison of progress against national or regional targets and mandates for biomass heat, biomass power and biofuels for transport, where these are in place (see also Annex 3).

Such analysis provides policy makers with information to assess the effectiveness of the regulatory and economic support measures in place, and whether potential revisions are required. If the level of bioenergy deployment is not in line with targets, this could suggest the need for further policy intervention to address the barriers identified in Phase 3 (see Tables 4 to 7).

Finally, in increasingly globalised energy and agriculture markets, it can also be useful to track bioenergy deployment against benchmarks relating to external markets, such as:

- Benchmarking against countries with similar conditions, resources and ambitions.
- International benchmarks – for example the UN's Sustainable Energy for All (SE4ALL) goal to double the contribution of renewables to global energy supply between 2010 and 2030.

The complementary use of international benchmarks is recommended, as they provide decision makers with valuable information on progress with implementation of the national or regional roadmap against wider trends, taking account of differences in resource availability.

Monitoring the sustainability of bioenergy production and use

As discussed under Phase 1 of the *H2G.BIO*, in order to ensure that bioenergy is developed in a sustainable fashion, policy and decision makers should regularly monitor the environmental, social and economic impacts during the roadmapping cycle, at both national or regional and project levels.

In this respect, it is important that sustainability indicators are established for the express purpose of assessing the sustainability of bioenergy deployment over time. The 24 GBEP sustainability indicators detailed at Annex 2 provide a useful model on which countries could base their design of nationally appropriate sustainability indicators. While the indicators generally express information aggregated at the national level, they rely on local data at the level of economic operators (e.g. farmer, processor, distributor, and end user). The proactive engagement of all relevant stakeholders, including government agencies, private sector organisations and civil society organisations, is key to the effective monitoring of the GBEP indicators and to allow the proper interpretation and use of the results (FAO, 2011).

Bioenergy standards and certification schemes

In addition to the 24 GBEP indicators, a range of other initiatives are being pursued at national and international levels that seek to foster sustainable bioenergy production and to disseminate good practice that can help ensure sustainable feedstock production and use.[16]

In recent years there has been a proliferation of international criteria, standards and certification schemes for biofuels and, to a lesser extent, for biomass for heat and power generation, to limit undesirable impacts and externalities of bioenergy deployment. A *Handbook on Sustainability Certification of Solid Biomass for Energy Production* was published under the Netherlands Programme for Sustainable Biomass (NPSB) and it provides an interesting classification of these sustainability certification schemes (Netherlands Enterprise Agency, 2013).

The NPSB is an example of how voluntary standards can be used to certify the sustainability of various biomass projects in different world regions (Box 14). Access to financial incentives can also be linked to independent verification of the sustainability of fuel use or production. It is important, however, to ensure that compliance is not overly burdensome so as to restrict industry development and also to consider the cost of compliance for smaller enterprises.

Other certification schemes relevant to bioenergy include: the International Organization for Standardization (ISO) Sustainability Criteria for Bioenergy,[17] the International Sustainability and Carbon Certification System (ISCC),[18] the Roundtable on Sustainable Biofuels (RSB),[19] NTA 8080,[20] Forest Stewardship Council (FSC)[21] and the Programme for the Endorsement of Forest Certification (PEFC).[22]

Efforts are underway to harmonise sustainability schemes and quality standards, and several stakeholders groups have offered valuable options with a view to strengthening the sustainability of the international biomass market; however, at a global level the regulatory framework remains complex and fragmented.[23]

16. Task 40 of the IEA Bioenergy TCP sought to map these initiatives worldwide.

17. www.iso.org.

18. ww.iscc-system.org.

19. www.rsb.epfl.ch.

20. www.sustainable-biomass.org.

21. www.fsc.org.

22. www.pefc.org.

23. At the project level, over the past few years a number of voluntary standards have been developed for biofuel certification, in response to concerns about the environmental and social impacts of biofuels and as a means for foreign producers to show compliance against the sustainability criteria of key importing markets, such as the European Union. These standards, most of which have been subject to field-testing and are currently being used for certification, address different elements of the biofuel supply chain, based mainly on a risk management approach (Netherlands Enterprise Agency 2014; FAO, 2011). The breadth and depth of the coverage of environmental and social sustainability is pretty diverse across these standards, with the majority focused mainly on environmental issues, in line with the sustainability criteria of some of the main importing markets.

Box 14: The Netherlands Programme for Sustainable Biomass

The Netherlands Programme for Sustainable Biomass (NPSB) is an initiative run by the Netherlands Enterprise Agency (RVO) with the overarching objective of globally promoting the sustainability of biomass production and fostering the development and application of biomass certification schemes.

The programme is jointly funded by the Netherlands Ministry of Economic Affairs and the Ministry of Foreign Affairs, and since 2008 has provided financial and capacity-building support for projects located in over 20 countries around the world, including Brazil, Indonesia, Mozambique, South Africa, Ukraine and Viet Nam. Beneficiaries of NPSB funding were able to gain experience in the production and sustainability certification of biomass feedstocks, such as palm oil, sugar cane, wood pellets and bamboo. Projects were carried out along five axes:

- mapping the availability and potential of biomass
- feedstock and technology developments
- enhancing sustainable production
- guaranteeing and monitoring sustainability
- fostering an attractive business environment.

Monitoring how biomass potential, production and trade have been developing in a particular country is a crucial element of the NPSB projects. RVO also played a role in identifying possible trade barriers to the importing of biomass and put forward proposals for different solutions. Both the direct and indirect effects of bioenergy production are taken into account in the assessment of sustainability aspects. Food security is considered to be of key importance as regards bioenergy production, and it is highlighted that it should not compete with food production. Where bioenergy production is carried out in a sustainable way it can make a contribution to improving food security.

The RVO has produced several reports on sustainability criteria in order to guide companies and other stakeholders. These also include the development of specific indicators or certification systems. In addition to this, the international "BioESoil" tool was created for calculating the impact of bioenergy on soil quality, taking into account nutrient losses or potential nutrient return during bioenergy production. Findings from the NPSB also highlight the importance of good governance in safeguarding the sustainability of bioenergy production.

Source: NPSB, www.english.rvo.nl/topics/sustainability/sustainable-biomass (accessed 30 June 2016).

International collaboration

International collaboration plays a key role in supporting effective implementation of bioenergy roadmaps around the world. The past decade has seen the emergence of a range of multilateral initiatives designed to foster collaboration and innovation in low-carbon energy technologies (IEA, 2014g). These initiatives have varying, and at times overlapping mandates, activities and foci, at global and regional levels. By bringing together multiple governments and non-governmental stakeholders to exchange information, to build capacity and to support technology and knowledge transfer (including through the promotion of public-private partnerships), some of these initiatives are making impressive contributions to global efforts to address energy, food and climate challenges. A number of these international initiatives are outlined below in alphabetical order.

European Biofuels Technology Platform

The European Biofuels Technology Platform (EBTP) is a public-private partnership established in 2006. It brings together stakeholders' expertise to contribute to the development of cost-competitive, world-class biofuel value chains. It also seeks to accelerate the sustainable deployment of biofuels in the European Union through a process of guidance, prioritisation and promotion of research, technology development and demonstration. The main activities are carried out through four principal working groups covering biomass resources, conversion, end use, policy and sustainability, and an *ad hoc* working group covering the European Industrial Bioenergy Initiative (EIBI).

Further information is available at: http://biofuelstp.eu/index.html.

GBEP

GBEP was established to implement the commitments taken by the G8 in 2005 to support "biomass and biofuels deployment, particularly in developing countries where biomass use is prevalent". It brings together 50 governments and 26 international organisations in a joint commitment to: promote high-level policy dialogue on bioenergy and facilitate international co-operation; support national and regional bioenergy policy-making and market development; favour the transformation of biomass towards more efficient and sustainable practices; and foster exchange of information, skills and technologies through bilateral and multilateral collaboration.

Further information is available at: www.globalbioenergy.org/.

IEA Technology Collaboration Programme on Bioenergy

Four decades ago, the IEA established the Technology Collaboration Programmes (TCPs) as a framework for international collaboration on energy technology research and development, demonstration and information exchange. The IEA Bioenergy TCP was established in 1978 to co-ordinate IEA member countries' efforts to increase bioenergy's contribution to meeting global energy demand, thereby providing increased energy security as well as reducing GHG emissions. The IEA Bioenergy TCP eventually grew to include participants from IEA partner countries. Activities are organised by task, seeking to integrate research themes across the entire bioenergy value chain, including biomass resources, supply systems, conversion and end products. The IEA Bioenergy TCP's Strategic Plan 2015-20 places great emphasis on pathways to overcome environmental, institutional, technological, social and market barriers to the near- and long-term deployment of bioenergy technologies (IEA Bioenergy TCP, 2014).

Further information is available at: www.ieabioenergy.com.

SE4ALL High Impact Opportunity on Sustainable Bioenergy

Launched by the UN Secretary-General in 2011, the Sustainable Energy for All (SE4ALL) is a multi-stakeholder partnership between governments, the private sector and civil society. Under this framework, a new initiative was created in 2015 and co-chaired by FAO and the Roundtable on Sustainable Biomaterials (RSB) that seeks to facilitate the development and deployment of sustainable bioenergy solutions: the High Impact Opportunity (HIO) on Sustainable Bioenergy. Its key goal is to deliver bioenergy options that are environmentally, socially, and economically sustainable, with a focus on emerging markets and rural communities in developing countries. The partnership pursues three objectives:

- knowledge enhancement and information sharing
- policy support
- deployment support.

Further information is available at: www.se4all.org/.

WBCSD LCTPI on Advanced Biofuels

The World Business Council for Sustainable Development (WBCSD) Low Carbon Technology Partnership Initiative (LCTPi) on Advanced Biofuels has four principal goals:

- It seeks to demonstrate that advanced biofuels can reduce emissions while helping to meet increasing demand for global transport.
- It identifies and activates appropriate national and international policies to support sustainable growth of the new sector.
- It demonstrates novel partnerships and models that will attract new investment.
- It provides scalable project opportunities for rapid execution through public-private partnership initiatives.

Further information is available at: http://lctpi.wbcsdservers.org/.

Conclusions

Bioenergy is unique among renewable energy technologies in that it is used in all sectors, including transport; this gives it the ability to directly displace fossil fuel consumption in a wide range of end uses. In addition, bioenergy can positively influence agriculture and rural development. It is therefore no surprise that modern bioenergy is already part of the energy mix of most developed and emerging economies. Biomass for power generation is generally a mature technology and, depending on the feedstock costs and economics of the system, many bioenergy projects operated in co-generation mode provide attractive investment opportunities in OECD member countries and non-OECD countries. Bioenergy is by far the most significant source of renewable heat globally. In the past five years, modern biomass heating technologies have recorded a slow but steady growth in both buildings and industry end uses. The biofuels industry has undergone dramatic growth in the last decade and while some established producers, such as the United States and Brazil, now face slower growth trends, certain emerging markets in Southeast Asia and parts of Sub-Saharan Africa are burgeoning.

Yet, more so than for other low-carbon energy technologies, the complex and multi-faceted supply chains of bioenergy projects call for sound policies and well-thought-out regulatory frameworks. These will enable continued bioenergy growth, while contributing to reduced GHG emissions and greater energy security while fostering the agricultural sector. Experiences from countries with high levels of bioenergy deployment illustrate the need to expose project developers to appropriate policy and regulatory signals so as to facilitate system-friendly design, sustainable sourcing of feedstock and cost-effective operation of bioenergy plants. Unarguably, enhanced bioenergy deployment requires stable and forward-looking policy frameworks alongside financial incentives where applicable.

National and regional bioenergy roadmaps can play a key role in assisting decision makers identify pathways that are tailored to local resources and priority actions to overcome economic and non-economic barriers. This *H2G.BIO* was developed by the IEA and FAO as a toolbox that can be used for both planning and implementing new bioenergy strategies, or to improve existing ones. As illustrated in this manual, there is no "one size fits all" solution and the case studies provide an overview of the array of contextual considerations to be factored in when determining the desirable bioenergy choices in each country or region.

In addition to biomass resource availability and the targeted level of technology deployment, one critical aspect that is likely to affect the success of a bioenergy roadmap in all countries and regions is its ability to cater for the drivers, constraints and objectives of diverse policy areas. Perhaps the most important message from this guide is that successful bioenergy deployment necessitates a cross-sectoral, integrated approach where the efforts of all stakeholders – ranging from energy, agriculture and forestry, infrastructure, environment, technology and innovation, to economic and social affairs – are co-ordinated into concerted, sustainable action. The co-authoring of the *H2G.BIO* by the IEA and FAO, with the active participation of national and regional experts, testifies to the willingness at international level to engage in multi-disciplinary collaboration to promote sustainable bioenergy deployment.

Annex 1: Overview of policy instruments to promote bioenergy uptake

Unless otherwise stated, information in this annex derives from IEA (2015d; 2015e) and the IEA/IRENA *Global Renewable Energy Policies and Measures Database*, as of 30 June 2016.

Regulatory support

Renewable energy laws

Renewable energy targets (RETs) have become a defining feature of the global energy landscape. Defined as the percentage of generation from renewable sources, renewable energy laws and targets can also be refined to include specific targets for bioenergy generation. RETs can take a wide range of forms and are often embedded into technology roadmaps, national renewable energy action plans, or broader national development plans. For example, the European Commission set a target for 10% renewable energy in transport in 2020. For many EU countries, this target was transposed through national blending mandates for biofuels.

Quotas with tradable green certificates (TGCs)

Quotas set a target share or total amount of energy to be generated from renewable energy sources (or bioenergy specifically) for electricity producers or suppliers. Obliged entities may then procure renewable energy in one or more of a number of ways – by directly developing projects, by purchasing power from another supplier, or by using other mechanisms such as TGCs. A market is established for certificates that are issued for each unit of green electricity generated towards meeting the quota. For bioenergy, as with all types of energy technology, TGCs are better suited to the consolidation phase, once the technologies' costs converge and the generation supply curve is "flat". TGCs have also been used to promote biofuels: Portugal set mandatory quotas for use of biofuel in diesel blends, requiring that these contain at least 10% biodiesel, and will use biofuel certificates (CdB) to ensure compliance. Producers are issued one CdB for every 1 000 litres of biofuel destined to substitute for fossil fuels in the transport sector, and diesel distributors must register with the government and demonstrate ownership of sufficient certificates to comply with the minimum biofuel quota.[24]

Renewable portfolio standards (RPSs): RPSs work in a similar fashion to the quotas, as they set a renewable energy obligation for electricity producers or suppliers. RPSs operate on the assumption that the obliged entity has sufficient opportunities to build or purchase renewable energy directly. When this is not the case, RPSs should preferably be combined with TGCs. For example, Korea mandates new buildings constructed after 2011 to meet 10% of their energy demand from renewable sources (KEMCO, n.d.).

Economic support

Feed-in tariff (FIT)

In power generation, FITs guarantee the electricity generator a certain price per unit of generation (kilowatt hour [kWh] or MWh) over an established period of time (e.g. 20 years). Tariffs are usually set according to technology type and attach specific eligibility criteria; for biomass, FITs may relate to the sustainability of biomass fuels or required GHG savings. This adaptability allows FITs to stimulate development of a broad portfolio of technologies with different costs and at different stages of maturity. This is a highly desirable characteristic considering the range of bioenergy pathways and variable investment and operating costs of different technology and feedstock combinations. Similarly, FITs can support renewable heat generation by guaranteeing biomass heat generators a price per unit of heat generated. For example, in 2014, the government of Viet Nam launched support mechanisms for the development of co-generation power plants using biomass. The mechanism took the form of a FIT set to VND 1 220/kWh for eligible plants for a period of 20 years.[25]

Feed-in premium (FIP)

In electricity production, FIPs are intended to complement revenues generated on the standard electricity market by paying investors according to the amount of electricity they generate or the amount of capacity they build. FIPs can take a variety of different forms (fixed, variable, per unit of energy generated, per unit of capacity installed), but all complement standard revenues and serve as a reference price to provide investor confidence. When power prices fall below a designated level, generators continue to receive the designated

24. Decree-Law 49/2009, Portugal Ministry of Economy and Innovation, General Directorate of Energy and Geology, hwww.dgge.pt/ (accessed 17 July 2015).

25. Viet Nam Ministry of Industry and Trade, webpage, www.moit.gov.vn/Images/FileVanBan/_Q%C4%90242014-TTg.pdf (accessed 17 July 2015).

remuneration. FIPs offer an advantage to bioenergy generators who can schedule generation and have significant marginal generation costs. A recent measure by Italy to encourage renewable generation from technologies other than solar PV, including bioenergy, took the form of a FIP for plants with capacity exceeding 1 MW; these plants receive an additional premium on the electricity generated. This incentive scheme is drawn from a renewable energy fund of EUR 5.8 million, allocated to incentivise renewable energy technologies other than solar PV.[26]

Capital grants and subsidies

Capital grants for biomass power or heat producers can be used to reduce net investment costs and so improve returns for investors. Capital grants are easy to manage, and they are applicable across a wide range of technologies and scales of operation. However, grants do not provide operational income certainty or motivation to reduce investment costs, and do not guarantee actual bioenergy or biofuel production. They are most appropriate for small-scale projects or at the demonstration phase for new technologies. Providing grants and rebates to reduce the upfront capital costs of renewable heat technologies is a straightforward measure to reduce investment costs, and has been the most widely adopted way of providing incentives for investment (e.g. in Austria, Germany and China). From July 2009 to June 2012 the government of New Zealand ran the 3-year Biodiesel Grant Scheme, to encourage the production of biodiesel in New Zealand. Grants of up to NZD 0.425 per litre were available to biodiesel producers who sold 10 000 or more litres of eligible biodiesel each month (Energy Efficiency and Conservation Authority, n.d.).

Soft loans and loan guarantees

Government-backed soft loans (loans with a low interest rate) and loan guarantees have been used in some countries as a means to open access to financing or reduce the costs of capital for projects, especially during the early stages of deployment when there are still perceived technical or financial risks associated with projects. Compared to grants, loans can be a low-cost measure for governments to reduce the cost of capital in renewable heat and power because the lender aims to recoup the cost of the loan over time. Governments can also encourage private-sector lenders, such as banks, to offer loans. In India, for instance, many banks offer soft loans for solar-water heaters, and in the United States, the government provided soft loans for the construction of a commercial-scale advanced biofuel plant. In Australia, the government's plan to promote the advanced biofuels sector includes recommendations for capital funding assistance for advanced biofuel demonstration and pilot projects in the form of grants, loans and loan guarantees (L.E.K. Consulting, 2011).

Tax incentives or credits

These are often used to reduce the cost of renewable energy projects from an investor perspective. Mechanisms include reduced tax rates or waiving certain taxes for equipment or revenues from energy sales. Tax incentives can also be given by reducing tax liabilities per unit of generated electricity; this is the case for the production tax credit in the United States. Tax relief or incentives can help improve project economics from an investor perspective, but do not provide income certainty or incentives to reduce costs, or signal the value of the generated electricity or heat. They are therefore best used in conjunction with other mechanisms, as in the United States where they complement renewable portfolio standards and other measures. To promote ethanol production in Brazil, sugar and ethanol exporters are eligible to receive a tax credit of up to 3% of the value of products exported from Brazil.[27]

Carbon pricing

This scheme incorporates into the price of energy the negative cost to society of carbon emissions. Manifested in the form of a tax or an emissions trading system (ETS), carbon pricing increases the cost of conventional, high-emission energy sources to encourage market uptake of renewable technologies (e.g. bioenergy). Sweden has operated a national carbon tax since 1991, which was introduced on top of an existing tax on fossil fuels. The tax is applied to sectors that are not covered by the EU ETS, and in 2014 had reached EUR 125 per tonne of CO_2 equivalent. By reducing the carbon tax liability for facilities using co-generation for heat to 7% (compared to 94% for non-co-generated heat), the carbon tax created strong price incentives to

26. Ministerial Decree 10 July 2012, Italian Ministry of Economic Development/Ministry for Environment, Territory and Sea, www.gse.it/it/Qualifiche%20e%20certificati/Incentivi_DM_06_07_2012/Pagine/default.aspx (accessed 17 July 2015).

27. Decree No. 7.633 of 1 December 2011, Brazilian Ministry of Finance, www.receita.fazenda.gov.br/Legislacao/Decretos/2011/dec7633.htm (accessed 17 July 2015).

use biomass heat, which saw a dramatic increase in bioenergy use.[28] Today, bioenergy use is around 30% of Sweden's total primary energy supply, used primarily for industrial processes and district heating (Swedish Institute, n.d.).

Auction schemes or tenders

Centralised procurement via a government or public body can be used to contract a certain amount of renewable energy or capacity within an overall allocation. Often, auctions are held to contract a predetermined quantity while the price is set in a competitive bidding process. Bioenergy project developers are invited to bid to win the contract and the bidders with the best offers are selected. Given upfront costs and the need for guarantees, tenders are best suited to larger scale projects and most tend to involve well-financed and experienced international developers (sometimes in collaboration with local participants and investors). Tenders or auctions for long-term power purchases can effectively reduce generation costs through competition. South Africa's REIPP Programme auctions off power generation to independent producers, setting ceiling tariffs for each technology, including biomass solids and biogas. Winning bidders sign PPAs, which are guaranteed for a period of 20 years (Republic of South Africa, Department of Bioenergy, n.d.).

28. On January 1 2013, Sweden determined that co-generated heat production would be completely exempt from the carbon tax as it is covered by the EU ETS.

Certification schemes

These are designed to provide market certainty regarding the sustainability of bioenergy. The overall aim of certification schemes is to mitigate the risk that bioenergy projects have unsustainable impacts and/or generate negative externalities for the parties concerned (investors, developers and end users). Schemes can be established by government or the private sector and can be either mandatory or voluntary. Under certification schemes, sustainability criteria are established which project developers must meet in order to be certified. Auditors are employed to assess whether projects have met sustainability criteria. Under the Renewable Energy Directive, the European Commission has mandated that its member states must establish national certification schemes or use existing voluntary certification schemes to certify the sustainability of all bioenergy (defined as biofuels and bioliquids for heat and electricity) sold in the European market. All bioenergy must meet a set of criteria, which include considerations of land use, GHG savings and production chains. [29]

29. To be considered sustainable, biofuels must achieve GHG savings of at least 35% in comparison to fossil fuels. This savings requirement rises to 50% in 2017. In 2018, it rises again to 60% but only for new production plants. All life cycle emissions are taken into account when calculating GHG savings. This includes emissions from cultivation, processing and transport. Biofuels cannot be grown in areas converted from land with previously high carbon stock such as wetlands or forests. Biofuels cannot be produced from raw materials obtained from land with high biodiversity such as primary forests or highly biodiverse grasslands. See: http://europa.eu/rapid/press-release_MEMO-11-522_en.htm http://europa.eu/rapid/press-release_MEMO-11-522_en.htm (accessed 27 October 2015).

Annex 2: GBEP Indicators for Monitoring the Sustainability of Bioenergy

ENVIRONMENTAL PILLAR	
1. Lifecycle GHG emissions	Lifecycle GHG emissions from bioenergy production and use, as per the methodology chosen nationally or at community level, and reported using the GBEP Common Methodological Framework for GHG Lifecycle Analysis of Bioenergy Version One.
2. Soil quality	Percentage of land for which soil quality, in particular in terms of soil organic carbon, is maintained or improved out of total land on which bioenergy feedstock is cultivated or harvested.
3. Harvest levels of wood resources	Annual harvest of wood resources by volume and as a percentage of net growth or sustained yield, and the percentage of the annual harvest used for bioenergy.
4. Emissions of non-GHG air pollutants, including air toxics	Emissions of the non-GHG air pollutants, including air toxics, from bioenergy feedstock production, processing, transport of feedstocks, intermediate products and end products, and use; and in comparison with other energy sources.
5. Water use and efficiency	• Water withdrawn from nationally determined watershed(s) for the production and processing of bioenergy feedstocks, expressed as the percentage of total actual renewable water resources (TARWR) and as the percentage of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources. • Volume of water withdrawn from nationally determined watershed(s) used for the production and processing of bioenergy feedstocks per unit of bioenergy output, disaggregated into renewable and non-renewable water sources.
6. Water quality	• Pollutant loadings to waterways and bodies of water attributable to fertiliser and pesticide application for bioenergy feedstock cultivation, and expressed as a percentage of pollutant loadings from total agricultural production in the watershed. • Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents, and expressed as a percentage of pollutant loadings from total agricultural processing effluents in the watershed.
7. Biological diversity in the landscape	• Area and percentage of nationally recognised areas of high biodiversity value or critical ecosystems converted to bioenergy production. • Area and percentage of the land used for bioenergy production where nationally recognised invasive species, by risk category, are cultivated. • Area and percentage of the land used for bioenergy production where nationally recognised conservation methods are used.

8. Land use and land use change related to bioenergy feedstock production	• Total area of land for bioenergy feedstock production, and as compared to total national surface and agricultural and managed forest land area.
	• Percentages of bioenergy from yield increases, residues, wastes and degraded or contaminated land.
	• Net annual rates of conversion between land use types caused directly by bioenergy feedstock production, including the following (amongst others):
	  ◦ arable land and permanent crops, permanent meadows and pastures, and managed forests
	  ◦ natural forests and grasslands (including savannah, excluding natural permanent meadows and pastures), peatlands and wetlands.

SOCIAL PILLAR	
9. Allocation and tenure of land for new bioenergy production	Percentage of land – total and by land use type – used for new bioenergy production where: • A legal instrument or domestic authority establishes title and procedures for change or title, and • The current domestic legal system and/or socially accepted practices provide due process and the established procedures are followed for determining legal title.
10. Price and supply of a national food basket	Effects of bioenergy use and domestic production on the price and supply of a food basket, which is a nationally defined collection of representative foodstuffs, including main staple crops, measured at the national, regional, and/or household level, taking into consideration: • Changes in demand for foodstuffs for food, feed and fibre. • Changes in the import and export of foodstuffs. • Changes in agricultural production due to weather conditions. • Changes in agricultural costs from petroleum and other energy prices. • The impact of price volatility and price inflation of foodstuffs on the national, regional, and/or household welfare level, as nationally determined.
11. Change in income	Contribution of the following to change in income due to bioenergy production: • Wages paid for employment in the bioenergy sector in relation to comparable sectors. • Net income from the sale, barter and/or own consumption of bioenergy products, including feedstocks, by self-employed households/individuals.

12. Jobs in the bioenergy sector	• Net job creation as a result of bioenergy production and use, total and disaggregated (if possible) as follows:
	  ◦ skilled/unskilled
	  ◦ temporary/indefinite.
	• Total number of jobs in the bioenergy sector and percentage adhering to nationally recognised labour standards consistent with the principles enumerated in the International Labour Organization's (ILO) Declaration on Fundamental Principles and Rights at Work, in relation to comparable sectors.

13. Change in unpaid time spent by women and children collecting biomass	Change in average unpaid time spent by women and children collecting biomass as a result of switching from traditional use of biomass to modern bioenergy services.
14. Bioenergy used to expand access to modern energy services	• Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), measured in terms of energy and numbers of households and businesses. • Total number and percentage of households and businesses using bioenergy, disaggregated into modern bioenergy and traditional use of biomass.
15. Change in mortality and burden of disease attributable to indoor smoke	Change in mortality and burden of disease attributable to indoor smoke from solid fuel use, and changes in these as a result of the increased deployment of modern bioenergy services, including improved biomass-based cook stoves.
16. Incidence of occupational injury, illness and fatalities	Incidence of occupational injury, illness and fatalities in the production of bioenergy in relation to comparable sectors.

ECONOMIC PILLAR	
17. Productivity	• Productivity of bioenergy feedstocks by feedstock or by farm/plantation. • Processing efficiencies by technology and feedstock. • Amount of bioenergy end product by mass, volume or energy content per hectare per year. • Production cost per unit of bioenergy.
18. Net energy balance	Energy ratio of the bioenergy value chain in comparison to other energy sources, including energy ratios of feedstock production, processing of feedstock into bioenergy, bioenergy use; and/or lifecycle analysis.
19. Gross value added	Gross value added per unit of bioenergy produced and as a percentage of GDP.
20. Change in the consumption of fossil fuels and traditional use of biomass	• Substitution of fossil fuels with domestic bioenergy measured by energy content and in annual savings of convertible currency from reduced purchases of fossil fuels. • Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content.
21. Training and requalification of the workforce	Percentage of trained workers in the bioenergy sector out of total bioenergy workforce, and percentage of requalified workers out of the total number of jobs lost in the bioenergy sector.
22. Energy diversity	Change in diversity of total primary energy supply due to bioenergy.
23. Infrastructure and logistics for distribution of bioenergy	Number and capacity of routes for critical distribution systems, along with an assessment of the proportion of the bioenergy associated with each.
24. Capacity and flexibility of use of bioenergy	• Ratio of capacity for using bioenergy compared with actual use for each significant utilisation route. • Ratio of flexible capacity that can use either bioenergy or other fuel sources to total capacity.

Annex 3: Overview of biofuels blending targets and mandates by country

The information provided in Annex 3 is primarily derived from the IEA/IRENA *Global Renewable Energy Policies and Measures Database* as of 30 June 2016.[30] It provides information on policies and measures taken or planned to encourage the uptake of renewable energy in IEA member countries, as well as in selected emerging and developing economies. Among these, special attention is given to countries represented at the expert workshops carried out in preparation for this *H2G.BIO* (Box 1).

30. www.iea.org/policiesandmeasures/renewableenergy/ (accessed 30 June 2016).

IEA MEMBER COUNTRIES			
Country	**Current mandate/target**	**Current status**	**Future mandate/ target (2020)**
Australia: New South Wales (NSW), Queensland (QL)	NSW: E7, B2 QL: E3, B0.5	M	National: E10
Austria	5.75% biofuels $_{(E\ content)}$	M	8.45% biofuels $_{(E\ content)}$
Belgium	E4, B6	M	10% renewables in transport
Canada	B2, E5	M	BC: E10, B2
Czech Republic	E4.1, B6	T	10% renewables in transport
Denmark	5.75% biofuels	M	10% renewables in transport
Estonia	5% biofuels	T	10% renewables in transport (M)
European Union	5.7% renewables in transport	M	10% renewables in transport
Finland	10% renewables in transport	M	20% renewables in transport
France	E7, B7	M	10.5% biofuels; 23% renewables in transport (T)
Germany	n.a.	n.a.	10% renewables in transport
Greece	5.75% biofuels	M	10% renewables in transport
Hungary	E4.9, B4.9	M	11.18% renewables in transport
Ireland	6.36% biofuels $_{v/v}$	M	9% biofuels 10% renewables in transport
Italy	5.5% biofuels; 0.6% advanced biofuels	M	10% biofuels; 1% advanced biofuels (2022)
Korea	B2.5	M	B3 (2018)
Japan	E10, B5	T	10% biofuels (2030)
Luxembourg	4.75% biofuels	M	10% renewables in transport
Netherlands	7% biofuels	M	10% renewables in transport
New Zealand	n.a.	n.a.	n.a.
Norway	6.5% renewables in transport	T	10% renewables in transport
Poland	7.1% biofuels	M	10% renewables in transport
Portugal	7.5% biofuels	M	10% renewables in transport
Slovak Republic	5.5% biofuels; E4.6, B6.9	M	8.5% biofuels $_{(energy\ content)}$, B11.5 and E7

IEA MEMBER COUNTRIES			
Country	**Current mandate/target**	**Current status**	**Future mandate/ target (2020)**
Spain	4.3% biofuels	M	10% renewables in transport, B8.5
Sweden	11% biofuels	T	10% renewables in transport
Switzerland	n.a.	n.a.	n.a.
Turkey	E3, B1	M	E3, B3
United Kingdom	4.75% biofuels	M	10% renewables in transport; 6.55% biofuels
United States	9.02% renewable fuels B: 68.5 billion litres	M	136 billion litres biofuels by 2022

SELECTED IEA PARTNER COUNTRIES			
Country	**Current mandate/target**	**Current status**	**Future mandate/ target (2020)**
Argentina	E5, B10	T	n.a.
Brazil	E27, B7	M	n.a.
Chile	E5, B5	T	E5, B5
China	E10 (9 provinces), B5	M	E10 (9 provinces), E15 (T)
Colombia	Depending on the region: E8 to E10; B8 to B10	M	E10
Costa Rica	E7, B20	M	n.a.
Ecuador	E10, B5	M	B10
India	E5	M	E20 (M), B20 (T)
Indonesia	E2 $_{(PSO)}$, E5 $_{(non\ PSO)}$, B20	M	E5 $_{(PSO)}$, E10 $_{(non\ PSO)}$, B30
Lao PDR	n.a.	n.a.	10% biofuels (2025) 150 million litres ethanol 300 million litres biodiesel
Malaysia	B7	M	B10
Mozambique	E10, B3	M	E15, B7.5
Philippines	E10 (M), B5 (T)	M, T	E20, B10
South Africa	E2-E10, B5	M	n.a.
Thailand	E10, E20 and E85, B7	M	E10-E85, B7, 25% biofuels (2036)
Ukraine	E5 $_{v/v}$	M	E7 (2017), 10% renewables in transport (T)
Viet Nam	E5, B5	M	E10 $_{(2015)}$ 5% or 550 million litres biofuels
Zimbabwe	E15	M	E15

Notes: E= ethanol (E2 = 2% ethanol blend); B = biodiesel (B2 = 2% biodiesel blend); CB = conventional biofuel; ABC = advanced biofuel category under RFS2; CBC = cellulosic biofuel category under RFS2; M = Mandate; n.a. = not applicable; T = Target; PSO = public service obligation in Indonesia, for ethanol refers to subsidised fuel used by small-scale industry, fishing and agriculture; this table includes key biofuel producers from both IEA member and non-memberpartner countries, as well as countries that were represented at the expert workshops that sourced information for the BIO.H2G (see Box 1). Lao PDR = Lao People's Democratic Republic.

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

ABC	Advanced Biofuel Category under RFS2
AEZ	Agro-Ecological Zoning
ANFAVEA	National Industry Association of Automobile Manufacturers (Brazil)
ASEAN RESP	Association of Southeast Asian Nations Renewable Energy Support Programme
B2	2% biodiesel blend
BBEP	Beema Bamboo to Energy Project (South Africa)
BBP	Bronkhorstspruit Biogas Plant (South Africa)
BCI	Biorefinery Complexity Index
BEFS	Bioenergy and Food Security Approach
BM	blending mandate
BtL	biomass to liquid
CAPEX	capital expenditure
CB	conventional biofuel
CBC	cellulosic biofuel category under RFS2
CdB	biofuel certificates (Portugal)
CH_4	methane
CO_2	carbon dioxide
COP	Conference of the Parties to the 1992 United Nations Framework Convention on Climate Change
CTC	Sugarcane Technology Center (Brazil)
DG NREEC	Directorate General for New, Renewable Energy and Energy Conservation (Indonesia)
DSO	distribution system operator
E85	fuel blend of 85% ethanol and 15% gasoline
EBTP	European Biofuels Technology Platform
EIBI	European Industrial Bioenergy Initiative
EMBRAPA	Brazilian Agricultural Research Corporation
ESMAP	Energy Sector Management Assistance Program
ETP	Energy Technology Perspectives
ETS	emissions trading system
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFV	flexible-fuel vehicles
FIP	feed-in premium
FIT	feed-in tariff
FSC	Forest Stewardship Council
GBEP	Global Bioenergy Partnership
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (Germany)
HIO	High Impact Opportunity (SE4ALL)
HVO	hydrotreated vegetable oil
H2G	How2Guide
H2G.BIO	*How2Guide for Bioenergy*

IEA	International Energy Agency
ILO	International Labour Organization
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISCC	International Sustainability and Carbon Certification System
ISO	International Organization for Standardization
LCA	life cycle assessment
LCOE	levelised cost of electricity
LCORE	Promotion of Least Cost Renewables Project
LCTPi	Low Carbon Technology Partnership Initiative (WBCSD)
LUC	land use change
META	Model for Electricity Technology Assessment
MME	Ministry for Mines and Energy of Brazil
MSW	municipal solid waste
NDC	Nationally Determined Contribution
NGO	non-governmental organisation
NPSB	Netherlands Programme for Sustainable Biomass
NREAP	National Renewable Energy Action Plan
NZD	New Zealand Dollar
OECD	Organisation for Economic Co-Operation and Development
OPEX	operating expenditure
O&M	operations and maintenance
PDP	Project Development Programme Indonesia
PEFC	Programme for the Endorsement of Forest Certification
PPA	power purchasing agreement
PSO	public service obligation
PV	photovoltaic
RACI	responsible, accountable, consulted and informed
RDF	refuse-derived fuel
REEEP	Renewable Energy and Energy Efficiency Partnership
REFIT	Renewable Energy Feed-In Tariff (South Africa)
REIPP	Renewable Energy Independent Power Producers (South Africa)
RET	renewable energy target
RFS	Renewable Fuel Standard (United States)
RFS2	Renewable Fuel Standard (2022) (United States)
RPS	renewable portfolio standard
RSB	Roundtable on Sustainable Biomaterials (FAO)
RVO	Netherlands Enterprise Agency
R&D	research and development
SANEDI	South African National Energy Development Institute
SASA	South African Sugar Association
SCC	stress corrosion cracking
SE4ALL	Sustainable Energy for All (United Nations)
SRW	small round wood
syngas	bio-synthetic gas
TARWR	total actual renewable water resources

TAWW	total annual water withdrawals
TCEP	Tracking Clean Energy Progress
TCP	Technology Collaboration Programme
TGC	tradable green certificates
TSO	transmission system operator
UN	United Nations
UNICA	Brazilian Sugarcane Industry Association
USD	United States Dollar
VND	Vietnamese Dong
VRE	variable renewable energy
WBCSD	World Business Council for Sustainable Development
1G/2G/3G	first/second/third generation
2DS	2°C Scenario (*ETP*)

Units of measure

°C	degree Celsius
bg/y	billion gallons per year
BTU	British thermal unit
EJ	exajoule
GW	gigawatt
GWh	gigawatt hour
km	kilometre
kW	kilowatt
kWh	kilowatt hour
MJ	megajoule
Mtoe	million tonnes of oil-equivalent
MW	megawatt
MW_e	megawatt electric
MWh	megawatt hour
TWh	terawatt hour

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