Biomass Waste-to-Energy Toolkit for Development Practitioners

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Foreword

The use of renewable energy sources is critical if we are to achieve the changes needed to transition to a more sustainable, low emissions development trajectory. Biomass residues already make an important contribution to meeting global energy demands and their role in the modern energy supply mix is likely to expand significantly in the future. Waste products from agricultural, forestry or industrial processes are often discarded or are used for basic services. Waste to energy projects allow greater value to be gained from these wastes and residues. They can play a role in addressing energy access challenges, providing opportunities for social and economic development in agricultural communities, contributing to local energy security, improving the management of resources and wastes and providing greenhouse gas savings and other environmental benefits.

By focusing on waste, a project developer or policymaker can ensure that activities are more likely to be more sustainable and are less likely to threaten food supplies or lead to encroachment into natural forests. Furthermore, biomass waste can offer a low cost source of energy that can be found in many places in good supply. Based on these facts, there is considerable scope to increase and improve the utilisation of biomass waste as a sustainable energy source, particularly in developing countries. Policy makers, investors and project developers therefore need a comprehensive decision support tool to design and implement biomass projects. However, there is a knowledge gap, and this has driven production of this toolkit; to help assess the feasibility of waste to energy projects.

The toolkit does not promote a one size fits all approach but provides a practitioner who is interested in developing a waste to energy project with relevant information and guidance to allow them to assess the feasibility of the project and improve its design. It is hoped that this toolkit will further help in the proliferation of activities to use wastes to produce energy and therefore achieve the multiple, economic, social and environmental benefits this can bring.

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Contents

List of boxes, figures and tables

Abbreviations

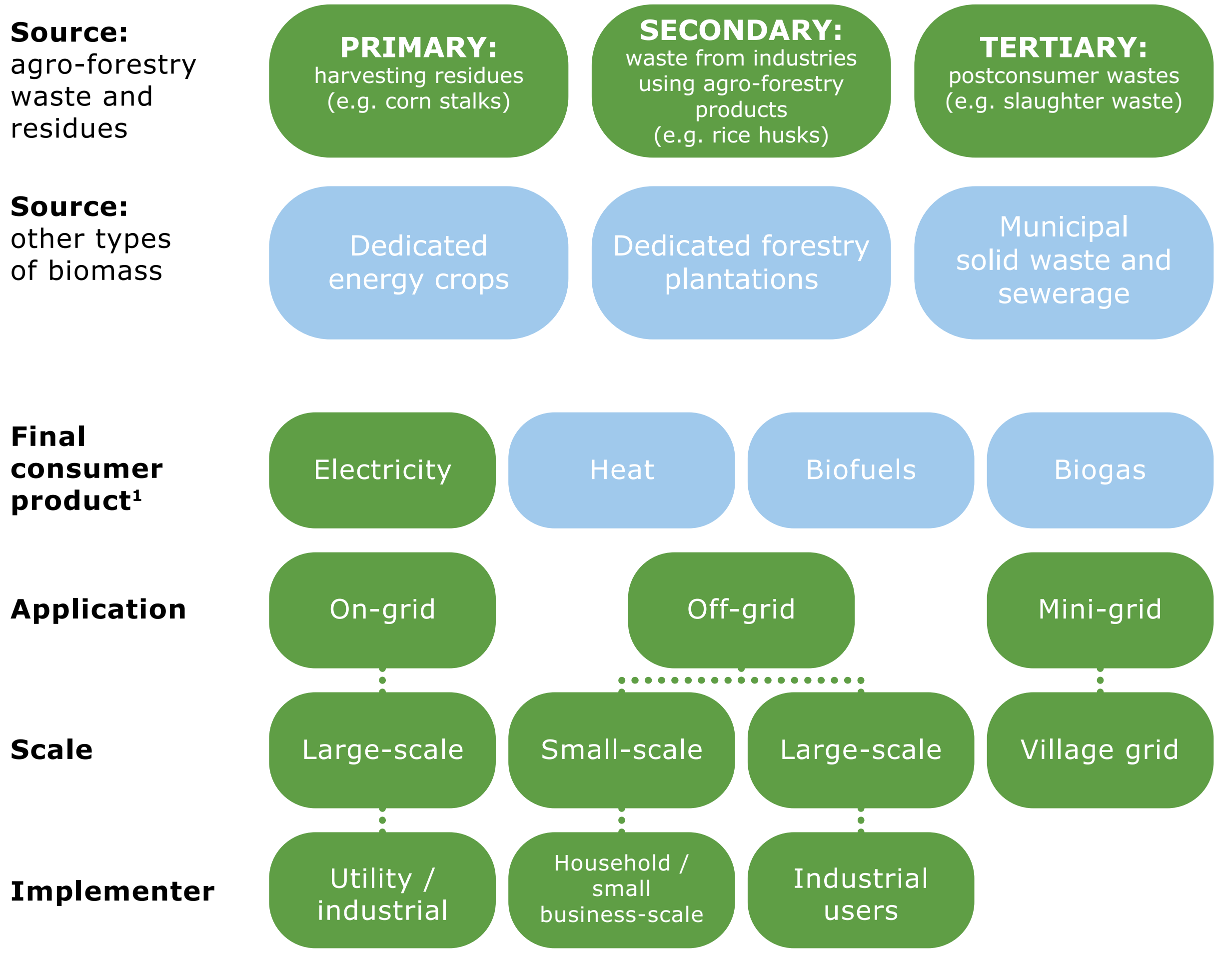
ACAD	African Carbon Asset Development
AD	anaerobic digestion
ADF	Asian Development Fund
AECF	Africa Enterprise Challenge Fund
AfDB	African Development Bank
ASEAN-RESP	Renewable Energy Support Programme for ASEAN
BFB	bubbling fluidised bed
BIG	biomass integrated gasification
CDM	Clean Development Mechanism
CECAFA	Clean Energy Access and Climate Adaptation Facility for Africa
CEDFC	Clean Energy Development and Finance Centre
CEIF	Clean Energy Investment Framework
CERs	certified emission reductions
CFB	circulating fluidised bed
CHP	combined heat and power
GHG	greenhouse gas
CSTR	continuously stirred tank reactor
CTF	Clean Technology Fund
DFI	development finance institution
EfW	energy-from-waste
EIA	environmental impact assessment
EIB	European Investment Bank
ENA	energy needs assessment
ESMAP	Energy Sector Management Assistance Program
FCMRA	Federation of Cambodian Rice Millers Association
FIP	Forest Investment Programme
FMO	Development Finance Facility
GEF	Global Environment Facility
HHV	higher heating value
I-ALC	agency lines of credit
ICI	International Climate Initiative
IKLU	Initiative for Climate and Environmental Protection
I-LOC	infrastructure lines of credit
IPPs	independent power producers
IPPC	integrated pollution prevention and control
IRENA	International Renewable Energy Agency
IRR	internal rate of return
LHV	lower heating value
MA	market analysis
MSW	municipal solid wastes
NAMAs	nationally appropriate mitigation actions
NGO	non-governmental organisation
NMMs	new market-based mechanisms
NPV	net present value
ODA	official development assistance
O&M	operating and maintenance
PDF	Partnership Dialogue Facility
POME	palm oil mill effluent
PPA	power purchase agreement
PPP	public private partnership
PV	photovoltaic
R&D	research and development
REDD+	Reducing emissions from deforestation and forest degradation
REEEP	Renewable Energy and Energy Efficiency Partnership
RHG	rice husk gasifier
RPS	Renewable Portfolio Standards
SEFA	Sustainable Energy Fund for Africa
SME	Small and medium enterprise
SME-RE	SME Renewable Energy Ltd
SREP	Scaling Up Renewable Energy in Low Income Countries Program
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
WACC	weighted average cost of capital
WB	World Bank
WtE	waste-to-energy

Introduction and scope

This document presents an introductory toolkit that has been developed with the purpose of supporting development practitioners and other interested stakeholders in assessing projects for the recovery of energy from waste biomass. It is meant as a decision support tool for SNV advisers wishing to engage in sustainable Waste-to-Energy (WtE) project development, either on an ad-hoc project basis or as part of a wider bioenergy promotion strategy.

The focus of the toolkit is on the use of agricultural and forestry waste for the generation of electricity using technologies including combustion, gasification and anaerobic digestion, both for on and off-grid applications, as shown in Figure 1. WtE and waste-to-electricity are used interchangeably in this toolkit; however it should be noted that electricity generation is only one of the possible energy applications of biomass waste. Much of the information and advice in this toolkit is also applicable to other bioenergy technologies and end-uses.

Figure 1: Biomass waste-to-energy toolkit scope (marked in green)



1. Heat is discussed within the toolkit as a by-product of electricity generation using cogeneration technology. Biogas generation is discussed as a fuel for electricity generation, but biogas can also be used directly for limited applications or further treated to for other purposes, such as a vehicle fuel.

The toolkit covers the following topics:

Chapter 1	Key definitions used throughout this document, the rationale for focusing on biomass wastes and residues and an introduction to the biomass waste value chain.
Chapter 2	The importance, challenges and opportunities for recovering energy for productive purposes from agricultural and forestry residues.
Chapter 3	A summary of four key WtE technology options and characteristics of their feedstocks, pre-treatment-requirement, conversion-processes and outputs (Chapter 3). These technologies are:[2] Combustion (fixed bed and fluidised bed boilers and co-firing) Anaerobic digestion Gasification (fixed and fluidised bed gasifiers) Cogeneration (combined heat and power; CHP).
Chapter 4	A checklist of market and regulatory conditions that need to be met in order for WtE developments to be sustainable.
Chapter 5	A step-based guide to conducting initial screening of projects and performing a pre-feasibility assessment. Following the provided questions can help an adviser (or other interested stakeholder) make an initial assessment of viability for a proposed project.
Chapter 6	Two illustrative case studies / success stories of WtE applications that demonstrate how efficient projects can provide a valuable source of power, create markets for waste products and help reduce the use of fossil fuels with the associated benefits of greenhouse gas (GHG) reductions and cost-savings.
Chapter 7	Information on funding sources for bioenergy project development.

A planned follow-up to this toolkit will develop a financial assessment tool that can be used to assess the financial outcomes of a biomass waste project.

The toolkit does not promote a one size fits all approach but provides a practitioner who is interested in developing a WtE project with relevant information and guidance to allow them to assess the feasibility of the project and improve its design. The information in this toolkit should be adapted as appropriate to national circumstances, to ensure the proposed intervention delivers the energy outcomes, as well as the environmental and socio-economic benefits, that are the drivers behind sustainable bioenergy.

2. A fifth technology, pyrolysis, has the potential to be combined with electricity generation, but is a relatively novel technology that is not proven at scale in a developing country context and is, therefore, not considered relevant to include in detail in a practitioner's handbook.

Section 1
Basic concepts and background

Before exploring the opportunities and challenges for the use of biomass waste in the generation of electricity, this chapter first introduces the definitions used in this toolkit and the rationale for focussing on biomass waste. The chapter also describes the biomass WtE value chain, which is the basis for the identification of challenges of WtE projects.

1.1 Definitions

Biomass as a general term refers to a wide range of biomass sources that can be used to produce bioenergy in a variety of forms. The term covers food, fibre and wood process residues from the industrial sector; dedicated energy and short-rotation crops and agricultural wastes from the agricultural sector; and forest residues, agroforestry residues and dedicated energy plantations from the forestry sector (Global Bioenergy Partnership 2007).

Bioenergy is energy derived from biomass.

Biomass waste represents a subset of broader biomass that includes waste products and residues. It encompasses (EU 2009):

- **agro-forestry waste or residues** (also often referred to as agricultural or forestry waste or by-products), that is waste from agriculture (including vegetable and animal substances), forestry and related industries including fisheries and aquaculture. Agro-forestry wastes and residues can further be distinguished as:
  - **primary**, usually meaning harvesting residues remaining on the field or in the forest after harvesting (for example corn stalks)
  - **secondary**, which refers to wastes and by-products generated by processing industries using agricultural products and wood as inputs (i.e. bagasse, rice husks, black liquor, etc.)
  - **tertiary**, which includes postconsumer residues and wastes, such as slaughter waste, used oils, construction and demolition wood debris, packaging wastes, vegetable, fruit and garden waste.
- the biodegradable fraction of industrial and municipal waste.[3]

Feedstock is the raw material supplied to a machine or processing plant.

Electricity grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centres and distribution lines that connect individual customers (Kaplan 2009). Within this toolkit, the electricity grid referred to is the national electricity grid, unless otherwise stated.

On-grid means connected to the national electricity grid, while off-grid means not connected to the national electricity grid. Off-grid electricity supply is therefore the generation and consumption of electricity at the same site, without making use of any transmission infrastructure.

3. Note that municipal solid wastes (MSW) and sewage sludge are an important potential source of bioenergy but are not considered in detail in this toolkit. However, much of the toolkit remains relevant for these sources of bioenergy.

Mini-grid Distributed-grid or mini-grid systems are decentralised power plants, effectively larger stand-alone systems, which supply power to isolated groups of householders, communities or even larger groups. They involve a local grid-network for the supply of power. Connecting the utility grid to remote regions usually requires electricity transportation over long distances to a dispersed population. For this reason, mini-grid systems can provide more cost-effective electrification than grid-extension for such areas (UNIDO 2007).

Small and medium-scale refers to applications up to approximately 1 MW, while large-scale applications refers to those in the MW range. The first group comprises distributed off-grid installations, e.g. small businesses, individual consumers and mini-grids (i.e. village grids). Large scale installations are typically power plants connected to the electricity grid and/or larger industrial consumers, which may consume some or all of the power on-site.

Traditional use of biomass refers to the (generally unsustainable) use of fuel wood, charcoal, tree leaves, animal dung and agricultural residues for cooking, lighting and space heating, which are technologies generally characterised by very low energy efficiencies (DBFZ 2013). By comparison, modern use of biomass relies on efficient conversion technologies for applications at household, small business and industrial scales. These include solid fuels (e.g. firewood, wood chips, pellets, charcoal, briquettes), liquid fuels (e.g. bioethanol, biodiesel, bio-oil), gaseous fuels (biogas, synthesis gas, hydrogen) and direct heat from production processes (Global Bioenergy Partnership 2007).

Waste-to-Energy (WtE) or **Energy-from-Waste (EfW)** covers any form of energy recovery from biomass waste, including:

- direct combustion with or without heat recovery
- combustion of methane produced in landfill sites
- controlled anaerobic digestion of organic waste to produce methane for burning
- gasification of biomass waste
- pyrolysis of biomass waste.

1.2 Benefits of biomass waste for energy

Bioenergy already makes an important contribution to meeting global energy demand and its role in the modern energy supply mix is likely to expand significantly in the future. Bioenergy can play a role in addressing energy access challenges; provide opportunities for social and economic development in agricultural communities; contribute to local energy security; improve the management of resources and wastes; and provide greenhouse gas (GHG) savings and other environmental benefits.

However, any biomass project and biomass use must be assessed carefully to ensure its sustainability. The fact that renewable feedstocks are used to produce bioenergy does not ensure that it is sustainable. Overuse of biomass resources that are not renewed (i.e. regrown) can threaten forests and conservation areas and decrease food security; sacrifice natural areas to managed monocultures; accelerate destruction of forest for feedstock; and increase emissions of carbon to the atmosphere.

Biomass waste avoids this problem of sustainability. Waste products from agricultural, forestry or industrial processes are often discarded or are used for basic services. These processes are occurring anyway, but a WtE project allows greater value to be gained from these wastes and residues. By focusing on waste, a project developer or policymaker can ensure that projects are far more likely to be sustainable and are far less likely to threaten food supply or natural forests. Furthermore, biomass waste can offer a low cost source of energy that can be found in many places in good supply. Based on these facts, there is considerable scope to increase and improve the utilisation of biomass waste as a sustainable energy source, particularly in developing countries.

Implementation of modern WtE can offer several other advantages in addition to meeting a primary need of electricity generation:

- *Wide availability:* organic waste is produced or processed in nearly all locations where there is agricultural or forestry activity, or human habitations.
- *Versatility:* most renewable energies generate one or two specific energy carriers from a particular source. WtE uses a multitude of processes to convert a wide variety of feedstocks into electricity along with possible by-products of heat, useful gases and/or transport fuels.

- *Flexibility:* electricity produced from biomass can generally be produced on demand, unlike the variability associated with other forms of renewable energy such as solar or wind.
- *Contribution to rural livelihoods:* most biomass waste is generated in rural areas and agro-forestry residues sold for energy purposes can represent an additional income stream for farmers, thereby offering a contribution to rural livelihoods. In addition, the dispersed nature of most biomass waste makes it well-suited to the smaller-scale developments that may be operated by communities.
- *Energy access:* sustainable biomass waste resources can be found in many rural areas which can make it suitable to generation of electricity in remote areas or for providing additional power in areas that may have previously had insufficient supply.
- *Impact on energy security and balance of payments:* dependency on imported fuel can have a significant negative impact on economic development and balance of payments. Biomass waste can contribute towards reducing such dependence and improving trade deficits.
- *Job creation:* provision of energy services from biomass waste tends to be labour-intensive due to the jobs associated with feedstock collection and processing.
- *Improved health:* the conversion of organic waste, especially human and animal waste, into energy can have advantages with regards improved hygiene through waste collection and removal, as well as reduction in respiratory diseases through improved indoor air quality with improved cooking practices (though the link for the latter to WtE is less common).
- *Environmental sustainability:*
  - Biodiversity conservation through reduced demand on non-sustainable biomass sources
  - Reduction in greenhouse gas emission reductions as a sustainable source of energy
  - Reductions in local pollutants (if appropriate technology is used) such as NOx and particulate matter
  - For forestry residues specifically, improved forest site conditions for planting, thinning from harvesting which leads to improves growth and productivity of the remaining stand and removal of biomass from over-dense stands can reduce the risk of wildfires (IEA Bioenergy 2009).

1.2.1 The bioenergy-forest sustainability nexus

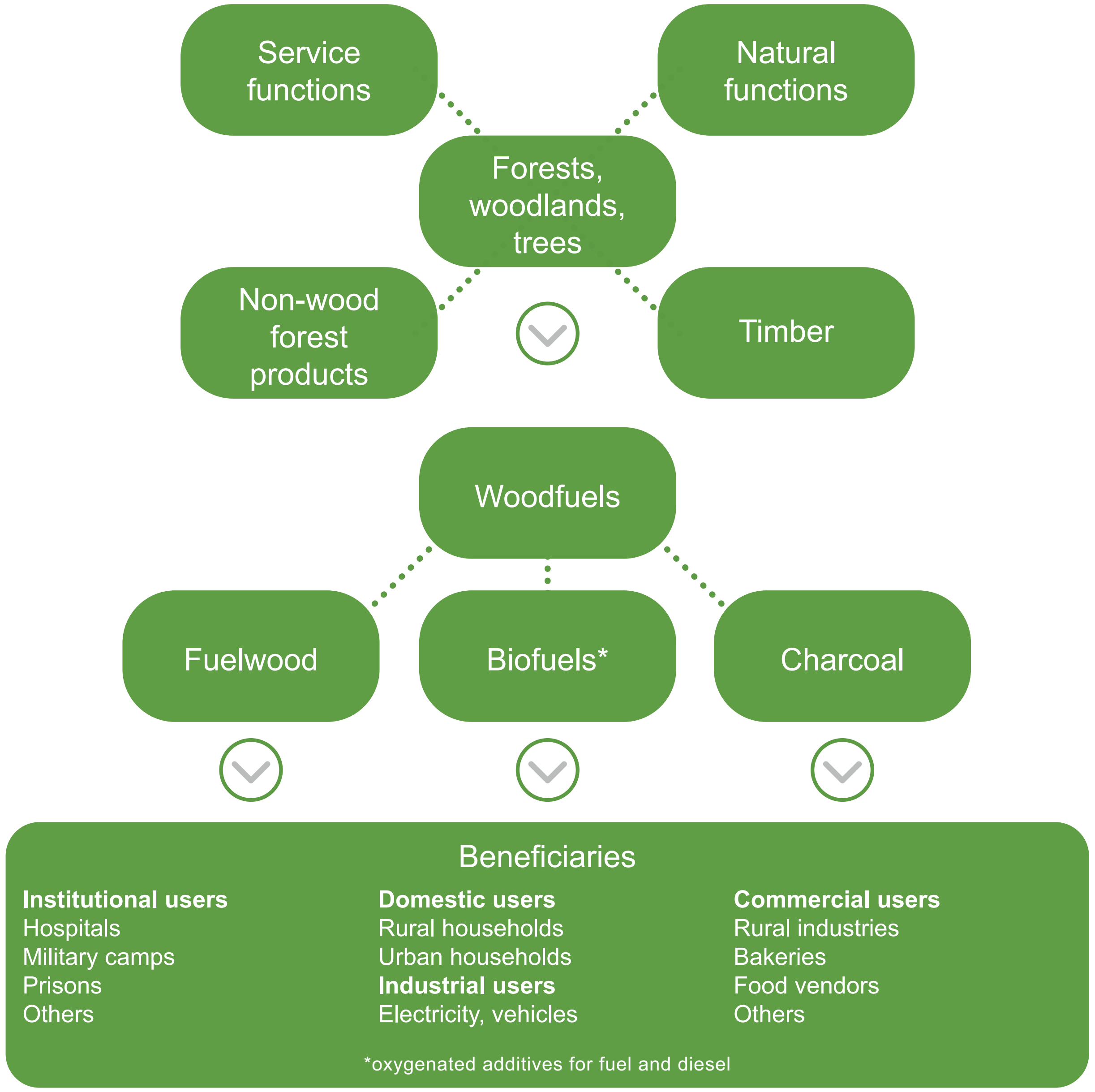
The potential impact of misguided bioenergy developments on food security has been extensively publicised and documented in recent years. The displacement of agricultural land for biomass production is the simplest example of such an interaction. However, the linkages between biomass use and forests do not always receive the same attention, yet the potential impacts of biomass use and bioenergy projects on forests can also have serious consequences for the sustainability of these natural resources.

Forests provide inputs to several different markets including energy, pulp and paper, construction materials, particle board and furniture, as well as more traditional uses of wood-fuel such as cooking and charcoal production (Figure 2). The contemporary view of sustainable forestry and forest management recognises that, in addition to the economic value associated with timber and biomass products, forests also provide many social, environmental and other economic benefits (Freer-Smith 2007).

Sustainable sources of biomass for energy production can include natural and managed forests, dedicated energy crops and non-forest trees, as well as by-products and wood waste from the forest industry. As a general rule, bioenergy production is considered sustainable if biomass utilisation levels do not exceed growth over time. This also ensures that forests continue acting as a carbon sink (Berndes 2013). Considering this, bioenergy use can represent a threat to forests by adding to the already substantial demand for forest products and by-products. Excessive demand can in turn threaten sustainable forest management:

i. by removing biomass faster than the rate of replacement from an area than is being regrown
ii. by directly replacing existing natural forest with monocultures for bioenergy production
iii. through indirect effects, such as displacing food production in a certain area that then moves into a forested area.

Figure 2: Multiple uses of wood energy (FAO 1996)



Sustainable bioenergy is thus achievable in cases where forest wood is used as feedstock. However, sustainable forest management, which is a pre-requisite to sustainable use of forest products, can be challenging to achieve. In such contexts, the use of waste and by-products from the forestry sector represents the safer route to ensuring sustainability of a bioenergy development. As a result, modern bioenergy use relies to a large extent on waste streams.

In developing countries, the proportion of biomass waste in the national primary energy mix can be considerable, yet is typically informal and based on traditional technologies. In these countries it may provide a significant portion of energy needs - primarily cooking and heating – but with few sustainability or efficiency considerations. This provides many opportunities for improvements in the way it is used. While biomass waste offers great potential as a renewable energy resource, it still needs to be closely monitored to ensure it will contribute to a country's sustainable energy supply without threatening its environmental integrity.

1.3 Overview of the WtE value chain

WtE projects can be complex to undertake and plan. Before going further into the details surrounding WtE it is useful to give a brief introduction to its general structure, or so-called value chain. This value chain describes the five physical stages of a project from procurement of biomass through to providing energy services, in this case electricity (Figure 3).

Often, the most challenging stage in the WtE value chain is the first one: establishing the mechanism to bring enough biomass waste to a central point for conversion to energy. This stage starts by identifying the waste stream and putting in place the necessary procurement agreements. Depending on the type and ownership of the biomass waste, procurement agreements could be in the form of purchase agreements or waste removal agreements. It is often the case that the biomass waste is already owned by the potential project developer; for example, a food-processing plant or agricultural producer who produce waste on site.

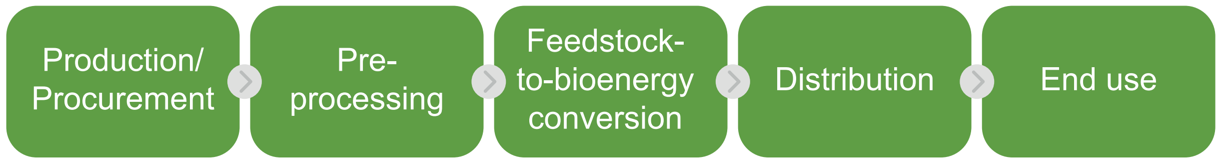
Pre-processing is normally used to make waste easier to transport, or improve its characteristics ready for bioenergy conversion. A number of technologies can be used to reduce transport and storage costs of dry biomass waste. Wet waste can be more challenging to transport over longer distances and its pre-treatment most often occurs at the conversion site, rather than at source.

Once the waste biomass has been gathered, there are a number of well-established technologies for converting biomass into useful energy. Chapter 3 of this toolkit describes three key conversion technologies - combustion, gasification and anaerobic digestion - to make biogas, as well as a fourth technology – combined heat and power (CHP) – that can use one of the other conversion processes to produce both electricity and heat.

Distribution and end-use in the context of this toolkit refers to electricity distribution or self-use. A number of different options can be considered, ranging from small-scale off-grid applications, through larger village grids, up to large-scale grid-connected projects or agro-industrial projects that are designed for heavy consumers.

A practitioner wishing to develop biomass waste projects faces challenges in relation to all of these stages. The aim of this toolkit is to provide sufficient background information to allow the project planner to make an assessment of feasibility of achieving a successful value chain. The specific aspects that need to be considered in planning a biomass waste project are discussed at length in Chapter 5.

Figure 3: Biomass WtE value chain



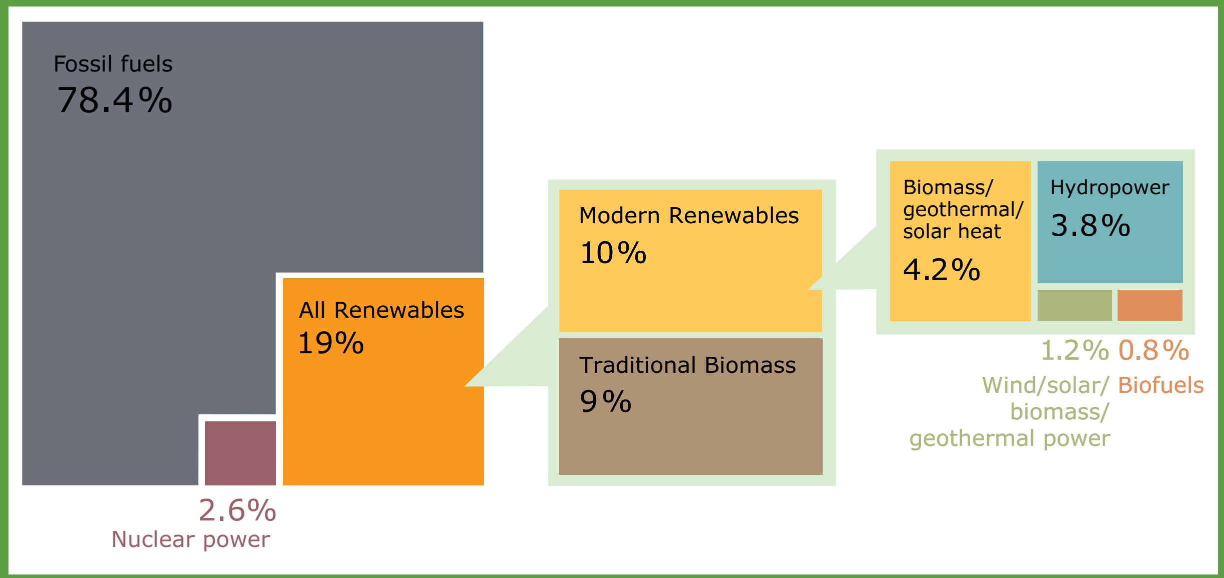
Section 2
Opportunities and challenges

It has already been established that the use of biomass, and in particular waste and residues, as an energy source offers several important benefits. This chapter provides an overview of the current utilisation of biomass in developing countries, describes the biomass waste resources available for increased energy uptake and introduces the main challenges that need to be addressed to achieve higher uptake of modern WtE.

2.1 Utilisation of WtE

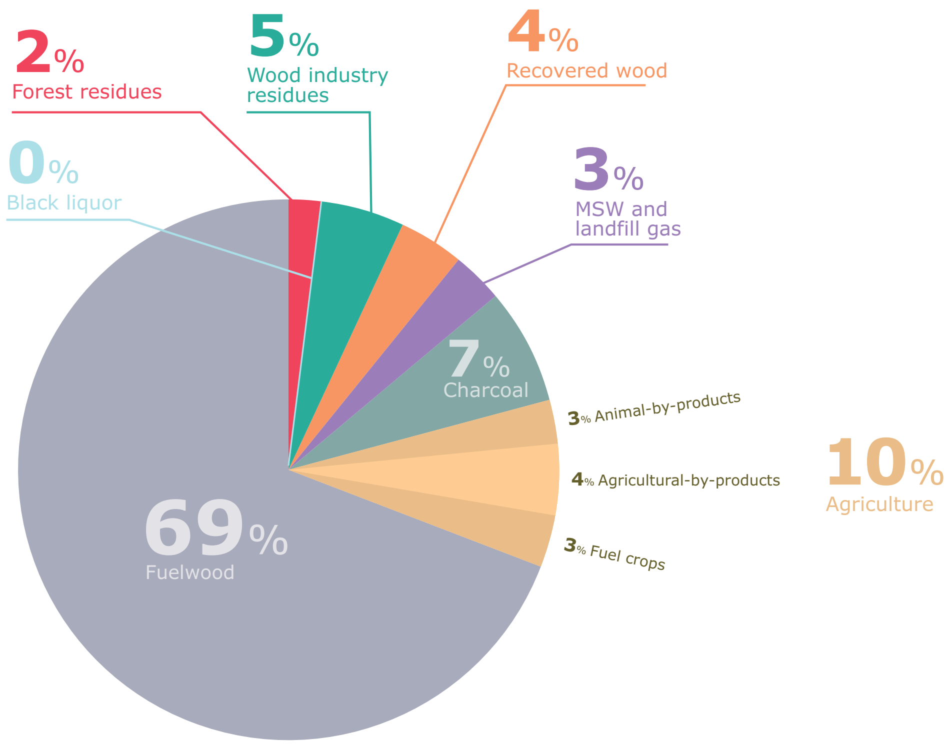
Biomass is by far the most important contributor to total renewable energy use globally, accounting for over 10 per cent of total global final energy consumption across its applications (Figure 4).

Figure 4: Share of renewable energy in global final energy consumption in 2010 (REN21 2013)



Most biomass use, however, is in the form of traditional applications and is generally not sustainable. Fuelwood, mainly used in developing countries in open fires for cooking and heating purposes, is the dominant biomass use globally (Figure 5). It is currently the primary energy resource for about 2.7 billion people worldwide (Wicke 2011). Primary and secondary biomass wastes and residues account for less than 20 per cent of total biomass sources, as shown in Figure 5.

Figure 5: Share of biomass sources in the primary bioenergy mix (IPCC 2007)



As mentioned, bioenergy use differs widely between countries, but a general trend can be observed of increased reliance on traditional bioenergy with decreased income. While bioenergy represents 3 per cent of primary energy in industrialised countries, generally, in modern applications, this figure stands at 22 per cent in developing countries due to prevailing traditional uses (IEA 2010). Figure 6 provides a representation of the role of bioenergy in the major developing regions of the world in 2011 and illustrates the often high use of biomass for basic energy services as compared to other types of energy production.[4]

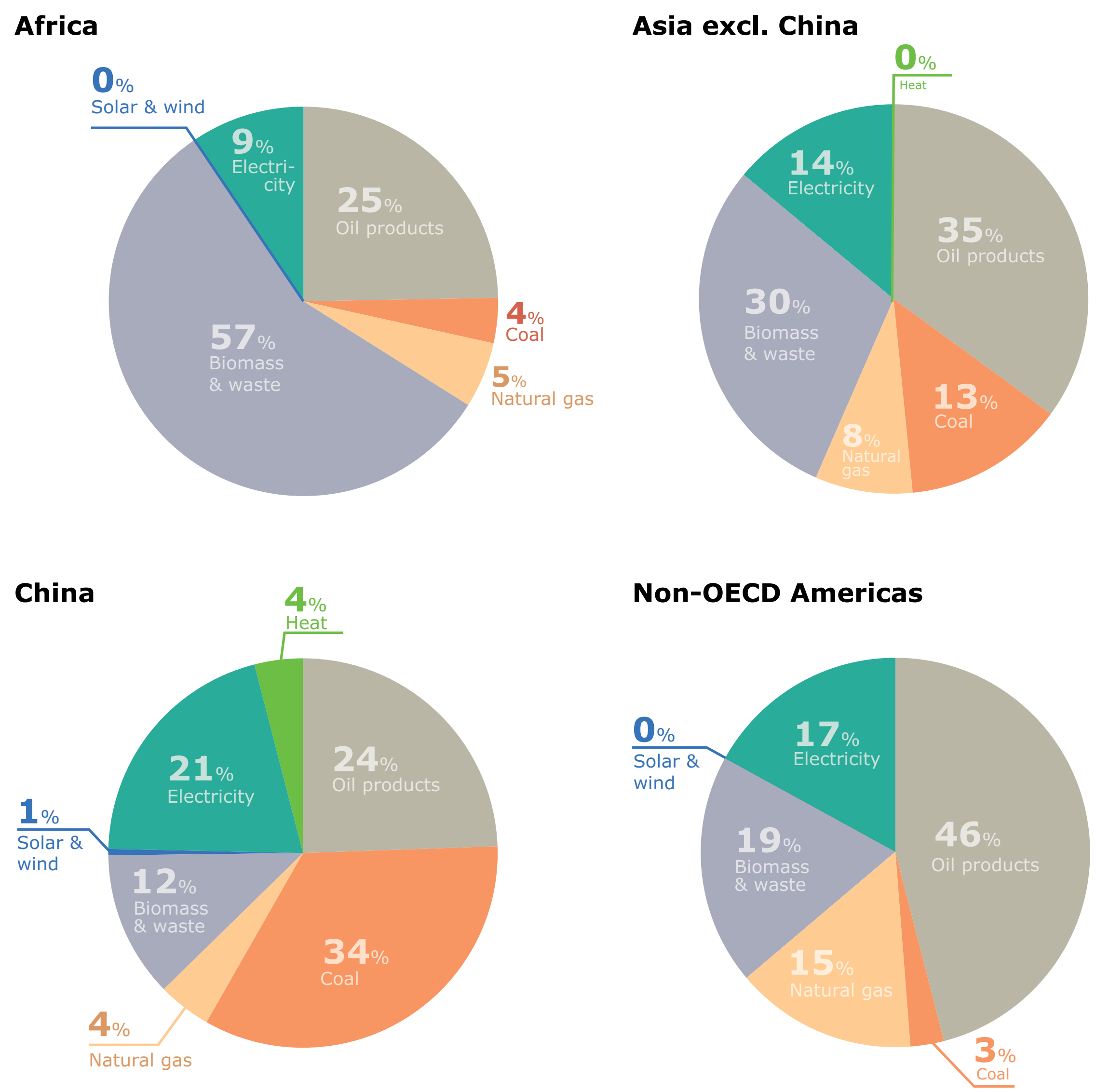
In Africa, bioenergy represents over 50 per cent of the total primary energy supply and a total of 657 million people (80 per cent of the population) rely on the traditional use of biomass, mainly wood-fuel and agricultural residues, for cooking (IEA 2010), with little or no sustainability considerations. At the same time, it is worth noting that a number of emerging economies are increasingly using modern bioenergy technologies on an industrial scale.

While the US and the EU still account for most biomass-based power generation, Brazil, China and India are also in the top five biomass-power producers in the world (REN21 2013). Most of this power is generated from solid biomass, often agricultural residues. In Brazil, the main source of bio-power is bagasse from sugar cane. The same is true in Africa, where sugar producing countries increasingly use bagasse in CHP plants to generate heat and electricity (REN21 2013). Grid-connected bagasse CHP plants now exist in Kenya, Mauritius, Tanzania, Uganda and Zimbabwe, while Cameroon, Côte d'Ivoire, Ghana, Liberia, Nigeria, Rwanda, Senegal, Sierra Leone, Sudan and Kenya all have plants in construction or planned (REN21 2013).

The most underdeveloped aspects of WtE utilisation are modern, small-scale WtE systems providing electricity to communities or businesses not connected to the national grid, mainly in rural areas. Part of the reason for this is that such systems must compete with other options for rural electrification, such as solar home systems and micro-hydro, which

4. The IEA uses the definition of "biofuels and waste" which comprises solid biofuels (what has been referred to as biomass in this report), liquid biofuels, biogases, industrial waste and municipal waste (IEA 2014b). For the purpose of this toolkit, we have re-named this category "biomass and waste".

Figure 6: Share of bioenergy in total final consumption for developing world regions in 2011 (IEA 2014)



may be considered to have a stronger track record or be more straightforward to implement. Nevertheless, the large reliance on biomass, as the main source of energy in many under-developed areas of the world, as well as the large untapped biomass waste resources that are available (see following section), both provide compelling reasons to improve the efficiency of biomass waste use and, where possible, replace unsustainable use of fuelwood with efficient use of biomass wastes.

2.2 Potential of WtE

Although biomass is already an important component of the energy mix, there are significant opportunities to expand the use of biomass as an energy source, as well as shift existing biomass use to more sustainable practices. Given the right policy framework, it has been suggested that biomass has the potential to sustainably contribute between a quarter and a third of global primary energy supply by 2050, or between 200 and 500 EJ/year (IEA Bioenergy 2009). In the same timeframe, forestry and agricultural residues and other organic wastes (including municipal solid waste), generally the safest biomass feedstocks in terms of environmental sustainability, could contribute between 50 and 150 EJ/year by 2050 (IEA Bioenergy 2009).[5]

Looking at regional potentials, the various assessments are difficult to compare because of inconsistent geographical scopes and the inclusion of different types of biomass, but a review of existing studies for bioenergy

5. By comparison, the current global energy demand is about 550 EJ/year (IEA 2013).

potential in Africa indicates a current potential for residues and waste of between 2,100 PJ/year and 5,200 PJ/year (DBFZ 2013), which remains more or less in the same order of magnitude until mid-century. By comparison, across the African continent, approximately 12 500 PJ of bioenergy is currently being consumed annually (IEA 2014a), the vast majority of it being unsustainable fuelwood. So although not all unsustainable fuelwood could be replaced by residues and waste, the increased use of these waste products could contribute significantly to making existing energy consumption patterns more sustainable. Some of the most promising residues in terms of energy potentials in Africa for which estimates exist are summarised in Table 1.

Table 1: Selected biomass waste streams and their energy potentials in Africa (DBFZ 2013)

Residue type	Potential (in PJ/year)
Bagasse	201-242
Coconut shells	5-11
Logging residues	82
Industrial wood waste	356

In Asia, residues offer a larger potential. Studies estimate that over 4 billion tonnes of agricultural residues (both field-based and process-based) and over 155 million tonnes of woody residues are already available (Koopmans 1997). In terms of energy supply, their combined availability in Sri Lanka, India, China, the Philippines, Malaysia and Thailand in 2010 was estimated to be over 13,000 PJ (Bhattacharya 2002).

Estimating biomass potential is a highly complex exercise, which relies on a number of assumptions and consequently is subject to a high variability of results. This is just as true for local potential estimates as it is for global ones. Development practitioners are therefore cautioned when considering any estimates on potential biomass waste supply and the related scale of a project or programme. For estimates of agro-forestry residues, particular attention should be paid to the following elements that can substantially impact the estimates (DBFZ 2013):

- Field or forest area
- Crop or forest productivity
- Recovery rates
- Harvesting efficiency
- Assumptions on the fraction of residue
- Varying sample site conditions.

The broad message, challenges with data collection notwithstanding, is that biomass waste streams have very large potential for use in those regions where information is available. Similar results could also be expected in other regions.

2.3 Challenges to WtE

While arguments for bioenergy development based on waste streams are compelling, their increased uptake faces several challenges, including:

- *Biomass production costs:* In the absence of policy support, the energy produced from biomass waste must be as cheap as, or cheaper, than energy produced from competing energy sources (Berndes 2013). Based on pure cost-considerations, bioenergy developments based on agro-forestry waste may compare unfavourably with conventional energy sources. This argument holds for both for on and off-grid applications. For on-grid applications, to match the low costs of fossil fuels, successful biomass energy projects need to start with low cost feedstocks and deliver them cleanly and efficiently for conversion to energy products (Tallaksen 2011). It is worth noting that certain waste biomass can sometimes be procured at negative cost.[6] For off-grid and mini-grid applications, the bioenergy supplied from wastes and residues must often compete with traditional energy procured by households at low or no cost. In this context, reliability and convenience play an important role in overcoming the cost differential.
- *Logistics:* Arguably one of the most critical bottlenecks for increased utilisation of waste (as well as other forms of) biomass for energy production is the cost of logistics operations. Residues require appropriate supply chain infrastructure, which is challenging to organise. For an industrial-scale bioenergy development a large number of point sources is usually needed. While the scale of the challenge is of course lower for mini-grid applications, so are the financial and technical capabilities of the project developers. Proper planning and review are key to developing an efficient supply chain at every scale.
- *Competition with other uses:* All forms of bioenergy interrelate with other uses of biomass. Developments in the bioenergy sector can influence markets for agricultural and forest products through their feedstock demand. This also holds true for residues, which need to be correctly allocated across all their alternative uses: as energy feedstock, animal feed and fodder, soil nutrient source, building material, etc. Competition with other uses is relevant on all scales of WtE development and a practitioner needs to evaluate all such possible inter-linkages.
- *Familiarity with WtE:* Modern WtE technologies and their benefits are still relatively unfamiliar to both end users and other stakeholders, such as finance providers, institutional authorities, etc. This can make acceptance, support and financing for a project much more difficult to obtain compared to technologies that may be better known or understood.

On-grid

Challenges specific to on-grid WtE projects have partly to do with their scale (usually large) and partly with the need to connect to the grid. The most notable ones are:

- *Permitting and licensing:* Obtaining all the necessary permits and licences for a utility-scale WtE plant may be a slow process, particularly in instances where the project is one of the first of its kind.
- *Access to the grid:* This may be restricted by regulations (i.e. where the permissions of independent power producers are less well recognised or where they must pay their own connection costs), weak grid infrastructure (restricting export of power) or the excessive distances to an appropriate connection point.
- *Access to the site:* If the plant site is located in a very remote area, access to it might not always be possible, which may be problematic when maintenance is required.

Off-grid and mini-grid

An essential aspect of off-grid electrification that poses an additional challenge to small scale distributed WtE generation is *community involvement*. If a project is not well explained, accepted and appreciated by its hosting community, its sustained operation may be threatened. Community involvement is thus crucial at all stages of the project cycle and no matter the business model chosen (those are discussed in Section 5). However, if the community is also the owner of the installations it is additionally required to clarify ownership claims and responsibilities for the continued maintenance and operation of the plant between community members.

Mini-grids face the additional challenge of *balancing the electricity supply and consumption between its generators and users*. On a national grid, the consumption over time is smoothed through a large number of users, each representing a very small fraction of power consumed. This is not the case for mini-grids, where a single load or user may represent a significant percentage of the generating plant capacity, making the matching of power produced and power consumed challenging. In this respect, the control of frequency and voltage on the mini-grid is crucial (Pittet 2013).

A further challenge to many off-grid projects is their non-commercial nature. When bioenergy (or any type of technology) is used for electrification as a public service, it is possible that much or all of the capital cost of installation will be paid by government or possibly a non-governmental organisation (NGO). In these instances, the ownership of the facility and responsibility for its operation and maintenance will generally be transferred to the local community or user. The challenge in such situations is to maintain a strong incentive and ability to keep the plant operating in the absence of a strong commercial drive (i.e. they are not run for profit). Revenues from the project have to be sufficient to cover maintenance costs, local capacity has to be high enough to deal with many issues as they arise and there needs to be enough buy-in for the project (referring to the point raised above) to ensure its successful running.

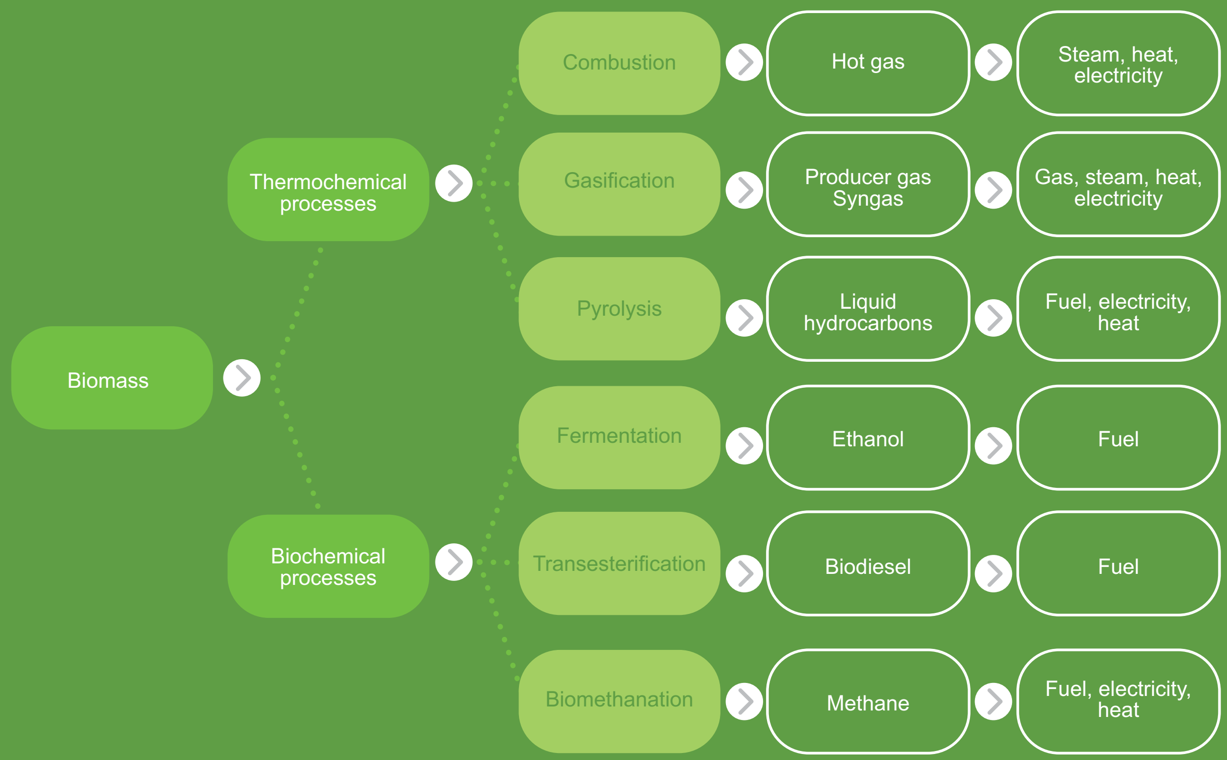
6. Processing industries may pay for the removal of their waste.

Section 3

Biomass waste-to-energy technologies

There are several bioenergy routes that can be used to convert a range of raw biomass feedstocks into a final energy product (Figure 7). The key driver for selecting a conversion process is normally the type of feedstock available, but desired energy products, scale and technology maturity can all play a role. A number of these technologies are already well-developed and fully commercialised, while a range of other conversion technologies are currently under development, which could potentially offer improved efficiencies, lower costs and improved environmental performance (IEA Bioenergy 2009). This chapter offers a relatively detailed technical introduction to a number of different technologies that can be used to convert biomass waste to electricity. More detail on the process of choosing technologies can be found in Chapter 5.

Figure 7: Broad categorisation of biomass conversion processes



In this toolkit, we focus on technologies that can be used to convert biomass waste into electricity and/or heat, which are mature, validated and most appropriate for the vast majority of developing country contexts (combustion, anaerobic digestion and cogeneration), as well as those very close to full commercialisation that offer strong potential for the use of biomass waste (gasification). Technologies for upgrading biomass feedstocks (e.g. pelletisation, torrefaction and pyrolysis) to convert bulky raw biomass into denser and/or more practical energy carriers for more efficient transport, storage and convenient use in subsequent conversion processes, are outside the scope of this toolkit.

The use of these technologies in smaller off-grid applications deserves a special mention (Box 1). Biomass powered mini-grid or off-grid systems can also be based on combustion, biogas or gasification technologies with a choice largely dependent on type of feedstock available and desired outputs of the system. All of these systems can be used in a variety of sizes, ranging from kilowatts to megawatts (UNIDO 2007). As with any type of bioenergy technology a reliable source of feedstock is a necessary pre-condition for off-grid generation.

Box 1: Biomass WtE technologies for off-grid applications (UNIDO 2007 and ESMAP 2007)

Combustion
Direct combustion systems may use steam turbines and, if so, are generally used for only the larger applications. However, much of the current stock of these systems use direct combustion in small, biomass-only plants with relatively low electric efficiency (in the order of 20 per cent). CHP (as discussed in the following sections) offers a way to dramatically improve the efficiency of these systems if uses for the resulting heat can be found. Feedstocks are generally dry agricultural waste, for example, rice-husks or any number of other combustible waste products.

Gasification
Biomass gasification systems produce a synthesis gas, which can be burned in a gas or diesel engine to provide electricity or motive power or burned in a boiler or furnace to provide heat. This possibility of providing motive or productive uses can be a key attraction of gasification systems for off-grid commercial applications. Typical feedstocks include rice husk, sawdust and wood waste and modular systems are increasingly available for off-grid applications (simplifying an otherwise relatively complex conversion process).

Biogas
A biogas power system converts biomass feedstock in the form of animal dung, human excreta and leafy plant materials anaerobically digested to produce a combustible biogas. This in turn is used with an engine to produce power with a generator. The simplicity and modularity of design, construction and operation and the variety of uses for the biogas product, make this technology well suited for small-scale applications. Typical feedstocks in off-grid applications are livestock wastes (e.g. manure) or agricultural waste from large remote plantations, such as palm oil mill effluent or other palm waste.

3.1 Combustion

The oldest and most basic form of biomass conversion is combustion. During combustion, biomass or another fuel reacts with oxygen with the release of heat. Heat can either be used directly or used to generate electricity. The level of sophistication of biomass combustion technologies ranges widely. In the simplest technologies, which have been used for centuries, the heat is used directly in stoves and brick ovens. Modern biomass combustion systems are used in domestic space heating and in manufacturing and industrial operations to provide steam and hot water for processes.

Technology overview

Producing electricity from biomass combustion requires a two-step process. The biomass is first burned to generate steam, which is then used to drive a turbine that generates electricity. The conversion of steam to electricity using turbines is well established, with the first thermal power stations (operating primarily on fossil fuels) having been built in the late 19th century. The use of biomass as a feedstock to generate the steam in place of fossil fuel was introduced later, with the biomass either replacing a proportion of the fossil fuel (co-firing) or being used as a fuel in dedicated biomass power stations. Although biomass combustion systems are considered to be mature technologies (IRENA 2012), with over 20 GW of installed biomass generation capacity in Europe alone (IEA 2010), electricity generation technologies are constantly advancing to improve efficiency.

Many different types of waste biomass are suitable for combustion, including residues from agro-industries, post-harvest residues that are often left on fields, wood wastes, residues from food and paper production, municipal solid wastes (MSW), sewage sludge and biogas from the digestion of agricultural and other organic wastes (FAO 2007). The water content of the biomass is a critical parameter that determines its combustibility, and so wet feedstocks may better be used in other energy recovery processes, or alternatively dried before use.

Technology costs

The cost of installing and operating a biomass electricity generation plant depends on the sophistication of the technology, as well as the system size, with larger plants costing less on a kW installed capacity basis than smaller plants. A trade-off exists, however, between capital and operating costs: operating costs (and hence the cost of electricity generation) increase significantly with fuel costs. Larger plants require significant amounts of feedstocks, which leads to increasing transport distances and material costs. At the same time, small systems have higher Operating and Maintenance (O&M) costs per unit of energy generated and lower efficiencies than large systems. The optimal system size for a particular installation thus needs to be determined by taking these factors into account (IRENA 2012).

In 2012 the International Renewable Energy Agency (IRENA) published a working paper that compared various studies on the capital and operating costs of biomass systems. The range of capital costs (expressed in 2010 USD) was found to be 1,880 to 4,260 USD/kW installed capacity for stoker boiler systems and 2,170 to 4,500 USD/kW installed capacity for bubbling and circulating fluidised boilers, with costs varying depending on the size, location, etc. The levelised cost of electricity ranged between 0.06 and 0.21 USD/kWh, with little difference between the two technologies (IRENA 2012). The capital costs suggested by the IRENA study are within the range of costs suggested in other studies (IEA 2010).

Where biomass is co-fired with coal in large scale coal-fired power stations, few modifications (and hence limited capital investment) is required to co-fire untreated biomass up to a level of 5-10 per cent. At higher levels of co-firing the biomass may need to be treated, modifications to the boiler feed systems may be required or biomass will be used in a separate parallel boiler system. The capital investment requirement for co-firing thus depends on the level of co-firing, as well as the modifications required and the requirement for feedstock preparation. The range of costs was suggested to be to the order of 140-850 USD/kW in 2010, (IRENA 2012).

Technology development trends

As stated previously, current technologies for biomass combustion for electricity generation are well established and are extensively deployed in both developed and developing countries. Any advancements in recovery of electricity from biomass by combustion are likely to parallel those of coal fired boiler technologies – notably the adoption of ultra-supercritical steam cycles which have higher efficiencies than those already widely used (supercritical and sub-critical). In terms of small-scale generation, options such as Organic Rankine Cycle engines could be pursued, where oil is used as the working fluid instead of water. The externally fired Stirling engine is another option that is not yet commercially proven but that could result in significant efficiency gains (IEA 2010).

Although technologies for generation of electricity from biomass are technically and economically viable, as discussed elsewhere, biomass availability and competition for resource will be the key determining factor in their increased adoption.

Global and regional potential

As with other biomass technologies, the technology potential is closely linked with availability of biomass as feedstock. With growing demand for electricity globally, and the move towards cleaner electricity supply options, there will be an extensive need for new power stations with lower emissions. In terms of co-firing, the potential will be constrained by the proximity of biomass sources to existing or planned coal-fired power stations. Furthermore, consideration needs to be given to the age of the power station as to whether the investment in biomass feedstock handling equipment is justified in terms of the number of years for which the power station will remain in operation.

Description of the process

Figure 8 shows a simple block flow diagram for the production of electricity from biomass through combustion. Prior to combustion, pre-processing of the biomass may be required, including size reduction and possibly drying. The biomass is then fed into a boiler, where it is burned to generate steam. As discussed previously, this may either be in a dedicated boiler or the biomass may be co-fed into a coal boiler. In the second stage, the steam drives a turbine to generate electricity.

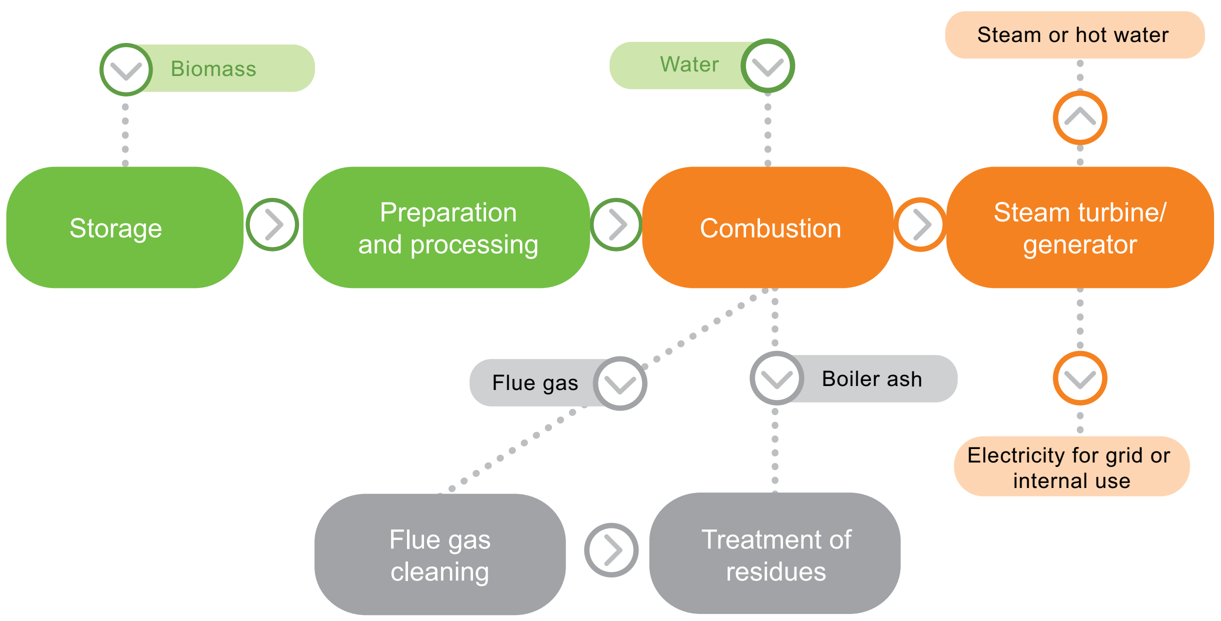
Direct biomass combustion plants are typically in the 1 to 100 MW size range; smaller than fossil fuel power stations due to the logistical requirements of large amounts of feedstock. There are a few installations of larger power stations. The efficiency of energy recovery in these plants is to the order of 30 per cent, depending on the size of the plant (IEA 2007). Indirect biomass combustion plants, meaning plants that combust biogas, are mainly in the range of few hundred kW to few MW.

Depending on the plant configuration and size, plants may require a consistent feed of biomass (in other words, they may not be suited to variable operation). Supply shortages may result in plants changing to alternative feedstocks or running at below plant capacities, with the ensuing negative financial impacts.

Dedicated biomass combustion systems often require more maintenance than fossil fuel systems, particularly as compared to those running on oil and gas. As mechanical feed systems are used, these will need regular maintenance. Regular checks on the feed systems will also be required to remove blockages, particularly if fuels with smaller particle sizes are being used. Biomass leaves a residual ash after combustion, which needs to be taken away. This maintenance requirement can be reduced by installing automatic ash removal systems. As with any boiler systems, there will be requirements for maintenance, such as descaling of lines.

Maintenance requirements for boilers co-firing biomass and coal are similar to those for coal-only boilers, providing the fuel is pre-processed to match the application. For example, using mulch-like material or biomass with a high fraction of fine particles can sometimes cause blockage of fuel flow openings in various areas of the conveying, storage and feed systems (US Department of Energy 2004).

Figure 8: Block flow diagram of the process for electricity generation from biomass via combustion



3.2 Cogeneration

Cogeneration is not a unique biomass conversion process but rather a way of providing more than one energy end-use – typically power and heat, but sometimes fuels as well – from a single source of energy. Multiple commercial, proven and cost effective technologies for converting biomass feedstocks to electricity and heat are currently available. These generally use combustion or biogas production as the basis for energy conversion, but there are also a newer systems that are based on gasification (EPA 2007).

Cogeneration systems can provide heat for heating, cooling or process applications, and in doing so they can greatly improve the efficiency of biomass use. By using waste heat recovery technology to capture the heat that is normally lost during electricity generation, cogeneration systems can achieve total system efficiencies of 60 to 80 per cent. Assuming that there is demand for this heat, then these efficiency gains improve the economics of using biomass, produce other environmental benefits and can stimulate economic activity that may require this heat (EPA 2007).

Technology overview

In cogeneration, or combined heat and power technologies, fuel is combusted to provide both electricity and useful heat in the form of steam. By utilising the energy from the biomass for both electricity generation and heat, the efficiency of energy recovery is significantly higher than systems that recover heat or electricity only. Although natural gas and coal are currently the main fuels used in CHP plants, a wide variety of fuels can be used, including biomass. Biomass can either by burnt directly, or alternatively converted to biogas which is used in the CHP engine.

Cogeneration is already used commercially around the world in a variety of applications for baseload electricity and heat supply. In 2010, more than 10 per cent of the world's electricity was generated in CHP plants (IEA 2010). Its successful application relies on a baseload demand for the heat close to the power station, while the electricity can either be used on-site (which is the more efficient option as it avoids transmission losses) or fed into the grid.

One of the benefits of CHP over combustion systems which do not recover heat is that units can respond to fluctuating electricity demands, with excess heat being stored in insulated tanks for use when it is needed (IEA 2010).

Technology costs

The costs of CHP systems are dependent on the size of the installation, location, etc. CHP systems are more expensive than biomass combustion systems, with the range of capital costs (in 2010 USD/kW) being seen in various studies ranging from 3,550 to 6,820 USD/kW installed capacity for stoker boiler systems and 5,570 to 6,545 USD/kW installed capacity for bubbling and circulating fluidised boilers. The levelised cost of electricity ranged between 0.07 and 0.29 USD/kWh, with little difference between the two technologies. This includes the credit associated with heat generation (IRENA 2012).

Technology development trends

CHP is already a mature technology with already high levels of efficiency. CHP is already used across developing countries, including in Africa and Asia, with the level of deployment varying from country to country. In many parts of the developing world, its use is primarily in industrial processing.

Research and development is focused on areas such as advanced combustion turbines and reciprocating engines, as well as on flexi-fuel systems that provide greater choice in terms of (biomass and non-biomass) feedstocks. Some evolution is also being seen in the development of modular systems.

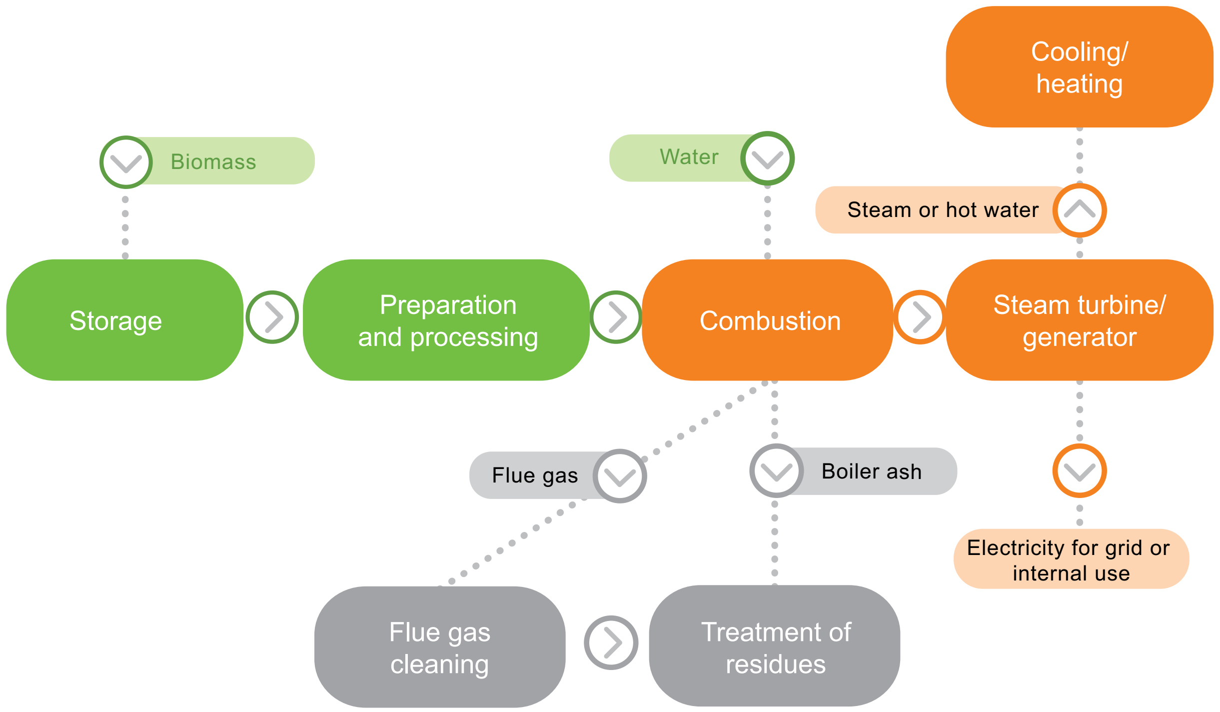
Global and regional potential

As for other technologies, the global and regional potential of biomass-based CHP is largely determined by an available supply of feedstock within a logistically feasible distance of the CHP plant. However, for CHP to be viable, the plant must also be located within close proximity to an off-take for the heat such as an industrial plant, agro-processing plant or even in an area which requires space heating. This need will thus constrain the potential location of the plants.

Description of the plant

CHP plants are similar to those used in combustion and include feed preparation (size reduction and possibly drying), combustion in a boiler, steam generation and an electrical turbine to generate electricity. In CHP plants the steam from electricity generation is piped off for further use. Figure 9 presents a schematic of the CHP process.

Figure 9: Block flow diagram of the process for electricity generation and heat recovery via CHP



A wide range of sizes of CHP plants have been built around the world, ranging from small-scale plants of 1 kW to large power stations of a few hundred MW. The largest biomass power station in the world is the Alholmens Kraft Power Station in Finland, which delivers 240 MW of electrical output, 100 MW of process heat and 60 MW of district heating (Alholmens Kraft Power Station 2012). CHP power stations operating on fossil fuels can be larger than those using biomass, with plants of over 1,000 MW having been built.

For plants larger than 1 MW, equipment is typically custom built for the individual application. Modular units for smaller-scale applications (up to 5 MW) are, however, available, and are often used in areas with no or limited grid access. CHP plants are usually sized to meet heat demand rather than electrical demand, with any additional electricity produced being sold back to the grid (IEA 2010).

Electrical efficiencies of biomass plants can be similar to combustion, although in modern plants electrical efficiency can reach 33-34 per cent, and up to 40 per cent if operated in electricity-only mode. However, with inclusion of the recovery of heat the overall energy efficiency recovery is anywhere from 75 to more than 90 per cent, depending on the age and sophistication of the plant (IEA 2007).

Operating and Maintenance (O&M requirements are similar to those described for combustion plants in terms of maintenance of mechanical components of systems for feedstock preparation and feed into the boilers, as well as ash removal. Additional maintenance of steam distribution systems is also required (such as descaling or management of steam of boilers).

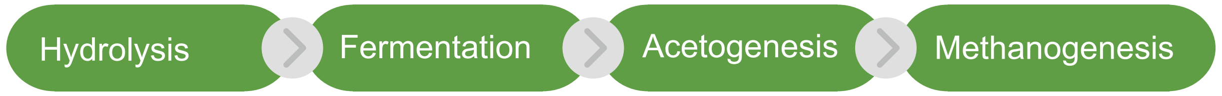
3.3 Anaerobic digestion (Biogas)

Anaerobic digestion, sometimes called biomethanation, is a natural process in which bacteria break down organic matter, in the absence of oxygen, into biogas[7] and so-called digestate.[8] The biogas can be used directly in cogeneration and electricity production, can be burned to produce heat or can be cleaned and used in the same way as natural gas or as a vehicle fuel. Depending on the process, the digestate can often be used as a fertiliser or soil conditioner (DEFRA 2011).

The anaerobic digestion (AD) process can be used with a wide variety of feedstocks, including animal manure, crop residues, municipal solid waste (that contains sufficient organic material), sewerage and other waste-water flows that contain organic material that undergo AD.

7. A roughly 2:1 mixture of methane, CH4 and carbon dioxide, CO_2.
8. The leftover material after biogas production.

Figure 10: Four stages of the anaerobic digestion process



Technology overview

Numerous technologies for generating biogas have developed over time and their use depends on factors such as type of feedstock (in particular what fraction of solid material is present), acceptable process complexity and end-uses requirement (including demands for the digestate and its qualities).

Biogas production through AD can be described in four generalised steps that involve different biological and chemical processes (Figure 10). The role of these processes varies depending on the feedstock and the stage of AD that is reached, but broadly they can be thought of as acting to sequentially break the biomass down, ready for the next stage, with biogas as the final end-product.

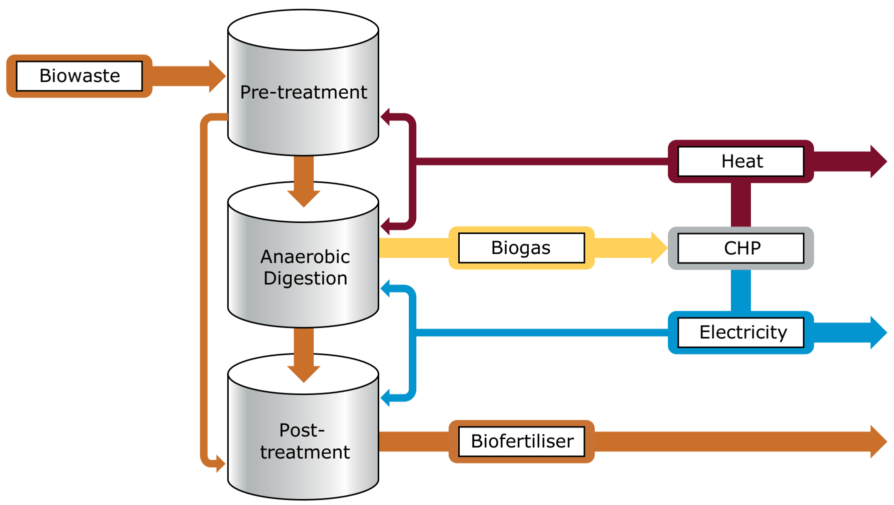
These four stages of anaerobic digestion take place inside a digestion unit that is designed to create the correct atmospheric, temperature, feedstock mix and other internal conditions. The process is implemented as part of a biogas plant that provides (often pre-processed) feedstock to the digester, extracts the biogas, deals with outputs, collects useful digestate and stores and processes to the biogas to be used in a final conversion process to provide electricity and/ or heat (Figure 11). There are also other final conversion paths, such as use as a replacement for natural gas and in vehicles for transport, but these are outside the scope of this toolkit.

Technology costs

As one might expect, with a wide variety of anaerobic digestion methods, feedstocks and implementation scales comes a wide range of energy delivery costs. As a general rule, with biogas systems often utilising low or negligible cost waste streams, capital investment becomes the dominant cost factor for many systems, even with the relatively high capacity factors (and therefore relatively continuous feedstock supply) associated with most electricity generating applications. With lower capacity factors in rural or village off-grid applications, the importance of capital costs in determining energy costs is even higher. In instances where processed biogas is used to supplement diesel to provide a dual-fuel system these diesel costs must also be considered in the overall estimates of cost.

The delivered power costs of many energy generation technologies reduce as scale increases. This is particularly true of biogas applications, with large scale industrial digesters having significantly lower costs per unit of gas produced versus smaller systems. ESMAP (2005) report that the total cost of methane from a large scale digester (300,000 GJ/year capacity or larger) with a typical industrial feedstock is less than USD2/GJ under European conditions and about USD1/GJ under Brazilian conditions and that large scale digesters may therefore become competitive with conventional fossil fuel generation in certain instances.

Figure 11: Example of a biogas plant configured to produce energy and fertiliser from waste feedstock (DEFRA 2011)



Technology development trends

The flexibility of biogas production – its ability to provide a number of useful outputs and its potential to be implemented at a range of technical complexities and scales – has meant that this method of bioenergy conversion is expanding in many developing countries and is well established in a number of developed countries. A good example from the developing country context is the growing effort to try and capture energy from palm oil mill effluent (POME) that is present in large volumes in many countries in South East Asia; a source of energy that already contributes approximately 200 MW of biogas power generation to Thailand's electricity system (Sutabutr 2013). It is important to distinguish between biogas produced at scale and used for electricity production versus domestic scale biogas produced for uses such as cooking. The latter is widespread, with millions of small digesters across Asia (Bond and Templeton 2011), while larger scale use for electricity production is still gaining widespread acceptance and application. The challenges for scaling up from household to larger scale largely revolve around the collection and supply of sufficient biomass at an appropriate cost. In many countries, agricultural residues or animal waste is widely disbursed among many producers making aggregation difficult.

To consider possible future trends for developing country biogas applications it can be illustrative to look at the developed country context, where biogas is used in a number of different ways in addition to electricity production. For example, in Europe a growing proportion of biogas is injected into natural gas networks as biomethane[9] and then used by households or industry or also used directly in CHP applications. However, its application as a transport fuel is becoming increasingly popular: in Sweden biomethane as a fuel has already overtaken compressed natural gas with a market share of 57 per cent (EBA 2013). Although this publication focuses on bioenergy from residues (due to the increased assurance of sustainability and avoided conflicts over land use), there has also been a move in many developed countries to produce biogas from dedicated energy crops.

Global and regional potential

Although individual studies suggest that many countries possess significant biogas production potential, no single assessment of biogas potential from sustainable residues and waste streams could be identified. Certainly, a large number of potential feedstocks are available to biogas systems and these feedstocks are often underutilised or not used at all in many developing countries. Feedstocks for biogas production may be solid, slurries and both concentrated and dilute liquids. These can come from a wide range of sources, including: municipal/industrial wastewater, crop residues, food waste, food processing wastewater, dairy manure, poultry manure, aquaculture wastewater, seafood processing wastewater, yard wastes and municipal solid wastes. Feedstocks typically have a high content of sugar, starch, proteins or fats, and a common feature is their ability to be easily decomposed through anaerobic digestion (IEA Bioenergy 2013). In so far as the scope of this toolkit is concerned, biogas systems will therefore lend themselves to locations where industrial bio-waste, aggregated manures, managed MSW sites and sufficiently concentrated residues are present. These resources can be found to some extent in all regions though it must be noted that the need for relatively high temperatures for efficient anaerobic digestion can make warmer climates more amenable to basic biogas systems.

In addition to this array of potential feedstocks, different residues and waste streams are often digested together – called codigestion – to enhance the total volume of feedstock and improve the digestion characteristics of the feedstock. For example, manure is often codigested with other feedstocks such as easily digestible organic wastes from various agro-industries, source-separated household waste, energy crops or sewage sludge (IEA Bioenergy 2013). Furthermore, certain feedstocks can be used as methane boosters, due to their very high methane potential, for example certain industrial wastes. The complex nature of the composition of an organic waste and the multitude of mixed feedstocks means that the methane yield is best determined from anaerobic treatability assays on a suitable sample (Wilkie 2013).

As Angelidaki et al. (2011) note: "emerging reactor technologies, development of advanced monitoring and control systems, as well as methods for increasing biodegradability of relatively recalcitrant feedstocks are making biogas production more economically feasible". Although biogas production will need to be subsidised in many countries during initial applications, with increased scale and continued development it has the potential to make a significant contribution to electricity production globally and regionally.

9. To allow injection of biogas into the natural gas grid or the use as a vehicle fuel it must be upgraded, which means that carbon dioxide is removed whereas the share of methane is increased to usually above 96% so that it meets the quality standards for natural gas (EBA, 2013)

Description of the plant

Generalising about biogas plant design, even for certain types of feedstock, is very difficult, due to the great diversity of designs, the large variability of waste compositions and the choice of operational parameters (retention time, solids content, mixing, recirculation, inoculation, pre-treatment, number of stages, temperature, etc.). Experience in design is vital and even among practitioners there is no clear consensus regarding optimal design in different contexts. The causes for this lie in the complexity of the biochemical pathways involved and the relative novelty and geographic isolation of some of technologies that have been developed (Vandevivere 2002).

What can be said more generally is that certain basic conditions must be met to enable the bacteria to degrade the feedstock efficiently. These are: (1) absence of air (anaerobic atmosphere); (2) uniform temperature; (3) optimum nutrient supply; and (4) optimum and uniform pH. A biogas plant designer must therefore know from the beginning what kind of feedstock the plant will utilise and understand its characteristics so that the right equipment can be selected (IEA Bioenergy 2013).

The key component or process in a biogas conversion facility is the digestion unit (Figure 13). The digestion unit is composed of one or more digesters, including feeding, agitation and heating systems, along with the potential for pre-digestion and post-digester tanks/processing. As noted earlier, the design configurations are numerous, with choices depending mainly on feedstock characteristics such as dry matter content, digestion rate, contaminant and inhibition risks (Table 2).

The methods of biogas production (Figure 12) can be characterised by the number of process steps, the process temperature, the dry matter content and the way in which the substrate is fed. Biogas plants feeding on agricultural by-products such as liquid manure, harvest residue and energy crops often employ a single-step process in the so-called mesophilic (32–42 degrees C) temperature range with wet fermentation and quasi-continuous feeding (IEA Bioenergy 2013). However, all of these factors can be varied depending on process and feedstock requirements to include mixing of the substrate, higher temperatures and batches of stacked substrates in so-called dry digestion processes (Figure 12).

Table 2: Processing options (IEA Bioenergy 2013)

Technology	Key parameter	Options
Feeding system	Digester type and matter content of feedstock	• Discontinuous feeding for batch digesters • Continuous or semi-continuous feeding for plug-flow or continuously stirred tank reactor (CSTR) digesters • Solid or liquid feeding system depending on dry matter content of the substrate
Reactor type	Dry matter content of feedstock	• CSTR for liquid substrates • Plug-flow or batch digester for solid substrates
Reactor temperature	Risk for pathogens	• Mesophilic temperature when no risk for pathogens • Thermophilic temperatures when risk for pathogens (organic household waste)
Number of phases	Composition of substrates, acidification risk	• One phase systems when no acidification risk • Two phase systems for substrates with a high content of sugar, starch or proteins
Agitation system	Dry matter content of feedstock	• Mechanical agitators for high solids concentration in the digester • Mechanical, hydraulic or pneumatic agitation systems for low solids concentration in the digester

Figure 12: Process configurations for anaerobic digestion of solid waste (Angelidaki et al. 2011)

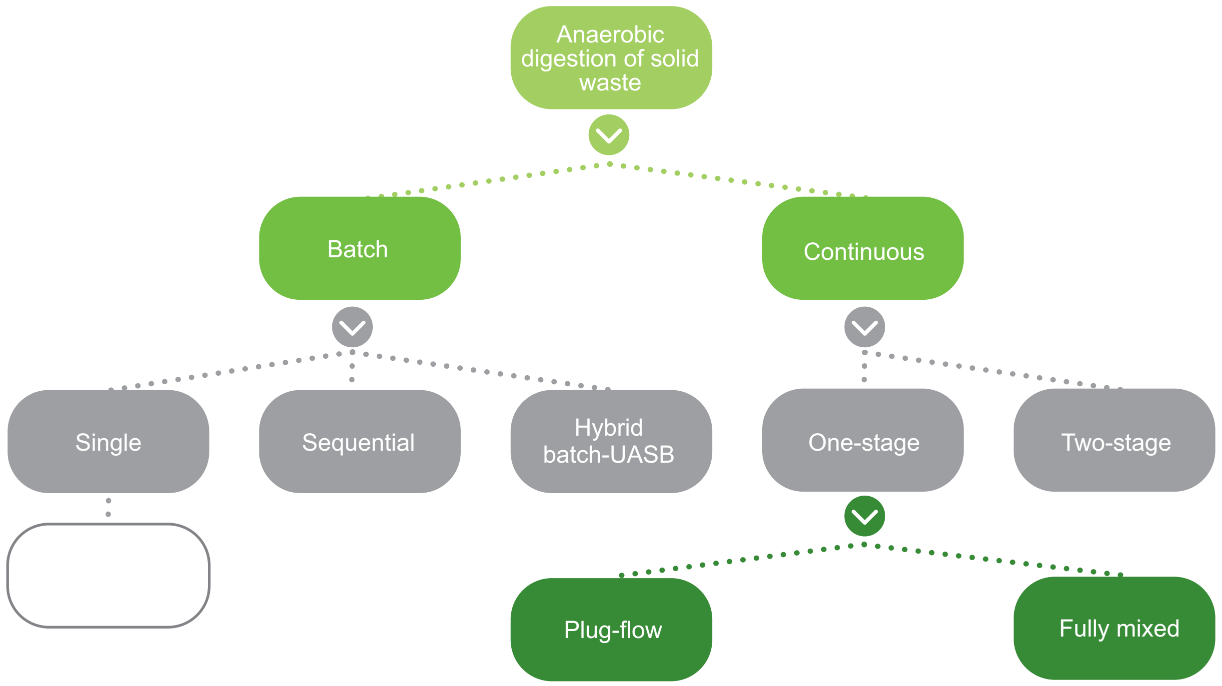
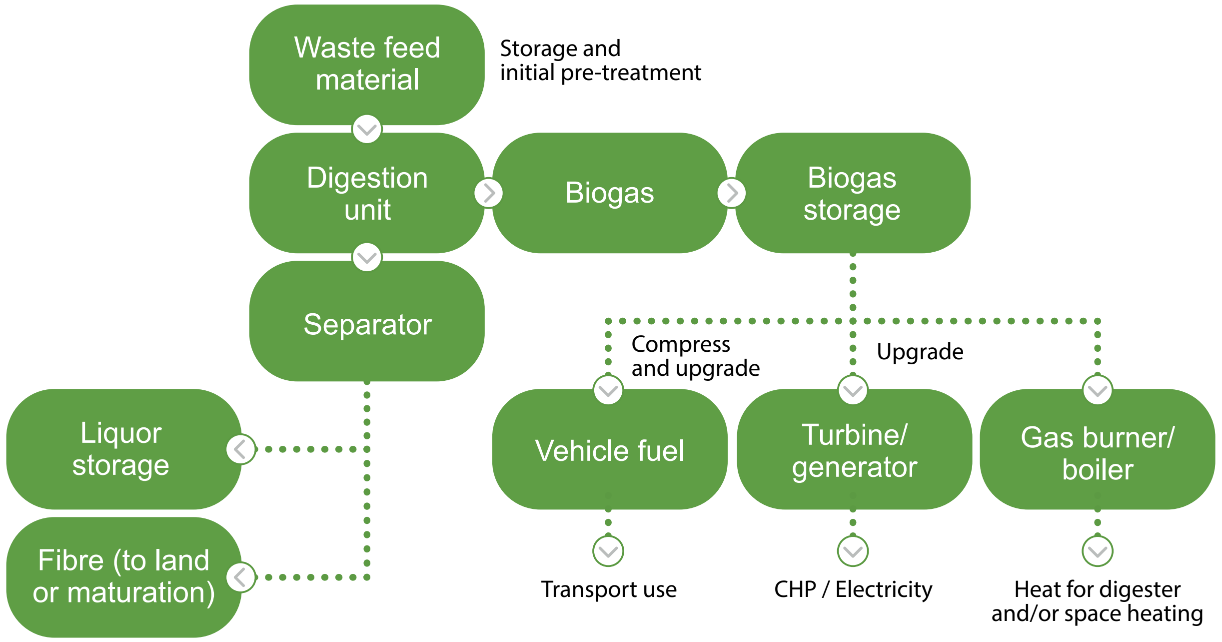


Figure 13: Anaerobic digestion as a means to produce energy and fertiliser (SSWM 2013)



Additionally, before biogas can be converted into electricity in turbines, the raw biogas must be desulfurized and have moisture exacted[10] (Figure 13). These summarise only a small set of the variables that a biogas plant designer must take into account, necessitating expert input for even relatively basic design decisions and estimates of feasibility.

Therefore, even once a biogas solution has been decided upon, the design of any new facility should be based on a thorough expert feasibility study, with special attention paid to all aspects of the treatment process, including feedstock/ waste collection and transportation, required pre-treatment processing (e.g. pulping, grinding or sieving), material handling, post-treatment processing (e.g. aeration and wastewater treatment) and strategic siting of the plant (Rapport et al. 2008).

10. IEA Bioenergy Task 37 has produced two technical papers that detail various technologies available for upgrading of biogas (IEA Bioenergy 2000; 2009)

3.4 Gasification

Gasification is a thermo-chemical process which takes place when biomass is heated under sub-stoichiometric combustion conditions. The heat required for the heating of the fuel and for the endothermic gasification reactions is supplied by the combustion of part of the fuel (direct gasification) or is supplied from an external source (indirect or allothermal gasification). The fuels for this external heat source are normally the residues (char and tar) from the gasification process (Meijden 2010).

Gasification results in the production of a combustible gas mixture, which has an energy content of 5-20 MJ/Nm^3 (depending on biomass and whether gasification is conducted with air, oxygen or indirect heating). Gasification has two key advantages over direct combustion (IEA 2009):

- First, gasification is a highly versatile process as virtually any biomass feedstock can be converted to fuel gas with a very high thermal efficiency of 85-95 per cent.
- Second, fuel gas can be used directly for heat or power applications or upgraded to syngas for biofuel production.

Coal and petroleum coke are used as feedstocks for many large gasification plants worldwide, at a regional scale of GWs of installed capacity in countries such as China and India (Dai and Rai 2013). Additionally, a variety of biomass and waste-derived feedstocks can be gasified: wood pellets and chips, waste wood, MSW, agricultural and industrial wastes, sewage sludge and numerous crop residues can all be suitable (E4Tech 2009). However, the number of such facilities is far more limited than those based on traditional fossil fuel gasification and also lower than those based on other bioenergy conversion processes such as combustion and biogas described earlier.

While the interest in biomass gasification in developed countries has often been driven by a shortage of oil, common denominators in developing countries are mounting foreign debts, heavy dependence on imported oil and the possession of a rich biomass resource. This leads to the consideration of biomass gasification as a favoured energy option, because it can contribute to displacing expensive imported oil by local fuel resources, which are often classified as waste and so have zero, or even negative, financial value (Knoef 2012).

Products for smaller modular systems are now emerging onto the commercial market. These are well suited to off-grid application and system sizes range from 3kW to 5MW. These types of systems have numerous applications, notably village power, as well as industrial process heat and electricity and even grid electricity supply (UNIDO 2007).

Technology overview

Gasifiers can be divided into high temperature gasifiers (typical 1300 – 1500°C) which produce a syngas and medium temperature gasifiers (typical 850°C) which produce a producer gas. Syngas contains almost no hydrocarbons like methane. Entrained flow gasifiers are the most common example of high-temperature gasifiers. These gasifiers are developed to produce syngas from coal and oil residues. Gas coming from medium temperature gasifiers contains on energy basis up to 50 per cent of hydrocarbons (mainly CH_4, C_2H_4 and C_6H_6).

The medium temperature gasifiers can be divided in fixed bed gasifiers and fluidised bed gasifiers. The fixed bed gasifiers can be separated into downdraft and updraft gasifiers. Both are in use for biomass gasification as well. Figure 14 depicts the basic operating principles of typical updraft and downdraft gasifiers.

Downdraft bed gasifiers are widely used for small-scale CHP generation. The typical size of a gasifier is between 100 and 1000 kW_{th} input. The fuel is normally dry wood. The gas is mostly used to fuel a gas engine.

The advantage of this type of gasifier is its simplicity and low investment cost. The produced gas is fairly clean (low tar and dust content). The gasifiers, however, require a well-defined dry fuel for continuous and reliable operation. Scale-up is limited to typically 1 MW_{th} of biomass input and the conversion of the fuel is limited (Meijden 2010).

Updraft gasifiers are better suited for scale up and less sensitive regarding moisture content and geometry of the fuel but produce a lot of tar. If tar removal technology is applied the gas can be fired in a gas engine. Tar is normally removed in combination with water. This water stream requires extensive cleaning before it can be disposed in a sewer system. The overall efficiency of the updraft process can be high because of the complete conversion of the fuel and the low outlet temperature of the gasifier. The tar removal and water clean-up make the process complex and too expensive for small scales of less than 1 MW_{th} (Meijden 2010).

Figure 14: Schematic comparison of updraft and downdraft gasification (van der Meijden 2010)

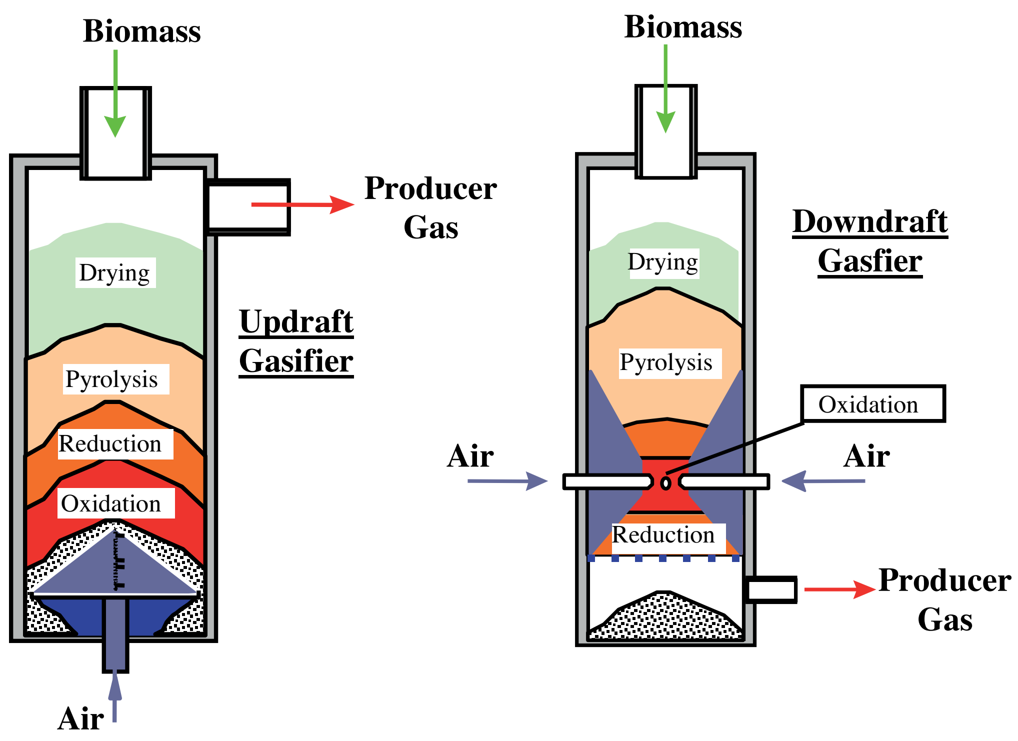
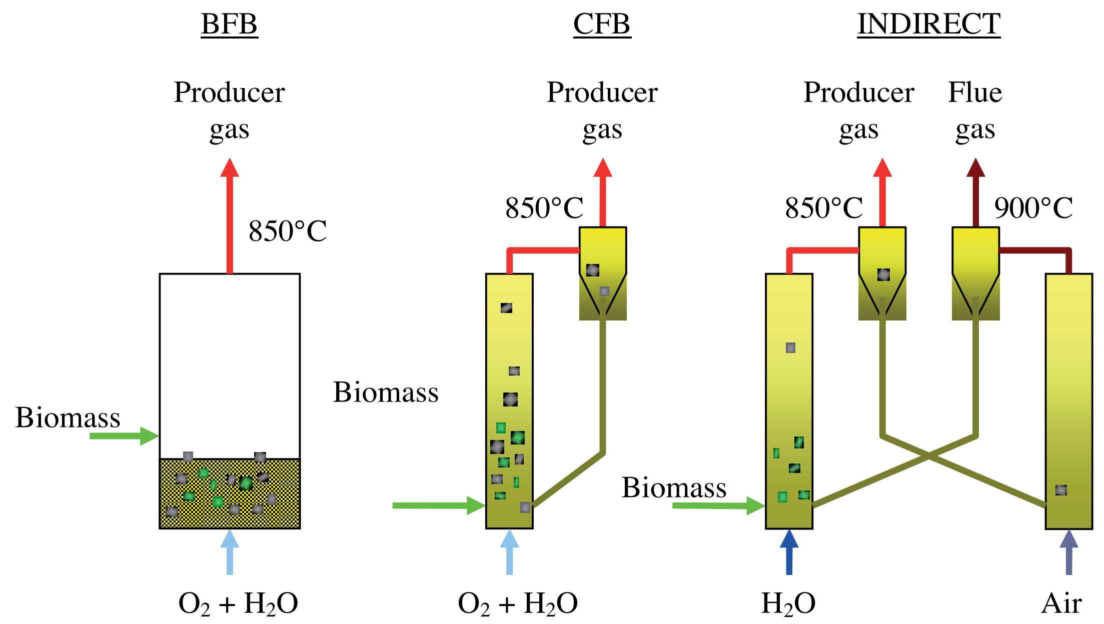


Figure 15: Schematic comparison of BFB, CFB and indirect gasification (van der Meijden 2010)



Fluidised bed gasifiers can handle a wide variety of fuels, with limited pre-treatment. This technology is the more logical choice for large-scale applications. Fluidised bed gasifiers can be divided into three main categories: bubbling fluidised bed (BFB), circulating fluidised bed (CFB) and indirect or allothermal twin bed concepts. All fluidised bed gasifiers use a bed material, which can be inert sand, the ash from the fuel or a catalytic active bed material such as dolomite or olivine. The purpose of the bed material is to distribute and transport the heat in the gasifier which prevents local hot spots, mixes the fuel with the gasification gas and the produced gases and, in the case of a catalytic active material, reduces the concentration of tars. Figure 15 shows the basic principles and differences of three types of fluidised bed gasifiers (Meijden 2010).

Wood and grasses are the main feedstocks for modern biomass gasifiers. Different types of gasifiers require feedstocks in different forms. Woody biomass feedstocks derive primarily from forest residues, sawmill or wood processing residues, woody agricultural residues and urban wood. Non-wood-fuels include grasses, straws, stalks, leaves, fibre, hulls and pits (Knoef 2012).

Grasses such as rice straw and wheat straw have been used for kitchen-scale gasifiers and community town gas systems in China. Bagasse, which is the waste fibre from sugar cane, is used extensively for power generation but has not been gasified at the industrial scale. It has been combined with wood in small-scale downdraft gasifiers. Switchgrass, miscanthus and other herbaceous energy crops have been tested in gasifiers but so far they are not in commercial use. Rice husks are an abundant feedstock for gasification. Updraft gasifiers have been used to convert rice husk to energy in the US and South East Asia. Pits, nuts and shells are dense and convenient forms of crops residues. Walnut shells are converted to power using a small downdraft gasifier (Knoef 2012).

Technology costs

The economic benefits of small-scale power gasifiers depend on the potential savings of switching from high-cost commercial fuel to locally available low-cost biomass. The potential fuel cost savings have to compensate the higher costs of the initial investment, labour, operation and maintenance. The investment costs for a gasification plant vary significantly. Data from Sri Lanka and European countries range from EUR150/kW$_e$ to EUR3,000/kW$_e$. It is likely that the cheap gasifiers from local production require far more maintenance and that these costs are often not documented and calculated correctly. In general, the small-scale power-gasifier technology proved to be unreliable and expensive. Even the few cases where the gasifier plants performed quite well over a prolonged period experienced many technical problems during the first one or two years. Only extraordinarily motivated and committed management and operation were able to overcome these obstacles (Energypedia n.d.).

Technology development trends

An increasing number of examples of commercial gasification plants as well as smaller modular systems are in service in off-grid or localised applications. In the longer term, if reliable and cost-effective operation can be more widely demonstrated, gasification promises greater efficiency, better economics at both small and large scale and lower emissions compared with other biomass-based power generation options (IEA Bioenergy 2009).

Global and regional potential

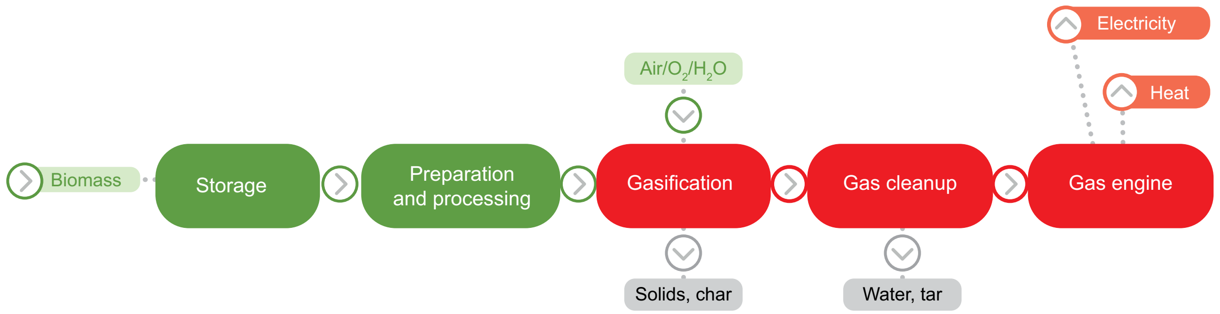
As with other biomass technologies, the potential of gasification technology is closely linked with availability of biomass as feedstock. Gasification technology could suit several possible applications in various market segments. In combination with a power-generation device, gasification can offer higher overall conversion efficiencies compared to combustion-based routes. This is particularly true for small-scale plants (<5-10 MW$_e$) where relatively simple gasification systems could be coupled with gas engines and where steam-based systems are disadvantaged by significant diseconomies of scale. At larger scales (>30 MW$_e$), gasification-based systems are coupled with combined gas and steam turbines, again providing efficiency advantages compared to combustion. However, such plants require more skilled operation compared to combustion plants and their efficiency and reliability still need to be fully established. Although several projects based on advanced concepts such as the Biomass Integrated Gasification Combined Cycle (BIG/CC) are in the pipeline in northern Europe, USA, Japan and India, it is not yet clear what the future holds for large-scale biomass gasification for power generation. Gasification can also co-produce a range of end-products, such as heat and electricity, together with liquid fuels and possibly other products in biorefineries. Such advanced concepts are currently being investigated in research and pilot plants.

The use of gasifiers for direct heat application is mainly confined to emerging countries, while gasification for the production of higher value energy products (e.g. electricity and transport fuel) is of greater importance to developed countries. Hundreds of smaller size biomass gasifiers (10-500 kW$_{th}$) are, for example, being deployed mainly for intermittently operating thermal applications in China, India and South East Asia with viable pay-backs. However, reliability and maintenance of these units for continuous operation seems be an issue (IEA Bioenergy 2009).

Description of the plant

Figure 16 shows a simple block flow diagram of small-scale (less than 100 kW_e up to 10 MW_e) medium temperature biomass gasification for electricity generation and heat recovery via CHP. Prior to gasification, pre-processing of the biomass may be required, including size reduction and possibly drying. Depending on the type of gasifier either air, oxygen and steam, or separate air and steam are used in the gasification step. The resulted producer gas can either directly be fed to a gas engine (in case of a downdraft gasifier) for combined heat and power generation, or it can be led to a gas clean-up unit for tar removal (in case of an updraft or a fluidised bed gasifier), after which it will be combusted in a gas engine.

Figure 16: Block flow diagram of biomass gasification for electricity generation and heat recovery via CHP



Section 4

Market and regulatory environment

As discussed at the beginning of Section 1, WtE offers significant potential to help provide energy in support of sustainable development if implemented under market and/or regulatory conditions that ensure its environmental, social and economic integrity. This section elaborates on those conditions. Common guidance, applicable to any WtE project, is presented first, followed by those factors that are more specific to either large on-grid or smaller off- or mini-grid applications.

4.1 Market conditions

A functioning WtE market is no different from any other functioning market. In order for the limited renewable resource (in this case biomass waste) to be efficiently allocated, ideally the following conditions should be met:

- *Market transparency:* All interested suppliers and users of waste biomass should have access to each other and have the opportunity to interact; all actors should possess the necessary information to be able to make informed decisions related to bioenergy development.
- *Competition:* Both suppliers and users of biomass wastes and residues should be present in sufficient numbers to avert any monopolistic behaviour on either the biomass supply or demand side; in other words, no single buyer or seller is large enough to determine the price of the biomass.
- *No barriers to market entry or exit:* There should be no barriers to the admission of newer, usually more efficient technologies and obsolete, unviable installations should not be locked-in.
- *No externalities:* Any bioenergy development should not have any negative effects on the environment or the local communities that are not realistically priced and reflected in its costs of operation – this ensures any such effects will not become a problem to be solved with public funds.

In addition, developing country markets warrant a special check on the following two conditions:

- *Access to finance:* The financial market should be sufficiently developed to provide the capital necessary for the construction and operation of the WtE project. This includes the presence of mechanisms able to mobilise domestic and international finance for off-grid and mini-grid projects for rural electrification.
- *Access to physical resources:* As an elaboration of the transparency condition, this requires that bioenergy developers are able to ensure the continuous supply of wastes and residues with specified attributes and have access to, or the possibility of developing, infrastructure to collect, transport, handle and store the biomass feedstock. While logistical challenges of biomass handling are by no means an issue unique to the developing world, they can be exacerbated in these areas.

Some of those conditions are more relevant for certain types of WtE developments than for others. Market transparency, competition and entry and exit barriers are more relevant for large-scale WtE developments aiming to supply the grid. Lack of externalities, access to finance and adequate supply of biomass is, on the other hand, equally crucial no matter the scale of the project.

As most markets for modern bioenergy, especially in developing countries, are only at the early stages of development, most of these conditions won't be met. It is then the role of the governments to create a regulatory environment that will support the development of efficient and sustainable bioenergy in their countries, and the role of the development practitioner to check that those are in place.

4.2 Policy environment

Policy interventions are needed to address both market and non-market barriers to the development of efficient and sustainable WtE projects. Biomass waste projects have a greater probability of being successfully developed in countries and regions with supportive policy frameworks. Although the policy environment for WtE developments is less complex than that for bioenergy as a whole, most developing countries rarely see this opportunity and rather seek to promote WtE as part of a wider suite of policy measures aimed at promoting bioenergy. Development practitioners are therefore less likely to see specific policies aimed at WtE but will rather have to distil the relevance of bioenergy policy, or even just renewable energy policy, for the WtE initiatives he or she wishes to engage with.

The lack of policy guidance is even more acute for off-grid and mini-grid (rural) WtE applications, because they tend to lack both the policy framework for WtE and that for off-grid or mini-grid electrification. This is certainly the case in the ASEAN countries, as well as in many African ones (ASEAN Centre for Energy 2013, Franz 2013).

Where policies are absent, provide insufficient incentives, or communicate uncertainty with respect to the duration and level of financial support, they can act as a barrier.[11] This is equally true for both large and small-scale applications though, clearly, the measures required to promote them differ to a certain extent.

4.2.1 Long-term vision for WtE development

The basis for long term development of a sector is the government's vision of its role in the country's development. A long-term vision should build on specific national or regional characteristics and strengths; for bioenergy that means existing or potential biomass feedstocks available, specific features of the industrial and energy sector and the infrastructure and trade context (IEA Bioenergy 2009). A vision should include sectoral targets for a specific resource in the national electricity mix. As mentioned, it is unlikely there will be such a target for biomass waste. In its absence, the role of biomass waste should be distilled from the national vision on biomass as a whole, or at least renewable energy.

Even if such a vision exists, it will usually apply to larger-scale development aimed at feeding the national grid. Any vision for the use of biomass waste in off-grid applications, including mini-grids, is more likely to come from rural electrification strategies, though even these often still underestimate the importance of off-grid and mini-grid installations in providing electricity to rural areas. Rural electrification targets should be underpinned by a review of energy access in the country and also present the criteria for the selection of target areas.

Such a vision, or strategy, should inform all specific regulations that govern bioenergy development in a country. It should also extend its focus to the sectors that will provide the biomass, in this case agriculture and forestry. Although the availability of residues is a side effect of such policies, it will be linked to the supply of crops and wood, so strategies to improve the productivity of the agriculture and forestry sectors are of crucial importance. Following the same rationale, any policies restricting agricultural production will reduce the amount of residues available.

Lack of such a vision (or high-level strategy) indicates uncertainty for long term sector development at all scales, which at the very least affects the ability of bioenergy projects to raise (private) capital but more often results in a stagnant, underdeveloped sector. Finally, it should be stressed that the successful development of bioenergy does not only depend on the specific policies and regulations outlined above but on the broader energy and environment legal and planning framework, as well as coordination between energy, agriculture and forestry sectoral policies.

To stand a chance of realisation, the vision on long-term WtE (or bioenergy, or renewable energy) needs to be complemented by a suite of practical policy support measures and instruments, which the development practitioner must thoroughly research and, where they are available, make full use of.

11. The EU Biomass Action Plan (2005) identifies this as the single most important success factor, observing that "it is convincingly proven that whenever appropriate policies are implemented, the market reacts positively and develops the necessary structures and operations systems to deliver results" (EC 2005).

4.2.2 Policy measures and instruments

Integral parts of a policy aiming to promote the generation and use of a renewable energy source are its support measures and instruments. In order to stimulate the deployment of renewable energy in general, and WtE in particular, governments have implemented a variety of policy measures and instruments, which can be grouped into direct and indirect support.

Direct support

Direct support can take many forms. Most commonly it provides a financial incentive to stimulate production or consumption of renewable energy, or a mandate to do so. The most common direct support measures relevant for WtE developments are listed below:

Regulatory financial incentives
This group of policy measures are of most interest to development practitioners involved in the planning of large-scale grid-connected WtE projects. They include:

- Feed-in tariffs: The most commonly-used policy instruments for the promotion of renewable energy, including grid-connected biomass based electricity generation. It guarantees the energy producer a premium energy price over a certain period of time. It is important that the tariff level and time period are chosen to motivate investors by providing security of income during part of the installation's lifetime; the tariffs are therefore normally guaranteed for a number of years. As feed-in tariffs are centrally set and paid by the government, the cost of the scheme is met by public money and is, effectively, spread across society.
- *Renewable portfolio standards (RPS)/ quota obligations and tradable certificates:* These set a target percentage of either the installed capacity or generated energy that must come from renewable sources. Energy generators are then required to ensure that the target is met and the system may be enforced with fines or penalties if the quota percentage is not achieved. In order to improve the flexibility and efficiency of the scheme, quota systems can be supplemented with tradable certificates, though trading schemes are generally well suited to the monopolistic or oligopolistic energy markets in developing countries.

  RPS provide a guaranteed market for renewable energy but not, generally speaking, for biomass energy in particular. If other forms of renewable energy are less expensive, they will tend to be favoured at the expense of biomass. If biomass energy, specifically, is the focus of policy makers' attention it may be necessary, depending on local circumstances and competing energy sources, to incorporate a specific biomass quota in addition to the broader renewable energy target.[12]

Fiscal incentives
Fiscal incentives can take the form of:

- *Increased taxes on fossil fuels and reduced taxes on biomass energy, or a combination thereof:* Key aspects include the existence of an adequate tax differential to encourage an increase in biomass energy production and consumption and an independent public service that can resist pressures from the fossil fuel industry lobbying against such a move.
- *Direct subsidies, grants or rebates:* A project may apply for any of those with a public (or PPP) fund, usually created especially for this purpose. These are particularly relevant for off-grid and mini-grid rural electrification. They can take the form of investment-based capital subsidies, granted to project investors or developers, connection-based subsidies granted according to number of connections, output based, topping up the price of electricity produced to project investors or developers, or operation-based, subsidising the operation cost of the power system (ASEAN Centre for Energy 2013).

Public financing
The two most commonly used methods of public financing are:

- *Public procurement/tendering of a target capacity allocation:* Government can choose to contract a specific amount of renewable energy capacity directly or through the national utility. This is one market-based incentive that can be used effectively to procure both on and

12. Another typical regulatory instrument is blending mandates, which only apply to liquid biofuels for transport. Although biofuel production technologies using biomass waste as feedstock (the so-called second generation biofuels) exist, their relative technological novelty and high costs exclude them from the scope of this toolkit and hence blending will also be omitted in this overview of support measures.

off-grid capacity. Once the target has been set, a bidding mechanism needs to be established, where bidders (that is, project developers) propose the price at which they will supply a fraction of the proposed generation capacity for a set period of time. The government then chooses the most competitive bids, usually in combination with whatever socio-economic development components it deems appropriate to entrench into the tendering mechanism.[13] The programme design is crucial, because in case it does not take due consideration of the challenges and economics of each specific type of renewable energy, it might not achieve its procurement goals.

- *Public investment, grants or loans:* Administered through state-owned agencies, usually awarded to flagship government projects.

Table 3 summarises the types of policy support used in SNV countries. While none of these policies are specifically targeted at WtE developments, they usually also do not preclude them. Development practitioners are therefore advised to investigate the support measures available in their countries of operation and their suitability to support the projects or programmes they are involved in.

It should be stressed that there are, necessarily, costs associated with all the incentive schemes listed above; put simply, someone must pay the additional costs of renewable energy generation. Whether this is passed on to consumers directly in higher prices, funded from public budgets or offset with international assistance, the ability to pay for such a scheme determines the amount of renewable energy that can be subsidised.

Other regulatory support measures

In addition to financial incentives, a number of other regulatory measures should be in place to ensure the WtE projects can deliver their benefits.

For larger-scale projects, a crucial aspect is market access. While direct off-taking can sometimes be an option, the logistics of feedstock handling often demands that an installation be located conveniently closer to the feedstock source, rather than a potential off-taker. In this case, regulation must ensure grid access and possibly preferential access for renewable electricity.

For off-grid and mini-grid projects, a clear legal framework for private investment in off-grid rural electrification is necessary in order to mobilise the private sector and a central institution/agency mandated with the coordination of off-grid rural electrification efforts should be in place (ASEAN Centre for Energy 2013).

Guidance and other supportive policies

While financial incentives are perhaps the most obvious type of support, there are a number of other ways in which development of WtE can be supported, either by the government or other stakeholders.

R&D and entrepreneurial development

Since many WtE technologies have seen limited deployment in developing countries -- at least on a large scale -- they might still need to be adapted to local circumstances to optimise their performance with local parameters. This can be achieved through R&D which also serves to promote cost efficiency and increase awareness of the opportunities that waste biomass affords.

In addition to promoting R&D, measures that focus directly on entrepreneurial development are important in achieving improved performance and efficiency. Governments can encourage entrepreneurial development by streamlining and facilitating registration, permit and licensing procedures and monitoring early commercialisation to ensure quality control. Other stakeholders, including development practitioners, can contribute to this process by:

- promoting consumer awareness
- creating partnerships with financial institutions to improve access to finance
- promoting institutions (such as co-operatives) to manage and reduce risk
- disseminating information to potential entrepreneurs that is scarce or difficult to access, including contacts, lessons-learned, technical data, meteorological data, management practices and legal regulations.

13. This approach has been very successful in South Africa, where a multitude of competing Independent power producers have brought down the costs of renewable energy substantially for wind and solar resources, although it has not immediately managed to attract much investment in bioenergy, mainly due to the minimum plant size requirements.

Table 3: Overview of policy measures in support of renewables in SNV countries

Country	Feed-in-tariff	RPS/quota obligation	Tax incentives	Capital subsidy/ grant/ rebate	Public procurement	Public investment/ loans/ grant
Latin America						
Bolivia						
Ecuador	X		X			X
Honduras	X		X		X	
Nicaragua	X					
Peru	X		X		X	
Africa						
Benin						
Burkina Faso						
Cameroon						
DR Congo						
Ethiopia			X			X
Ghana	X	X (heat)	X			
Guinea Bissau						
Kenya	X		X			
Mali			X			
Mozambique						X
Niger						
Rwanda			X			X
South Sudan						
Tanzania	X		X	X		
Uganda	X		X	X		X
Zambia				X		X
Zimbabwe						
Asia						
Bangladesh			X	X		X
Bhutan						
Cambodia						
Indonesia	X	X	X	X	X	X
Lao PDR						
Nepal			X	X	X	X
Pakistan	X					X
Vietnam			X			X

Capacity development and awareness raising

Technical know-how and awareness, both among the developers undertaking projects and the institutions providing services, are crucial to the successful adoption of WtE. But detailed understanding of WtE opportunities is often initially limited. Energy facility operators may be unsure of the technical requirements associated with displacing fossil fuel with biomass fuel - or may have no prior experience of generating any form of energy. Demonstration projects can go a long way in mitigating such uncertainties and raising awareness on the opportunities presented by modern WtE applications.

Awareness-raising among the financial community is equally crucial. Although financial institutions are usually adept at developing financing plans, their knowledge of WtE investments is generally limited. Often, financial institutions find it difficult to construct a credit structure that is acceptable to all parties involved, particularly as individual farmers or foresters are usually regarded as being unreliable debtors. When specialist consultants are employed to supply the needed technical expertise, the cost of the consultants is then invariably passed on to the project developer, which inevitably increases the overall financing costs for the project. In conjunction with awareness-raising in the financial community, the bundling of small-scale WtE investment opportunities can facilitate project developers' negotiation of attractive terms from financial institutions. As such, bundling helps to realise economies of scale and diversify risk.

Established constituencies

The ability to align entrenched sectoral interests (for example, the sugar and paper and pulp industries) with a biomass energy strategy is often critical in overcoming the negative risk perceptions and high initial costs that characterise many biomass energy applications.

4.3 Sustainability regulation/ certification

The market conditions and possible policy support measures listed above mainly ensure the viability of WtE projects. A large body of literature exists on the conditions that need to be in place for bioenergy developments to be sustainable, identifying a great number of potential risks that policy needs to address to ensure any proposed bioenergy initiatives are not only economically but also environmentally and socially viable. To this end, Europe is introducing biomass sustainability certification, which places the burden of ensuring compliance with environmental and social good practices on the energy producer that uses imported biomass.

This is arguably less relevant in a context where the biomass is both produced and consumed within a country. In such cases, sustainability mainly still relies on the government providing clear regulations and enforcement, or simply the goodwill of the project developer. To achieve sustainable bioenergy developments, even based on wastes or residues, development practitioners should be mindful of the following areas (adapted from Cramer 2006):

- For environmental sustainability:
  - Use of chemicals: prevent excessive use of chemicals to treat biomass wastes and residues
  - Maintenance of biological diversity: residues sometimes carry important roles in maintaining biological diversity, which should not be compromised by residue-based bioenergy developments
  - Protection of the soil and ensuring regeneration following harvesting: crop residues provide the important service of nutrient replenishment, especially in poor quality soils with lower organic content – this means the optimal share of residue harvesting versus ploughing it back into the soil needs to be worked out on a case-by-case basis.
- For social sustainability:
  - Recognition and respect for the customary and traditional rights of indigenous/local people (including explicit protection of their land right and ensuring sufficient supply of residues for traditional domestic uses and crafts)
  - Protecting the health and safety of employees
  - Provision of information to increase public awareness of the opportunities, benefits and limitations of the use of biomass waste and residues as energy sources.

Generally, a greenhouse gas balance, competition with food and protection of conservation areas and areas of particular historic, cultural or spiritual value would be added to the above list; however, these are less applicable to residue-based bioenergy projects, as it is unlikely that non-food crops would be planted and new areas would be converted to agricultural land primarily for residues supply.

Section 5
Project development

Developing a WtE project is a time consuming and resource intensive undertaking that requires progressively more investment until it is ready for operation. For this reason, it is important that viable projects can be identified early in the project development process. This chapter describes a simple step-wise approach to making a very early assessment of a biomass waste project, at the stage of conception, as well as providing questions to guide the assessment of projects at the pre-feasibility stage. These represent only the very first step of a much longer project development cycle (Figure 17) but play an important part in deciding whether to invest further resources to develop a potential project.

At the pre-feasibility stage a market opportunity is identified, together with its rough costs and barriers. Subsequently, during a more substantial and detailed feasibility assessment, the market opportunity is analysed; concept process alternatives developed; specific challenges identified; order of magnitude capital costs estimated; and one or two process alternatives selected for further development (Janzé 2010). It should be noted that this split between the pre-feasibility and full-feasibility stages is somewhat artificial, as these steps may not be distinct.

The following section provides a set of steps that an adviser can follow along with some process guidance and is complemented by Section 5.2 that provides a series of questions that a project should satisfy in order to be broadly viable, in line with the level of detail that one might expect at the pre-feasibility stage of project assessment. Section 5.3 summarises the pre-feasibility process into a checklist for project developers.

Figure 17: Generalisation of the project development cycle

5.1 Initial project screening

This section provides a step-wise guide for an initial, qualitative project screening that would allow an advisor to make a simple go/no-go decision with regard to further involvement with a particular project based on a project proposal. The screening process is shown in Figure 18 and described below.

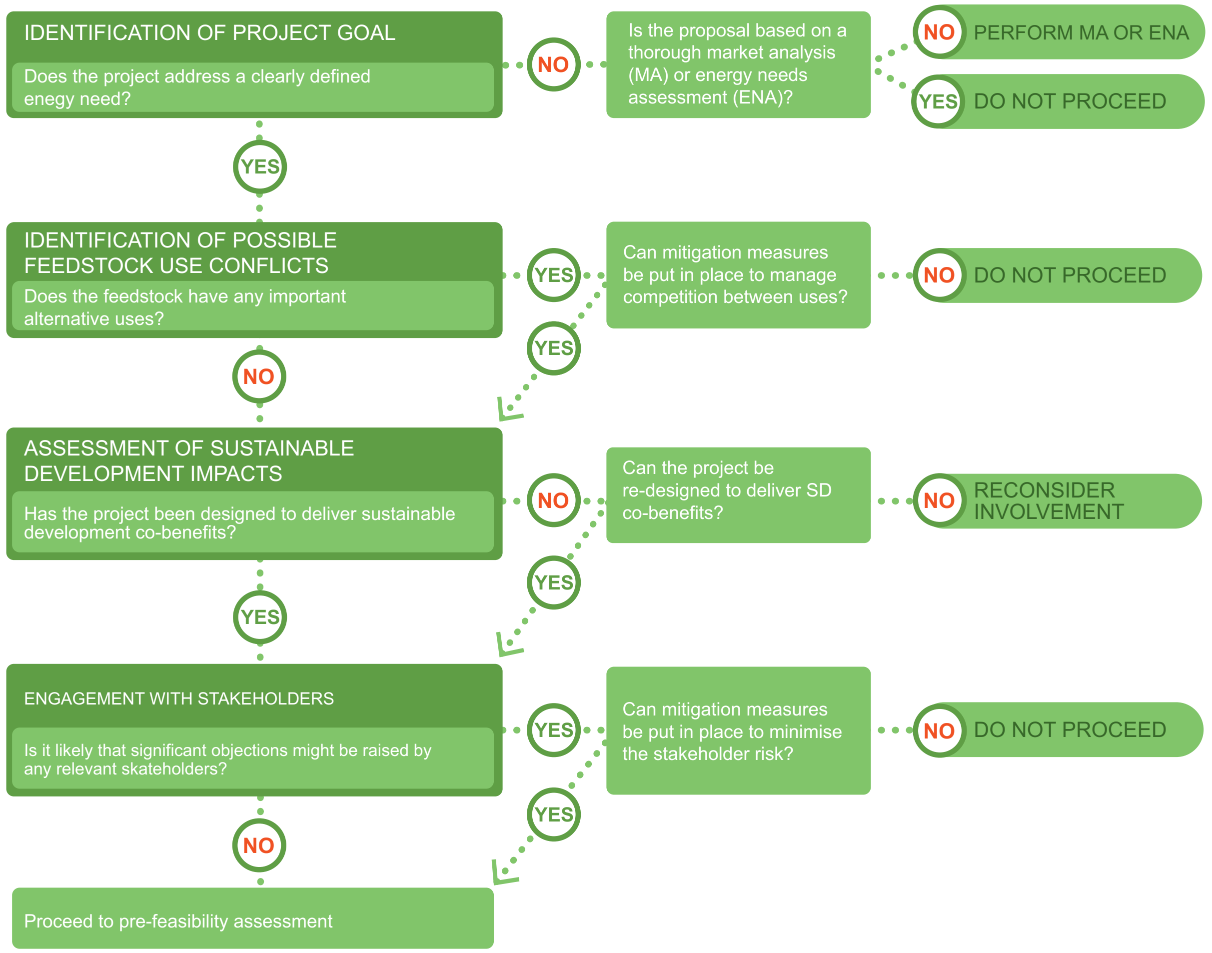
These steps are all equally relevant regardless of the project size, although they will be more straightforward in the case of a small-scale biogas-based village mini-grid project as opposed to a utility-scale waste combustion plant aiming to supply the national grid.

1. Identify the project goal
For a WtE project to be successful, it needs to address a clearly defined energy need. Depending on the scope of the project, the energy need can be formulated very specifically or more broadly. Examples of project goals that could fall within the scope of this toolkit are listed below:

- Deliver off-grid electrification of a village using local renewable resources
- Provide an alternate to diesel generation for a remote commercial power consumer that has a readily available source of agricultural or forestry waste
- Recover energy from an industrial process's wastewater to reduce reliance on expensive and/or unreliable grid electricity
- Supply electricity to the national grid as a commercial enterprise.

The energy need will typically be formulated based on a market analysis or energy needs assessment.[14] If a clearly defined energy need is not immediately identifiable, the adviser should first assess the market analysis (MA) or energy needs assessment (ENA) underpinning the proposed project. If these assessments are found to have been satisfactorily performed, but they do not identify a clear energy need that the project would address, then the process should end here, as the initial project idea does not seem to be centred on an identifiable and resolvable energy issue. If, on the other hand, the assessments are found to be unsatisfactory, a project idea might still be validated by an improved assessment.

Figure 18: Project screening process



2. Identify possible feedstock use conflicts
One of the most important aspects of the initial project screening is to determine whether the proposed feedstock has any other uses. This aspect of assessing bioenergy projects remains relevant even for projects based on biomass wastes or residues. It is rarely the case that a residue or waste stream is being produced and simply discarded. Wastes and residues often have important alternative economic, environmental and socio-cultural uses that need to be considered. Such streams present a relatively low cost resource for local farmers, nearby households or industry to utilise. Some typical uses are shown in Table 4 for a number of residues, bearing in mind that these uses may be different across countries or regions.

It is hence important to assess whether the use of the residue or waste as energy feedstock will have a negative effect on any of its other possible uses. To determine this, a thorough biomass resource assessment needs to be complemented with observations obtained with the assistance of local stakeholders. If the waste stream of interest proves to have one or more important other socio-economic or environmental functions, the adviser needs to investigate whether mitigation measures can be put in place to manage this competition and minimise negative impacts. If that is not the case, the project should not be pursued as initially proposed.

3. Assess sustainable development impact
Addressing an energy need in a developing economy typically brings about economic development benefits. In addition to these, WtE projects can deliver other sustainable development impacts, which can depend on their location, beneficiaries, feedstock sourcing practices, etc. Co-benefits of WtE projects could include improved food security, skills transfer, employment, rural development, social cohesion, improved health and gender equity, as discussed earlier in this Toolkit. Environmental co-benefits could include improved agro-forestry management practice and improved waste management with the related reduction in odour, disease, soiland groundwater pollution and risk of fires.

Table 4: Indicative current uses of crop residues[15] (UNDP 2000)

Crop	Residue	Typical current residue uses
Coconut	shell	household fuel
Coconut	fibre	mattress making, carpets, etc.
Cotton	stalks	household fuel
Mustard cotton	gin waste	fuel in small industry
Groundnut	shells	fuel in industry
Groundnut	haulms	household fuel
Maize	cobs	cattle feed
Maize	stalks	cattle feed, household fuel
Millet	straw	household fuel
Other seeds	straws	household fuel
Pulses	straws	household fuel
Rapeseed	stalks	household fuel
Rice	straw	cattle feed, roof thatching, field burned
Rice	husk	fuel in small industry, ash used for cement and soap production
Sugarcane	bagasse	fuel at sugar factories, feedstock for paper production
Sugarcane	tops/leaves	cattle feed, field burned
Tobacco	stalks	heat supply for tobacco processing, household fuel
Wheat	straw	cattle feed

14. A market analysis is usually the term associated with utility scale projects, whereas smaller projects aiming to improve the energy situation of households, for example, are usually based on an energy needs assessment.

15. The use to which residues are put varies greatly from one region of a country to another and from country to country. The uses listed here are illustrative only. They are typical uses in parts of India.

Box 2: Possible sustainable development co-benefits of coffee waste projects

The concept of sustainable development co-benefits can be illustrated by the example of small coffee producers in Honduras. Here, a coffee cooperative developed a system that uses pulp and coffee effluent from small-scale coffee processing to generate biogas, bioethanol and biofertilisers, primarily to be used in coffee production with the surplus used by the community or sold on the open market (Samayoa 2012). Besides reducing the coffee cooperative's reliance on expensive fossil fuel based electricity and heat (which is the main project goal), the project also has many environmental co-benefits, such as reduction of water consumption and GHG emissions from untreated wastewater, reduction of odours, diseases and pollution of soil and surface and underground water. It also has social benefits in the form of improved health for the surrounding communities that use water sources, which are no longer threatened with pollution from coffee processing (Samayoa 2012).

It is thus important to assess whether a project has been designed with due consideration of its potential to deliver such sustainable development benefits. If that is not the case, it is advised to explore possibilities to re-design the project to ensure such co-benefits are an integral part of the intervention. If that is not possible, the continued involvement with the project should be reconsidered based on the objectives or mandate of the adviser.

4. Engage with stakeholders
Finally, during the initial project screening an advisor needs to consider whether the project proponent has given due consideration to any objections to the project by relevant stakeholders, which could be raised at any point during the project's lifetime. If that has not yet been done, it is recommended the adviser requests (or directly undertakes) such an analysis. This could require consultation with various stakeholder groups.

Stakeholder objections that need to be taken into account could take many forms, for example:

- Objections from the local community based on a misunderstanding of the project and its impacts
- Objections from the project beneficiary's competitors fearing unfair competitive advantage
- Objections from the government if the project is not aligned with their policies and regulations.

Once the possible stakeholder risks have been identified, it is important to check whether the necessary mitigation measures have already been, or can be, put in place in the future. Such mitigation measures could entail:

- Project awareness campaigns in the local community
- Open tendering for project beneficiaries
- Alignment of the project with government policy objectives.

Reducing the risk of stakeholder objections can significantly increase a project's financial and time requirements. However, if the project is unlikely to be able to implement the necessary measures to secure the necessary stakeholder support, the risks to the project are likely to be too high and further involvement should not be pursued.

If the initial project screening answered all the above questions positively, the proposed project may warrant further investment of resources and a more detailed pre-feasibility assessment should be undertaken, as discussed in the following section.

5.2 Pre-feasibility assessment

Any party that is considering the development of a WtE project, or biomass waste strategy for an area or waste stream, must consider a number of important technical, logistical, legal, environmental and financial questions. For example, whether a WtE plant will be feasible and whether it will sustainably contribute to energy needs requires that: appropriate feedstock is available; this feedstock can be collected, processed and transported; a suitable conversion technology exists; and market conditions for the products produced are favourable, among many other factors. Operational aspects also need to be considered, in relation to the way in which a project is managed, structured and run over time.

This section provides a set of qualitative parameters, framed as questions, against which advisors can make a pre-feasibility assessment of technology viability (Figure 19). This means that an early go/no-go judgment can often be made without extensive technical experience of WtE projects. That being said, there are a number of aspects of project development, particularly related to technology/system design, which cannot be generalised in a guidance document such as this. The enormous variety of feedstocks, conversion pathways and end products, will mean that many projects, which don't have a clear precedent, will require expert assistance to be adequately assessed.

A checklist of these questions for project developers along with key factors is provided in Section 5.3.

While making an initial assessment of a WtE project, or considering bioenergy options from

Figure 19: Assessment questions at the pre-feasibility stage of a waste bioenergy project

FEEDSTOCK

- Can a reliable source of feedstock for the WtE project be identified?
- Is the available biomass suitable for use?

TECHNOLOGY

- Is there a WtE technology that is appropriate to the available resource and local context/needs?
- Is pre- or post-processing required?
- Is there a supplier readily available with appropriate technology?

LOGISTICAL

- Is the distribution of feedstock amenable to my project?
- Can the necessary storage be provided?
- Is there a suitable location for the plant?

SUSTAINABILITY

- Will the project provide a reasonable mitigation impact?
- Will the project meet local environmental requirements?
- Is the project aligned to local interests?

FINANCIAL

- Is the project financially viable?
- Is the project financially feasible; i.e. can finance be raised?

REGULATORY / POLICY

- Can independent parties generate electricity and connect to the grid?
- Can the necessary permits be obtained?

OWNERSHIP & SKILLS

- Can a suitable ownership structure be found?
- Is the necessary expertise available?

the perspective of a policymaker or planner, there are also some general pieces of guidance that should be borne in mind:

- Look at similar applications and feedstocks, ideally cases in similar country contexts. Finding successful stories will inform your design choices but also demonstrate the potential viability of a possibly new technology to local stakeholders.
- Involve appropriate technical expertise for novel applications or where experiences with existing projects cannot be applied. The design and costing of a village or utility scale project is a complex challenge that requires expert input.
- In the absence of an early-stage project sponsor, consider looking for project development support from the resources in Chapter 7 or locally. A full pre-feasibility study, of the type that can be used to attract potential investors, can represent a significant cost.
- When resources for conducting a detailed cost assessment are scarce, focus on the main elements that will determine feasibility – i.e. key items of capital expenditure and feedstock costs – and use nominal figures for other aspects.

5.2.1 Feedstock

The starting point for assessing the potential feasibility of a bioenergy project or strategy is to understand the characteristics of potential feedstocks, in terms of availability and suitability for electricity production from one of the conversion processes discussed in Chapter 3, as well as at the appropriate scale.

Availability: Can a reliable source of feedstock be identified?
A project developer may have a specific potential feedstock in mind, or may have a number of potential residue and waste streams available in a certain location. A major focus of implementing any WtE project then becomes reliable feedstock procurement. In the pre-feasibility stage, feedstock supply must be investigated in detail at a local level.

WtE plants are dependent on feedstocks that often require more sophisticated procurement arrangements and greater certainty of price and availability than do conventional fuels. Indeed, many past bioenergy activities have faced difficulties, and in some cases failed, due to an insecure feedstock supply (ESMAP 2005). In the longer term, when biomass markets are more mature, it is likely that many of the supply risk problems would have lessened, but in the meantime, early projects need to establish mechanisms for reducing these risks. Summarised here are a number of factors that should be considered during the pre-feasibility stage of project assessment in regards to procurement.[16]

Security of supply
It is vital to the bankability and long-term viability of a WtE project that it can be confident of reliable supply of feedstock over time. There may be limited sources within a reasonable distance of the plant, or there may be changes in availability over time (for example some residues reduce in volume or competition for residues arise), which could have serious consequences for the operation of the plant.

The most straightforward example of guaranteeing supply is when the project developer is also the producer of the biomass, a type of project that could be considered as vertically integrated. In such an instance, the two activities, of residue creation and electricity generation, are inherently linked and the viability of the plant is much easier to guarantee (assuming that sufficient feedstock can be produced in-house).

However, only some projects will be of this nature. More commonly, WtE projects will have to arrange part or all of their feedstock from external sources. If the feedstock required is a waste, they can sometimes be obtained at negative costs, as businesses might normally have to pay for its removal.

Projects usually manage this risk through long-term supply contracts with farmers, firms or other sources of biomass waste that is planned for use. These contracts may specify volumes, shares of residues and prices for a known period into the future, greatly reducing risks. That being said, a contract with a single supplier may still carry significant risk and suppliers who depend on sales to a single local consumer could be similarly vulnerable if they come to rely on this revenue. Sometimes, such a situation cannot be avoided, but in that instance contracts and contract enforcement should be robust.

The most practical way of managing the risk of supplier pricing is to engage with multiple sources for the planned feedstock. By diversifying, there is less risk that problems with any one supplier will impact unduly on the project. This should be considered in the early stages of a project, when assessing where biomass resources may come from. At the same time, the developer should be aware that producers are often numerous, small and dispersed. While this might increase competition among waste or residue suppliers and yield lower prices, the project could face significant transaction costs in establishing and coordinating a reliable supply chain from many different small sources.

Taking the idea of diversification one step further, it may be possible to adopt conversion equipment that is flexible and can use a variety of feedstocks. Biomass technologies may be suited to a specific type of biomass and cannot tolerate much deviation from their design specifications; however, in some instances, it is possible to design multifuel capability into a project through boiler design, flexible fuel handling and feedstock densification. Such measures could add costs, or reduce efficiency, which need to be balanced against the benefits of feedstock diversification.

Lastly, advisers and other interested stakeholders are advised to investigate whether any government actions that can help reduce risk for project developers might be available. Potential actions include incentives and support to encourage secure, long-term supplier/consumer contracts and granting concessions for certain areas from which consumers could exclusively (or semi-exclusively) procure feedstock.

Seasonal price fluctuations and availability
In addition to understanding which sources of feedstock may be practical for a project, it is also important to consider how their availability may change throughout the year. Some waste streams are subject to greater variability than others. Municipal solid waste, for example, has a relatively constant stream. On the other hand, agricultural residues and wastes are generally linked to seasonal production of crops or foods. Data for production (and where possible for price) therefore needs to be collected over a period of at least a year, and ideally longer, to understand year-to-year variations. As with any agricultural product, biomass feedstock yields are vulnerable to the whims of weather, outbreaks of disease or pests and other unpredictable conditions. A certain level of contingency needs to be built into assumptions on feedstock volumes and seasonal changes need to be considered when designing storage of feedstock to ensure consistent supply (see later in this chapter).

For small-scale off-grid applications, the seasonality of the feedstock supply can sometimes be solved by establishing a hybrid system with another source of energy. In the case of village mini-grids, diesel generators have often been used for this purpose, although their attractiveness has been considerably reduced in recent years by higher oil prices.

Competition for feedstocks
As discussed in Section 5.1, residue and waste streams often have a number of alternative uses including feed of livestock and household fuel. The social impacts of creating a market for a feedstock is discussed later in this chapter, but it should also be recognised that many residues already have a market for their use and a value associated with that. As biomass has lower value as an energy feedstock than for many competing demands, the price of biomass feedstocks could be driven to unaffordable levels by competing uses. These existing consumers and their willingness to pay must therefore be considered at the outset through a thorough analysis of existing use patterns.

Potential for up-scaling in the future
Lastly, it can be useful to consider a future in which the planned WtE project is successful and there may be a desire to expand or replicate. While not vital for project feasibility, there can be added value in having sufficient excess resource, either nearby or elsewhere in the country/region, to justify future projects of a similar nature.

Community-based feedstock procurement
For small-scale off-grid projects such as village mini-grids, the local community might be involved in feedstock procurement. There are a number of successful examples of community-based biomass procurement, though few are focused on biomass waste (with oilseeds being the more common ones). Where the community is involved in feedstock provision, experience has shown that the most effective and reliable feedstock procurement takes place if the feedstock suppliers are also the main beneficiaries of the power generated and where responsibilities have been clearly assigned and their execution is monitored by a designated entity, for example an agricultural cooperative.

Characteristics: Is the available biomass suitable for use?
Not all biomass wastes are equally suitable for bioenergy production and in some cases bioenergy production might not be profitable.

16. Partly adapted from ESMAP (2005)

The suitability and profitability of biomass feedstock depend mainly on its type and properties. Biomass feedstocks can be divided into primary, secondary and tertiary biomass (US DoE 2011).

1. *Primary biomass* is produced directly by photosynthesis and includes all terrestrial plants used for food, feed, fibre and fuel wood. All plants in natural and conservation areas (as well as algae and other aquatic plants growing in ponds, lakes, oceans or artificial ponds and bioreactors) are also considered primary biomass. Examples of primary biomass feedstocks currently being used as energy crops for bioenergy include: grains, oilseeds, miscanthus, switch grass, willow, sugar beet for ethanol, etc. Examples for primary residues (at the source) are: beet tails, straw, grass verge, wood pruning, greenhouse waste, etc.
2. *Secondary biomass feedstocks* differ from primary biomass feedstocks in that the secondary feedstocks are a by-product of processing of the primary feedstocks, available later in the production chain. In this case, processing means that there is substantial physical or chemical breakdown of the primary biomass and production of by-products; processors may be factories or animals. Specific examples of secondary biomass include potato peelings, beet pulp, brewers' spent grain, sawdust from sawmills, waste wood from the wood-processing industry, black liquor and cheese whey. Manures from concentrated animal-feeding operations are collectable secondary biomass resources. Oilseed cake, cocoa shells, coffee grounds, vegetable waste, fish waste and residual fats are also secondary biomass resources.
3. *Tertiary biomass feedstock* includes postconsumer residues and wastes, such as slaughter waste, used oils, construction and demolition wood debris, packaging wastes, vegetable, fruit and garden waste, municipal solid wastes and landfill gases.

When using biomass feedstocks, it is important to know their properties. Several characteristics affect the performance of biomass waste as fuel, including the calorific value, chemical composition, moisture content, and size and density of the fuel. These characteristics can vary noticeably from fuel to fuel.

The calorific value, or amount of heat available in a fuel (MJ/kg), is one of the most important characteristics of a feedstock because it indicates the total amount of energy that is available. The calorific value in a given feedstock type is mostly a function of the feedstock's chemical composition. The calorific value can be expressed in one of two ways: the gross or higher heating value or the net or lower heating value. The higher heating value (HHV) is the total amount of heat energy that is available in the fuel, including the energy contained in the water vapour in the exhaust gases. The lower heating value (LHV) does not include the energy embodied in the water. In addition to heat content, other differences in fuel performance are related to composition of the various feedstocks. The three most significant compositional properties are (1) ash content, (2) susceptibility to slagging and fouling and (3) percent volatiles.

Ash content (the mass fraction of incombustible material) is an important parameter, with grasses, bark and field crop residues typically having much higher amounts of ash than wood. Systems that are designed to combust wood can be overwhelmed by the volume of ash if other types of biomass are used, which can reduce the combustion efficiency or clog the ash handling mechanisms. Slagging and fouling are problems that occur when the ash begins to melt, causing deposits inside the combustion equipment.

The percent volatiles in a fuel is a less commonly known property that refers to the fraction of the fuel that will readily volatilise (turn to gas) when heated to a high temperature. Fuels with high volatiles will tend to vaporise before combusting (flaming combustion), whereas fuels with low volatiles will burn primarily as glowing char. This property affects the performance of the combustion chamber and should be taken into account when designing a combustor (Ciolkosz 2010).

Fresh, green wood is often about half water and many leafy crops are primarily water. A low moisture level in the fuel is usually preferable because high-moisture fuels burn less readily and provide less useful heat per unit mass (much of the energy in wet fuel is used to heat and vaporise the water). Extremely dry fuel, however, can cause problems such as dust that fouls equipment or can even be an explosion hazard. The size and density of the biomass fuel particles is also important. They affect the burning characteristics of the fuel by affecting the rate of heating and drying during the combustion process. Fuel size also dictates the type of handling equipment that is used. The wrong size fuel will have an impact on the efficiency of the combustion process and may cause jamming or damage to the handling equipment. Fuel size and density are probably the most overlooked factors

affecting fuel performance and should be given careful consideration when selecting a fuel type (Ciolkosz 2010).

A preliminary assessment of a feedstock can often be carried out using standard data available in the literature. One of the commonly used free sources of information is the Phyllis database.[17] The database contains information on the composition of biomass and waste. From the database one can obtain analysis data of individual biomass or waste materials or average values for a group of materials. Each data record with a unique ID-number shows information (if available) on:

- type of material (group)
- subgroup
- proximate analysis: ash content, water content, volatile matter content, fixed carbon content
- ultimate analysis: carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, fluorine and bromine
- biochemical composition
- calorific value
- (alkali)-metal content
- composition of the ash
- remarks (specific information).

For each data record the source (reference) is indicated. In the database three types of weight units are used:

- As received (ar): weight percentage from the material in its original form (including ash and moisture)
- Dry: weight percentage from the dry material (including ash)
- Dry and ash free (daf): weight percentage from the dry and ash free material.

Table 5 presents the Phyllis data for cocoa husks, palm oil kernel shells and coffee husks.

In terms of biogas production, similar databases are available to help understand the methane

Figure 20: Extract from Phyllis biomass database (ECN 2012)

17. Now in its second revision, available from www.ecn.nl/phyllis2/

Table 5: Properties of cacao hulls and palm oil kernel shells and coffee husks (ECN 2012)

Property	Unit	Cocoa husks			Palm oil kernel shell			Coffee husk		
		Value			Value			Value		
		ar	dry	daf	ar	dry	daf	ar	dry	daf
Proximate analysis										
Moisture content	wt%				21.4			10.1		
Ash content	wt%		8.2		3.4	4.4		2.2	2.5	
Volatile matter	wt%		67.9	74.1				74.8	83.2	85.3
Fixed carbon	wt%		23.8	25.9				12.9	14.3	14.7
Ultimate analysis										
Carbon	wt%		48.2	52.6	36.7	46.7	48.8	44.4	49.4	50.7
Hydrogen	wt%		5.2	5.7	4.6	5.9	6.1	5.5	6.1	6.3
Nitrogen	wt%		3.0	3.2	0.8	1.0	1.1	0.7	0.8	0.8
Sulphur	wt%		0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.1
Oxygen	wt%		33.2	36.2	33.0	42.0	43.9	37.0	41.2	42.3
Total (with halides)	wt%		98.0	97.8	100.0	100.0	100.00	100.1	100.1	100.1
Calorific values										
Net calorific value (LHV)	MJ/kg		17.9	19.5	14.0	18.5	19.3	16.9	19.1	19.6
Gross calorific value (HHV)	MJ/kg		19.0	20.7	15.5	19.8	20.7	18.3	20.4	20.9
HHVMilne	MJ/kg		18.9	20.6	14.5	18.4	19.3	17.8	19.8	20.3

production characteristics of a potential feedstock/substrate. A key reference is the Online European Feedstock Atlas,[18] which compiles the currently available information on gas yields of 225 different feedstock for biogas production across three categories: energy crops, livestock manures and residues (Figure 21). It also includes the ability to estimate methane costs and predict methane production based on local feedstock data if these are known. For specific feedstocks that cannot be found in central databases, for example feedstocks that may be less common or novel in application, then this information must be either by looking at pilot applications or testing elsewhere, or conducting local testing of a sample. Good practice dictates that proposed feedstocks are tested as part of the pre-feasibility assessment in order to determine gas yields, a critical aspect of project design and feasibility.

It can be observed that the selection of an appropriate biomass technology is dependent on the characteristics of the feedstock and application, something discussed more in the following section. Looking at similar projects in other countries can give a good indication of what is possible. Similarly, buying an effectively off-the-shelf system for a given feedstock can also simplify selection. However, there are few firm rules for the final design of the system and appropriate expertise should be sought where possible.

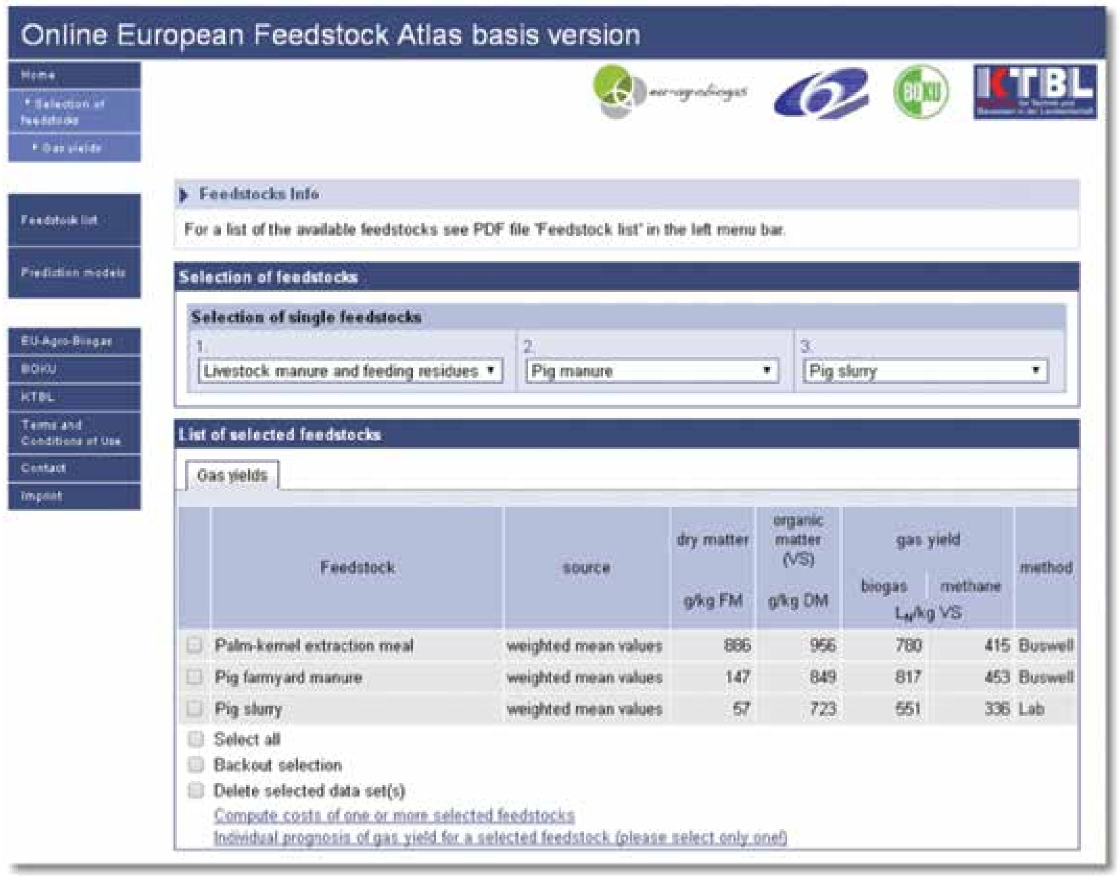
Further resources

ECN (2012): Phyllis2 Database for biomass and waste

EU-AGRO-BIOGAS (2010): Online European Feedstock Atlas for biogas potentials

18. Available from: http://daten.ktbl.de/euagrobiogasbasis/

Figure 21: Extract from Online European Feedstock Atlas for biogas potentials



5.2.2 Technology

Selecting and designing conversion processes for WtE projects is a technical skill and requires a certain level of expertise and familiarity. A first step for those seeking to understand project feasibility is to look for similar cases or projects, ideally in an analogous context. This can be the most practical way to understand design requirements and challenges. Beyond this, a number of general insights can be made on technology suitability for different feedstocks and the need for additional processing (beyond the primary conversion process).

Conversion technology: Is there an appropriate bioenergy technology?

Many bioenergy routes can be used to convert raw biomass feedstock into a final energy product (Figure 22). Several conversion technologies have been developed that are adapted to the different physical nature and chemical composition of different feedstocks, and to the energy service required (including heat, power, transport fuel).

The production of heat by the direct combustion of biomass is the leading bioenergy application throughout the world and may be cost-competitive with fossil fuel alternatives in many contexts; particularly off-grid when electricity supply costs can be high. Technologies range from rudimentary stoves to sophisticated modern appliances. For a more energy efficient use of biomass waste, modern, large-scale heat applications are often combined with electricity production in combined heat and power (CHP) systems.

Different technologies exist or are being developed to produce electricity from biomass waste. Co-combustion (also often referred to as co-firing) in coal-based power plants is the most cost effective use of biomass for power generation. Dedicated biomass combustion plants, including MSW combustion plants, are also in successful commercial operation, and many are used in industrial or district heating CHP facilities.

For sludge, liquids and wet organic materials, anaerobic digestion is currently the best-suited option for producing electricity and/or heat from biomass, although its economic case relies heavily on the availability of low cost feedstock. All these technologies are well established and commercially available. There are fewer examples of commercial gasification plants and the deployment of this technology is affected by its complexity and cost. In the longer term, if reliable and cost-effective operation can be more widely demonstrated, gasification promises greater efficiency, better economics at both small and large scale and lower emissions compared with other biomass-based power generation options (IEA 2009). This makes it particularly interesting for smaller scale off-grid applications for small- to medium scale industrial uses and village grids.

Figure 22 gives a sense of the potential complexity of bioenergy project design, although in practice certain feedstocks are more commonly used with certain conversion processes. Based on the combinations of feedstocks and conversion routes, presented in Figure 22, the following waste feedstocks can be converted via anaerobic digestion, combustion and gasification.

Anaerobic digestion

- Sugar and starch crops
- Lignocellulosic waste biomass (waste wood, straw, MSW)
- Biodegradable MSW, sewage sludge, manure, wet wastes (farm and food wastes such as industrial wet waste from agro-processing plants), coffee grounds, palm oil mill effluent

Combustion in combination with biomass upgrading (e.g. pelletisation, pyrolysis, torrefaction)

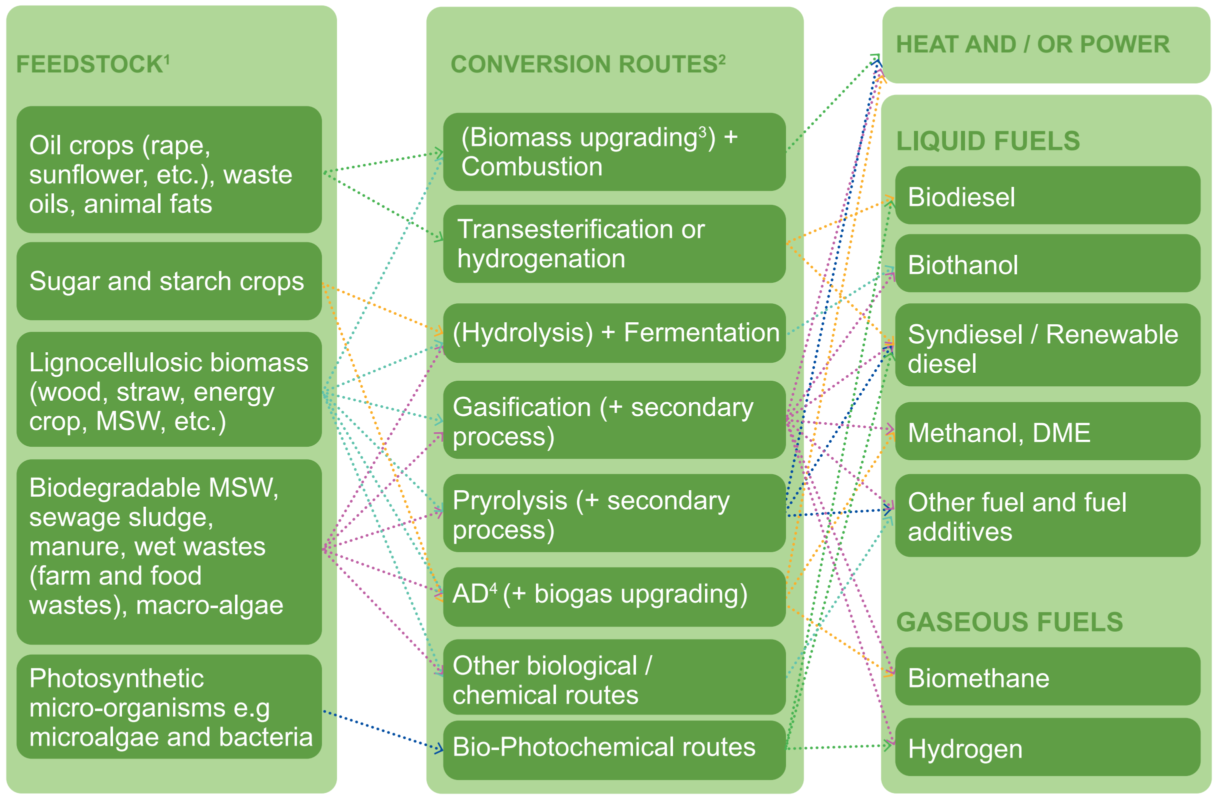
- Waste oils, animal fats
- Lignocellulosic waste biomass (waste wood, straw, MSW, cacao shells, palm oil kernel shell and similar)

Gasification (+ secondary process)

- Lignocellulosic waste biomass (waste wood, straw, MSW, cacao shells, palm oil kernel shell and similar)
- Biodegradable MSW, sewage sludge, manure, wet wastes (farm and food wastes; such as industrial wet waste from agro-processing plants), coffee grounds

Process: Is pre- or post-processing required?
The need for pre-and post-processing depends on the feedstocks, applications, conversion options and end-use markets that are under consideration. A variety of pre-processing and post-processing options can be considered as part of the bioenergy system. The pre-processing options can include various methods for drying, cleaning and/ or compressing biomass. The post-processing options generally involve various types of refining, filtering or other methods to

Figure 22: Schematic view of the wide variety of bioenergy routes (IEA 2009)



1 Parts of each feedstock, e.g. crop residues, could also be used in other routes
2 Each route also gives co-products
3 Biomass upgrading includes any one of the densification processes (palletisation, pyrolysis, torrefaction, etc.)
4 AD = Anaerobic Digestion

adjust the product to the desired applications. Although it is not possible to define specific rules that determine when pre-or post-processing is necessary, there are some general reasons for considering pre-and/or post-processing:

- Reducing the moisture and increasing the energy density of the waste biomass, making it more valuable and reducing the costs of transport, thereby extending the spatial range of applications
- Removing impurities and/or non-combustible elements
- Improving the uniformity of feedstock and thus its quality and reliability
- Tailoring the final product for particular markets and applications.

The bulk density of solid biomass waste is a major factor in organising the logistics and transport aspects of WtE systems, as it determines cost, feasibility and the extent to which pre and post-processing are needed. The low bulk density of agricultural and forestry wastes such as straw and wood chips results in high costs for transport and/or the need for pre-processing. Essentially, pre-processing is generally used to improve the quality and/or increase the energy density of biomass.

Post-processing is generally used to adjust the characteristics in favour of particular end-uses or applications. Some examples are listed below:

- *Pelletisation:* creates a uniform product of higher energy density that is more easily traded
- *Refining/cleaning:* removes impurities and otherwise upgrades energy density and ease of use
- *Charcoal production:* removes moisture and increases the energy density
- *Torrefaction:* a form of pyrolysis that makes higher-quality fuel by drying and removing impurities; eating reduces the mechanical strength of the biomass so that less energy is required to densify or pulverise it for co-firing (Knoef 2012).

As noted earlier, it can often be a wise course of action to look at similar projects in other locations (or even countries) when designing a new biomass waste project. This could also give an indication regarding suppliers of the technology, which may be a key factor in deciding on a certain process or size of installation. Ideally, technology is proven, available locally (or at least conveniently) and requires little modification from its previous design specifications. These factors may not be able to be satisfied for many projects, but understanding what is available from different suppliers can be a useful starting point for scoping a design.

There is no single, recently updated resource that provides a comprehensive overview of technology providers and their products. A 2009 publication produced a long compendium of technologies for converting agricultural biomass into energy products (UNEP 2009), but its length and age make it less relevant to a practitioner today. The choices available to a project developer for supplier selection once again suggest the value in obtaining expert assistance.

There are two specific recommendations to consider regarding supplier selection for off-grid and mini-grid projects (Box 3); to use a quality supplier and plan for the availability of spares. Both relate to remote location of most of these projects, as well as the limited technical capacity that the owners/operators will have in terms of maintaining the facilities.

5.2.3 Logistics

Location: Is the distribution of feedstock suitable for my project?
The distance between the feedstock source and the WtE plant should be as short as possible. Long transport distances and associated transport costs have negative impacts on the economics of WtE plants (IEA Bioenergy 2013). The ideal situation is when a large volume of suitable residues or waste products is produced at a single site, for example food processing or large animal farms. In such instances the volume can be sufficient to justify a dedicated bioenergy system with low or negligible transport costs. However, in many instances feedstock will need to be collected from a number of sites and brought to a central facility. This may or may not involve some kind of pre-processing of the waste to make its transportation more efficient.

It is therefore important to understand the distribution of feedstock in the local area, what type of transport could be used, what type of pre-processing might be needed and their costs. All of these factors will influence the costs of feedstock delivery to a plant and depending

Box 3: Recommendations for supplier selection for off-grid applications (Cu Tran 2013)

Avoid cheap and low quality equipment for rural electrification projects. It is common to see off-grid projects using relatively inexpensive, but low-quality, equipment to reduce initial investment and generation costs. While the initial investment for low-cost equipment may be lower, generation costs are most probably higher in the long run. Low quality leads to unreliable supply of electricity, low plant load factor due to regular shutdowns for system maintenance and an increase in operation and maintenance costs over the project lifetime. In many cases these issues have led to the failure ofmade rural electrification projects.

Take into consideration the spare parts supply when selecting the technology for off-grid power systems. Unreliable or costly supply of spare parts for off-grid rural electrification projects is one of the main causes of project failure. The availability and costs of spare parts need to be included in the economic and financial analysis to select the most appropriate technology for off-grid electrification.

on volumes and characteristics this can be a significant proportion of the overall feedstock cost. A detailed example is provided in Figure 23 which attempts to map supply costs versus transport distance based on a minimum loading and unloading cost. The very top line shows that the delivered feedstock costs increase with transport distance.

It is difficult to provide rule of thumb figures for transport distances as this will depend on local infrastructure, transport costs and feedstock needs. Epp et al. (2008) attempt to provide such figures for biogas applications, suggesting that it is not feasible to transport feedstock such as animal slurries further than 5 km and energy crops further than 15 km, but this number should be considered as indicative only as local circumstances may reduce or increase this distance.

Storage: Can the necessary storage be provided?[19]
Storage is an important element of a reliable feedstock supply and helps compensate for seasonal fluctuations; it may also be used to blend different feedstocks. The type of storage facility depends on the feedstock used. Storage facilities can be bunker silos for solid feedstock, often covered with plastic sheets to minimise environmental exposure, and storage tanks for liquid feedstock, frequently used for liquid manure and slurries. Usually, bunker silos have a storage capacity of more than one year's worth of feedstock supply, while for storage tanks it is usually several days (particularly as these types of feedstock sources typically don't have the same seasonal fluctuations).

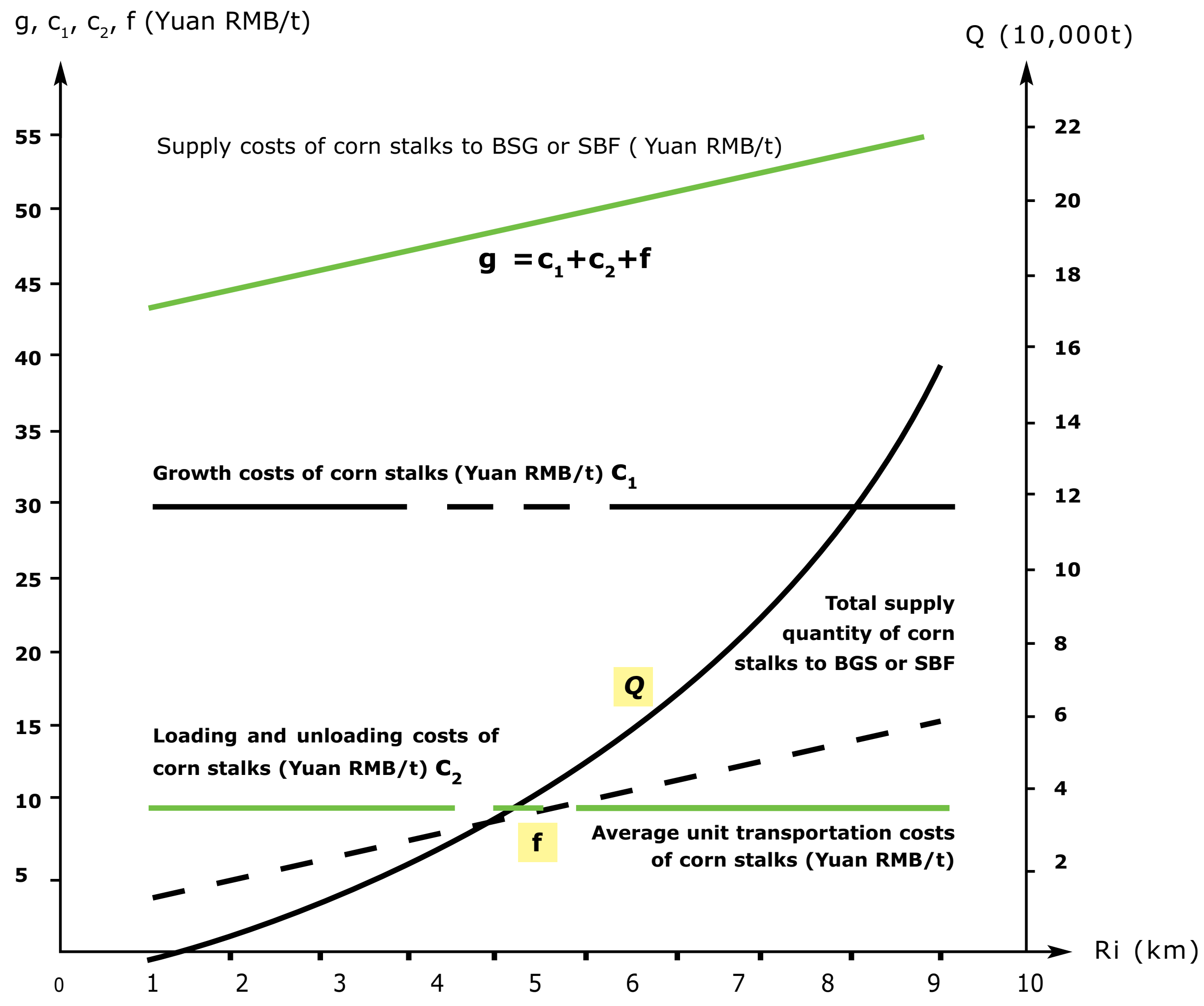
The dimensioning of storage facilities is determined by the quantities to be stored, delivery intervals and the daily amounts fed to the plant. Depending on the concept, feedstock storage facilities as well as digestate storage facilities (for biogas) may be located at a bioenergy plant or decentralised in the agricultural surroundings of the plant (which is more often the case for digestate storage). Plants that operate on a just-in-time delivery, for example plants continuously using manure or MSW, need smaller areas. Moreover, the produced waste products (e.g. ash) or useful by-products (e.g. digestate) require storage facilities. In many countries, digestate and any other fertilisers can only be applied during the vegetation season and must therefore be stored during winter in specially established storage facilities that can be significant larger than the bioenergy plant itself.

Finally, every bioenergy plant, including WtE plants, needs equipment for measuring mass flows; this usually includes truck scales or mass flow meters for pumpable feedstock. The inputs and outputs of bioenergy plants need to be measured for management of revenue. It is also generally mandated to keep records of the mass flows for electricity feed-in tariff systems or for gate fees for waste treatment.

Location: Is there a suitable location for the biomass plant?
The choice of location for setting up a bioenergy plant is primarily determined by the availability and logistics of feedstock. Distances of feedstock supply and road access are the main elements to consider when selecting the location of a WtE plant. Along with these, other general aspects

19. Adapted from IEA Bioenergy (2013)

Figure 23: Example of a detailed analysis of quantity and cost of corn stalks in a province in China showing transport costs (Cai 1998 in UNDP 2000)



that should be considered include (IEA Bioenergy 2013, Kant and Shuirong 2011):

- the size and ownership of the property
- classification of the property in official spatial plans
- legal aspects, including the required permits
- dedicated characteristics of the site
- access to necessary infrastructure
- opportunities to sell heat
- vicinity to neighbours
- competition with other biomass plant operators and farmers
- biodiversity and wildlife conservation
- energy security.

Potential sites for WtE plants should ideally be owned by the plant operator or operating company. Often, this is also a precondition of investors and financing bodies. Long-term land leasing contracts may be also an option. If the site is already owned by the proposed plant operator (e.g. a farmer), the existing infrastructure (e.g. sheds etc.) may be used for the WtE plant and may improve the economics of the facility (IEA Bioenergy 2013).

Further resources

IEA Bioenergy (2013): The biogas handbook

Kant and Shuirong (2011): Model for Optimizing Site Selection for Biomass Energy Systems in the Himalayas

5.2.4 Sustainability

Biomass waste systems can have a large interaction with their surroundings, both in terms of socioeconomic and environmental impacts. However, these interactions are often lower for waste-based projects than for dedicated energy crops. In addition, it can be important to understand what the GHG impact of a project will be, as this can vary widely depending on the type of technology and implementation.

The use of biomass waste streams will generally guarantee that a project is broadly sustainable from a natural resource and GHG perspective, i.e. there is no net loss of carbon stocks / biodiversity in order to obtain the biomass, because it is obtained as a waste product from something that was renewably grown for other reasons.

Social: Is the project aligned to local interests?
A number of factors need to be taken into account to ensure that projects respect the rights of local land-owners, residents and traditional users of residues that may be planned for bioenergy conversion. Bioenergy projects are somewhat special in this regard as so-called up-stream issues, such as where residues and waste are sourced from and how, can have impacts on the appropriateness of a project, in a way that doesn't impact most conventional forms of electricity generation (UNDP 2000). Below are some key aspects that need to be considered in developing a WtE project. It is important to note that a waste-based approach to bioenergy development inherently avoids the major issues of land use competition and land tenure that can be highly contentious for dedicated energy crops that may replace other types of crops.

Current uses of feedstock residues
As noted earlier, it is rarely the case that a residue or waste stream is being produced and simply discarded. These streams often represent a traditional resource for local farmers, nearby households or industry to utilise. An example of a waste stream that turns out to have implications for local communities could be animal manure that is used as an effectively free resource for cooking. By giving a value to the collection of the manure it becomes unavailable to those that had come to rely on it for basic services.

It is therefore vital to understand the existing flows of biomass resources within a community, based on data and observations obtained with the assistance of local people. Only after carrying out a thorough biomass resource assessment is it possible to consider options for supplying a bioenergy project (UNDP 2000). This can impact local acceptance/appropriateness of a project, prices for feedstocks (due to competition for their use) and availability of feedstocks over time.

Local involvement
Another aspect to consider is whether the local community leads/owns, has a share in or provides input to the development of the project. Projects are more likely to be developed in an appropriate way if a local institution is involved

Equally the role of locals in terms of supplying feedstock and labour needs to be considered. In most rural areas, at most times of the year, unemployment or underemployment is common. Bioenergy projects will support development only to the extent that they expand employment opportunities and find ways to involve locals in appropriate ways (for example, recognising potential seasonal availability of labour). Additionally, trusting market forces for independent projects may not always give the best results. In particular, farmers who supply feedstock need to be able to negotiate fair terms of trade and workers need to have basic protections as labourers (UNDP 2000).

The Bioenergy Primer from UNDP (2000) expands considerably on the above ideas, as well as the need to consider aspects such as the participation of women and the impacts on rural enterprises.

Productive use
Finally, for small-scale off-grid projects in particular, it is important to take advantage of any opportunity to initiate or enhance productive activities as they significantly increase the prospects for long term project sustainability (WB 2008). This can include improved productivity and increased use of electricity by existing productive users (mills, manufacturers, etc.) or an increased number of newly established productive users.

Further resources

UNDP (2000): Bioenergy Primer: Modernised Biomass Energy for Sustainable Development – Chapter 3

Environmental: Will the project meet local environmental requirements?

As with social considerations, the use of residues and waste streams as a feedstock greatly reduces the likelihood of severe environmental impacts; for example, land is not cleared for energy crops. However, there are still a number of aspects that must be considered in the design of a bioenergy project to ensure that they are sustainable and environmentally appropriate. That being said, these impacts have to be viewed in comparison with the likely alternative uses for these residues and wastes. In some instances the treatment of residues through a bioenergy conversion process can have environmental benefits.

In developing a bioenergy strategy or project the following aspects, among others, should be considered, depending on the type of process:

- *Air quality:* The combustion of biomass for electricity production, while significantly cleaner than most traditional uses, such as for fuel, still needs attention in terms of particulate emissions and air quality.
- *Disposal of process waste:* The leftover ash or waste products from a bioenergy project need to have a suitable disposal plan or method of treatment.
- *Digestate treatment:* The by-products of biogas production need appropriate storage and treatment processes to prevent soil, air and water pollution. Even without issues of leakage, digestates will often need to meet certain standards or levels of heavy metals, other inorganic contaminant or pathogens. Issues of odour may also need to be considered.
- *Soil quality:* The most direct way that bioenergy systems affect soil nutrient cycles is by removing nutrients when biomass feedstock is harvested from the field, interrupting the natural process by which decomposing plant matter would replenish soil nutrients. Especially in the case of rapid-growth bioenergy crops and complete removal of agricultural residues, there is a concern about depletion of nutrients and decline in soil fertility (UNDP 2000).
- *Water consumption:* Depending on the need for substantial volumes of water in a process, the availability and possibility of contamination may need to be considered.

Further resources

UNDP (2000): Bioenergy Primer: Modernised Biomass Energy for Sustainable Development – Chapter 4

Carbon: Will the project provide a reasonable mitigation impact?
Although energy from biomass residues is a renewable resource, it is still important to understand the lifecycle emissions from any new facility, as a number of factors can determine the efficiency of the carbon reduction that is achieved and these are often technology dependent. These include:

- emissions from construction and operation of the bioenergy plant
- feedstock used
- offset electricity and/or heat that would normally be produced from fossil fuel sources
- conversion efficiency and flue emissions if present
- emissions from any by-products, such as digestate from a biogas plant, versus non-sustainable products they might replace (e.g. standard fertiliser)
- avoided emissions (typically from methane) from using the residues
- escaped methane emissions from biogas plants.

Although mitigation is not the driving force behind many bioenergy projects, and may not be a critical issue in determining project viability, it is often required for incentive schemes or for support from international sources. There are a number of online resources and calculators available for different circumstances. Listed below is a tool to help users choose the appropriate methodology for performing GHG calculations for different bioenergy applications.

Further resources

FAO/GBEP (2011): Clearinghouse on GHG methodologies

5.2.5 Financial

Viability: Is the project financially viable?
The question of financial viability is relevant to any private project that will be profit driven. This will be the case for the vast majority of on-grid projects and large scale projects but will also apply to certain off-grid projects. In these instances a private company invests in an off-grid rural electrification project where it seeks to make a profit. However, the generally low ability to pay for rural customers and the higher costs in providing energy services, mean that few electrification projects are completely privately funded. Instead they will rely on public funding or a combination of public and private (Box 4).

Determining financial viability is primarily governed by the costs (such as loan repayments and operation and maintenance costs) and revenues (the payments incoming for the provided energy services). Ultimately, the question becomes, does the project return an appropriate profit? It is an essential part of the business case that needs to be presented to investors/banks to secure financing but also for Power Purchase Agreement (PPA) negotiations for grid connected plants. A financial viability analysis usually involves collecting necessary input data, applying a financial tool and performing a sensitivity analysis.

Identifying relevant costs and revenues

Identifying relevant costs and revenues for the project and constructing cash-flow tables is the first major step. It usually involves answering the questions below. IRENA (2012)[20] provides a good initial resource for generic estimates of the relevant costs.

- What are the capital costs? This includes construction and pre-operation costs such as final engineering and design, construction and land acquisition, as well as planning costs related to pre-feasibility and permitting.
- What are the operations and maintenance costs? These include overheads for the facility -- energy, water and material costs -- as well as maintenance costs typically estimated as both a fixed and variable percentage of capital costs.
- What are the fuel costs? This includes the cost of feedstocks, transport, pre-processing and volumes.
- What are the plant operating parameters? These are the technical characteristics of the plant that determine what products are produced, such as expected full load hours, conversion efficiency and rates of production of by-products.
- What are the unit selling prices? i.e. what are the expected tariffs for electricity generation, process waste and by-products? This should take into account any government incentives or support.
- What are the financial parameters associated with the project? Such as debt terms, debt equity ratio, applicable taxes and depreciation rules. This should take into account any government concessions provided to renewable energy projects or biomass waste projects.

In the case of WtE, the most significant cost is often the feedstock supply. The cost of feedstock supply needs to be assessed locally. As a rough indication of the order of magnitude, Table 6 provides costs for selected agro-forestry residues in Brazil and India.

Moreover, feedstock costs and supply are more uncertain in comparison to the capital costs, hence more of the investment risk relates to reliable feedstock supply at a predictable price (FAO/UNEP/UN-Energy 2008). It is therefore important that a number of mitigating factors are considered in the design of a facility, be these alternate sources or feedstocks or sufficient storage capacity, as discussed in the preceding section.

The other key financial risk that many WtE projects face is demand for their main products and by-products (FAO/UNEP/UN-Energy 2008). In the case of grid-connected electricity generation, this is less of an issue, as these arrangements will be governed by long-term power purchase agreements (PPAs) or similar with a utility. However, for off-grid applications it is important to consider how that project could change over time, for example through grid-connection of the previously unconnected area. Biogas projects, which can produce a saleable residue or fertiliser should also consider the risks of changes in demand and price for that product, especially if it is an important aspect of making the project feasible.

Risks such as these are best considered through a comprehensive sensitivity testing of the various financial parameters as discussed below.

Application of a financial decision making tool
Once information has been gathered regarding costs and revenues, a variety of different financial decision making tools can be applied. The use of different tools depends on a particular investor's preferences. Three of the most prevalent appraisal tools utilised by firms include break-even analysis, Net Present Value (NPV) analysis and Internal Rate of Return (IRR) analysis (Graham and Campbell 2001).
See Table 7.

Sensitivity analysis
A sensitivity analysis is also commonly utilised to assess the impact of variation in the assumptions about the costs and revenues. This is particularly important for biomass waste projects, where feedstock costs can represent 40-50 per cent of the total cost of electricity produced by biomass technologies (IRENA 2012). Typical sensitivity analyses include what-if scenario development

20. IRENA (2012) Renewable Power Generation Costs in 2012: An Overview. Study. Taken from website: https://www.irena.org/DocumentDownloads/Publications/Overview_Renewable%20Power%20Generation%20Costs%20in%202012.pdf

Box 4: Financing off-grid biomass waste projects (Cu Tran 2013)

Public power utility financing is commonly applied for rural electrification through grid-extension. In recent years, public power utilities are increasingly obligated by legislation to invest in off-grid rural electrification in order to reach all un-electrified households.

The public power utilities (e.g. PLN in Indonesia, EVN in Vietnam) are investing in off-grid rural electrification projects using their equity capital and (soft) loans from local and/or international financing institutions, thereby cross-subsidising rural electrification activities and - in some cases - creating business cases for private developers.

This financing mechanism/cross-subsidy results in affordable electricity tariffs for rural villagers. The project revenues are usually used for paying operation and maintenance costs of the project but are not sufficient for reinvesting in expansion of the project or new projects. Government financing is usually used for projects that are not commercially viable. These projects rely on government budget, international/local grant (Official Development Assistance, ODA), and/or local/international long-term soft loans for financing the projects.

Projects are tendered and commonly realised by private developers or NGOs. The developers are responsible for developing and constructing the off-grid power system and, after its commissioning, usually hand over the ownership and responsibility for operation and maintenance to a local community-based entity such as village electrification committee, community cooperatives, etc.

Government financing can offer low, affordable electricity tariffs to rural villagers. However, the investment is hardly paid back. In some cases, subsidy is even required to pay for operation and maintenance costs. The project setup and implementation often takes a long time due to the complexity of project arrangements and coordination between the numerous public and private actors involved.

In addition, government financing depends on the availability of budget which is regular subject to re-negotiation and political interests and therefore predictable only to a limited extent.

A *Public Private Partnership* (PPP) combines the advantages of the private and the government financing mechanisms. It can offer lower tariffs of electricity, reduce the time for project setup and implementation and ensure sustainability through the inclusion of a business case.

Investment in off-grid power facilities can be jointly or separately made. However, the operation and maintenance of the whole power system is usually done by the private partner. In most PPP off-grid rural electrification projects, financial incentives such as direct and indirect subsidies are applied.

The key is to design financial incentives that are effective (triggering actual market activity), targeted (leading to the electrification of poor households) and cost-effective (achieving electrification at the lowest costs).

Subsidies – for example investment, connection, output or operation subsidies – are regularly provided by the government or international partners in order to ensure financial viability for the project developers/investors and affordability for the costumers at the same time (see Cu Tran 2013 for more details).

Table 6: Cost of selected biomass waste streams in Brazil and India (Rodrigues 2009, UNFCCC 2010)

USD/GJ	Heat value (kJ/kg)	USD/GJ	USD/tonne
Bargasse	5,600 – 8,900	1.30 – 2.30 1.40 – 2.50	11 – 13 (Brazil) 12 – 14 (India)
Woodchip	7,745	9.30	71 (Brazil)
Charcoal mill	18,840	5.30	95 (Brazil)
Rice husk	12,960	-	22 – 30 (India)

Table 7: Decision making tools

Decision making tool	Description	General decision rule	For WtE projects
Break-even analysis	How many years does it take to recoup the investment?	Accept if number of years to pay-back capital less than maximum desired	Investors often tend to seek a short payback period of 2-4 years which favours conversion plants with low capital cost, albeit usually with a high fuel cost (IEA 2007).[21]
Net Present Value (NPV) analysis	Determines discounted net rate of return of the project	Accept if NPV > 0	A key variable is the discount rate. Typically projects are financed with debt and equity, so the Weighted Average Cost of Capital is used. In Germany, typical WACC (nominal) is 6.4%[22] - in developing countries this will be higher, given increased risks and increased costs of borrowing. IRENA (2012) indicates a global cost of capital in the order of 10 per cent.
Internal Rate of Return (IRR) analysis	What kind of % return does the project bring?	Accept if IRR greater than cost of capital	IRR should be above cost of capital, i.e. the minimum required return on invested/borrowed capital.

(e.g. What-if feedstock prices double?), and Monte-Carlo analyses. Given the sensitivity of biomass projects to feedstock costs, basic what-if sensitivity analysis is recommended.

Determination of financial viability can be complex, requiring significant data gathering and expertise on determining appropriate input variables – which usually necessitates engaging an appropriate expert. At the pre-feasibility stage it is often sufficient to undertake a simplified analysis, for which a variety of tools are available online. For example, the so-called RETScreen (2013) tool is a free clean energy decision-making software along with tutorials and example projects with supporting data. SNV and ECN are jointly preparing a financial assessment tool specifically for bioenergy projects that will be made available in 2014.

Further resources

RETScreen (2013): RETScreen Clean Energy Project Analysis Software

IRENA (2012): Renewable Power Generation Costs in 2012: An Overview. Study

AfDB (2006): Guidelines and Financial Analysis of Projects

Owens (2002): Best Practices Guide: Economic & Financial Evaluation of Renewable Energy Projects

Cu Tran (2013): ASEAN Guideline on Off-grid Rural Electrification Approaches

Financing: Is the project financially feasible, i.e. can finance be raised?
Demonstrating appropriate profit and financial viability is only one aspect of a successful financial design for a biomass waste project. It is also important that the necessary capital can be raised to implement the project. This question could be thought of as financial feasibility.

In the case of public projects, or publically subsidised projects (at least when the subsidy relates to upfront costs), this question may be easier to answer. If the project is a private one, with public contributions, then these subsidies would be considered in the financial structure of the project as another financial input.

The type of financing usually varies with the stage of the project (see below). In the early stages, the developer or owner's equity (often in the order of 20-30 per cent of project costs) usually covers all of the costs. These include studies such as pre-feasibility, feasibility and detailed design, as well as permitting and negotiation of legal contracts. A bank or a Development Finance Institution (DFI) will then enter with construction finance, which covers the construction period, commissioning and the first year(s) of operation. Once the asset is proven, it is common that refinancing of the asset occurs, given the higher rates of interest generally provided for construction finance. As hinted at above, the level of investment that will be needed to establish a bioenergy project does not only include costs associated with plant construction, operation and fuel purchase but also for obtaining the necessary consents and negotiating the relevant legal contracts (IEA 2007).

Securing construction finance can be challenging in countries with poor investment climates, for example banks that are unfamiliar with biomass technologies, which offer excessively high interest rates or only lend for short terms. However, a variety of financing channels may be available for WtE projects in these countries (see Chapter 7).

The Global Bioenergy Partnership offers a tool to facilitate access to financing for bioenergy in developing countries (FAO/GBEP 2011). It provides a comprehensive collection when assessing different financing opportunities for bioenergy projects and programmes, giving a clear picture of selection criteria and bioenergy project characteristics that should be fulfilled to receive financing.

Further resources

FAO/GBEP (2011): Financing options for bioenergy projects and programmes

Climate Funds Update

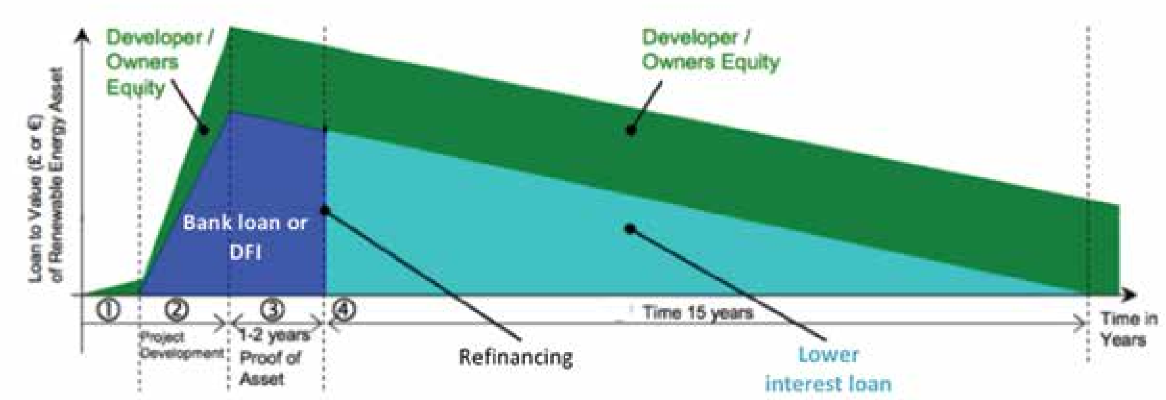
Climate Finance Options

5.2.6 Regulation / policy

Regulatory constraints to project development must be carefully observed and planned for, whether it is an on- or off-grid project. Typically, on-grid projects will face a much more substantial burden in order to receive the necessary permissions to operate and sell electricity.

Permitting: Can the necessary permits be obtained?
A variety of different permits are required in the process of developing a WtE plant. The list of permits varies from country-to-country and depending on the plant scope and size. Therefore not all projects will experience the same issues relating to their planning and development. In order to provide some guidance as to the kind of permits that may be required, Box 4 lists the main bioenergy permitting procedures in the European Union. This is likely to be

Figure 24: Stage of a project and different types of financing (adapted from CBI 2009)



21. IEA (2007) Bioenergy Project Development & Biomass Supply – Good Practice Guidelines. http://www.iea.org/publications/freepublications/publication/biomass.pdf
22. Fraunhofer ISE (2013) Levelized cost of electricity for renewable energy technologies. Study. http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf

more extensive than for many other country contexts where bioenergy projects are less well established but gives a sense of what a project developer should look for. The costs of obtaining necessary permits for the project consist of the opportunity costs for the project developer (determined by the project duration), the administrative fees and the costs to contract a consulting agency to prepare the documents and apply for the permits (or opportunity costs in case of in-house services). According to Belfiore et al. (2009) in terms of a percentage of the total development costs, between 5 per cent and 14 per cent is a typical range. In terms of time, large-scale developments may take years to get all permissions approved, showing that this task should be started from the outset.

Larger off-grid projects (for example for industrial users) will most likely be subject to the same permitting requirements as grid-connected projects. For isolated mini-grids or stand-alone systems, however, such requirements should be considerably less stringent, depending of course local context. For example, operators of systems below 300 kW may only have to register once and provide an annual update of basic information (WB 2008).

Regulation: Can independent parties generate electricity and connect to the grid?
Whether the project comprises a dedicated generation facility, undertaken as a stand-alone project, or the sale of electricity from a commercial/industrial consumer that is generating on-site and is looking to export its excess generation to the grid, it is important that the local regulations allow for connection and electricity sales. In non-liberalised electricity markets this is not always the case, or, even if the regulations are in existence there may be little experience in their application. It is therefore important to confirm that appropriate rules and capacity are in place to govern the establishment and connection of independent power producers (IPPs) and/or metering of sales from own-use producers. Experience has shown that proceeding with projects without this in place can leave generation facilities effectively stranded with no way to export power.

This issue is not precisely relevant for off-grid projects, but it is still important to understand if there are any regulatory limitations on the establishment of mini-grid systems or of off-grid own-use systems.

Further resources

Belfiore et al. (2009): Benchmark of bioenergy permitting procedures in the European Union

5.2.7 Ownership and assistance

Ownership: Can a suitable ownership structure be found?[23]
The type of bioenergy project will depend on the local context and needs. For larger scale, often commercial, projects the source of equity and investment determines ownership source of equity. However, for mini-grids and similar off-grid projects, there is often a choice about whether a project should be owned and operated by a local community or if this should be centrally controlled by a public body.

Dedicated bioenergy plant
This implementation model refers to an industrial scale WtE plant whose primary business is to procure feedstock and produce an energy commodity (in this case, electricity). Such plants may be viable in areas with ample feedstock availability, significant employment needs at appropriate wage and skill levels and access to large demand centres and transportation infrastructure. Examples are ethanol distilleries and biomass power plants such as the megawatt scale wood fired CHP plants in Europe. A facility might be vertically integrated with feedstock supply or might purchase from smaller growers.

Industry self-supply
Here, an existing agro-processing facility or other biomass intensive industry such as a saw or paper mill invests in energy production from residues, for its own consumption, or with export as an ancillary business activity. Such entities would be most appropriate in regions with the capacity to support processing of agricultural or forestry products (for example, rice milling and lumber production in sawmills) and where sufficient biomass residues are available for use as energy feedstock. The energy output could be process heat (for example, for crop drying, small- to medium-scale pulp and the paper industry) and potentially cogenerated electricity to meet internal needs or for export to the grid. It is often the case that the owner of the facility is also the primary investor and developer of the project, but there are also business models whereby dedicated project developers will partner with these organisations to sell back electricity or claim a share of the energy savings.

23. Adapted from ESMAP (2005)

Box 5: Main bioenergy permitting procedures in the EU (Belfiore et al. 2009)

Spatial planning coherence
Initially, in conjunction with the local authorities -- usually the municipality and/or other regional authorities -- the developer has to establish, to what extent the proposed biomass facility fits in the current land use plan. Good examples of spatial inconsistency are biogas plants, since they are often planned in agricultural areas thus contradicting their actual purpose, i.e. energy production.

Planning permit
In some countries, a planning permit is required by the regional authorities. This document generally lists all the permits that are obligatory before operating the production plant; the applicable authorities; the crucial technical documentation; a basic planning of the various steps of the project; a time line of the activities; etc.

Environmental permit
The environmental permit controls the emissions to the environment, primarily to the atmosphere. It is considered in most countries to be the most important permit since in case of appeal, most appellants protest against the environmental permit. An environmental permit may include an environmental impact assessment (EIA), an integrated pollution prevention and control (IPPC) procedure or some other country specific procedure.

Construction permit
The environmental permit is followed by the construction (building) permit, granting the right to build the facility. This permit can be part of the environmental permit in case of an integrated permit.

Operational permit

After construction, in some countries an operational permit is required to license the project developer to exploit the facility.

Production permit
In several countries, a production permit in order to license electricity and/or heat production is required.

Grid access
In case of non-private use, a permit or license to access the grid may be required.

Other permits
Depending on project type and geographical location, additional permits may be required. One can think of a separate water (effluent) discharge permit or groundwater license in case of water abstraction or abduction for biogas plants, particular safety permits, fire prevention documents, waste management plans, etc.

Figure 25: Pros and cons of centralised (i.e. public infrastructure) and decentralised (i.e. community owned) ownership and management of rural power supply (UNIDO 2007)

For	Against
Centralised management of grid	
Financial risk on utility	No stake in power supply, so lack of interest in maintaining it
Management capacity already exists	Operation and maintenance staff often brought in from outside community
Technical capacity already exists	Bureaucratic management
	Repairs take longer because they must be approved by central management
	Tariff collection expensive
	No load management
	Disputes between utility & community possible
Decentralised management (community-owned stand-alone scheme)	
Interests in continual operation of scheme	Financial risk placed on community
Load management possible	Technical training required
Flexible tariffs possible	Management training required
Repairs made quickly	Outside assistance required for major repairs (costly)
Less bureaucracy	Local disputes possible if management breaks down
Local person employed as operator	
Local people provide labour, reducing initial capital required for scheme	

Mini-grid – off-grid electrification
Bioenergy based mini-grid systems can be developed for villages, or clusters of villages, through a number of approaches. However, the lack of organisational structures, high levels of initial capital investments and lack of ability or willingness to pay by rural customers are some of the major issues that make it challenging to develop a business model for off-grid rural electrification (ASEAN-RESP 2013). As a result, public sector programmes, for example from a central or regional government, or NGOs often directly facilitate or finance the implementation of biomass-waste-based mini-grids. These typically become community owned systems, where the community is organised to become the owner and operator, providing maintenance, tariff collection and management services (WB 2008). Such a community-based model usually requires substantial technical assistance during the design and feasibility assessment stages, training and institutions of self-governance and management but can have important benefits for the sustainability of these projects (Figure 25).

Mini-grid projects can also be developed and owned by the private sector, often in cooperation with government. However, the challenges noted earlier mean that risk-return profiles are not attractive without subsidies. Case studies show that virtually all potential business models require subsidies to commence, or to sustain, operation over the long term (ARE/REN21 2013). An examination of business models in the ASEAN region suggested three broad categories of business model for off-grid electrification: (i) market-based business models (fee-for-service model, dealer model, lease model), (ii) government induced community based business models (grant-based models, partially grant-based models), and (iii) public private partnership models (Table 8). The same report noted, however, that in reality hybrid types of these models are often applied, combining the advantages of different approaches.

Stand-alone
The most common type of small-scale stand-alone system involves the use of a renewable energy power source (i.e. a wind generator or PV array) to maintain an adequate level of charge in an electrical storage battery. The battery in turn can provide electricity on demand for electrical applications such as lights, radios, refrigeration, telecommunications, etc. (UNIDO 2007). However, as noted in Table 8, these types of very small systems, at least for power provision, are more suited to technologies such a solar PV and wind. Small-scale biogas can be attractive for individuals for uses such a cooking, but for electricity generation a larger scale of bioenergy project, for example that supplies a community or farm/industry (as discussed above), is the norm.

Is the necessary expertise available?[24]
A multitude of expertise is required to bring forward a WtE plant. The main areas of expertise include market, financial, engineering and management. Within these areas, and depending on the application, a number of particular skills need to be established through training or provided as assistance. Furthermore, should the project draw on a wider supply chain (for example local manufacturers for certain components) or involve local banks who are not familiar with biomass waste technologies, then this can increase the task to educate stakeholders or provide the necessary external expertise. Table 9 provides a summary of the types of skills that different stakeholders will need to have in order to successfully bring a biomass waste project to completion, whether this is on- or off-grid.

Further resources

Cu Tran (2013): ASEAN Guideline on Off-grid Rural Electrification Approaches

5.3 Pre-feasibility assessment checklist

The pre-feasibility assessment questions provided in this chapter provide a starting point for understanding the requirements of a biomass waste project, whether this is at a larger scale for commercial purposes, or off-grid providing power to a village system. Table 10 summarises these questions along with application specific factors that influence a project developer's answers.

Conceptually, if a question is clearly satisfied, a developer can confidently can move forward. However, if there are some doubts on specific aspects, expert input may be required, recognising that bioenergy system design and planning is a highly technical task. If a question clearly cannot be answered satisfactorily, and no mitigating measures can be found with assistance, the project may need to be reconsidered. See Table 10.

24. Adapted from Janzé (2010)

Table 8: Project types and business models for off-grid electrification (ASEAN-RESP 2013)

Business model	Key features
Market-based models:	
Fee-for-service model	A project investor/developer invests in and owns the off-grid power generating system and supplies electricity to rural customers. The investor/developer ensures operation, maintenance and replacement of the power system. The customers pay for the electricity they use either based on metering (kW/h) or a fixed (monthly) charge. The electricity tariffs are usually set at a financially viable level (cost covering) and are relatively high compared to other approaches. • Ownership of the power system: ESCOs (e.g. private company, public utility, community cooperative, etc.) • Financial sources: Equity/investment, loans, financial incentives (subsidies), fees • Tariff system: Market-based tariffs • Operation and maintenance: ESCOs
Dealer model	Customers/end-users purchase the power system either with their own cash and/or loans. The customer is normally a household or a facility owner (e.g. rice miller). Beyond a warranty service, the customer assumes responsibility for all operational and replacement costs. There is no payment for consumed electricity, only consumables and spare parts required for the operation and maintenance of the power system have to be purchased. • Ownership of the power system: Customer/end-user • Financial sources: Cash payment and/or loans (e.g. microfinance institutions, dealer credits) • Tariff system: No payment for electricity consumed, but the costs of consumables and spare parts have to be paid by the customer him/herself • Operation and maintenance: Customer
Lease model	In contrast to the dealer model, the equipment is owned by the lessor (e.g. ESCO) and transferred to the customer only at the end of the leasing period. The lessor remains responsible for maintenance and repair, while the customer pays a (monthly) rental fee during the leasing period. Generally applicable for small-scale stand-alone systems, hence less relevant for biomass WtE projects. • Ownership of the power system: ESCO/lessor (during the leasing period) and customer/end-user (after leasing period) • Financial sources: Equity/investment (by ESCO/lessor), fees • Tariff system: Market-based rental fee • Operation and maintenance: Lessor (during the leasing period) and customer(after expiring of the leasing period)

Government induced community-based business models:	
Fully grant-based model	An off-grid power system is 100 per cent grant-financed, usually by government or international partners, while the projects implemented under the partially grant-based business model will be financed by a mix of grant and long-term soft loans and/or local contributions (e.g. from the government budget or the community). The power system is usually owned, operated and maintained by a community based entity such as village committee, community cooperative, etc. • Ownership of the power system: Community-based entities • Financial structure: 100 per cent grant from government (or international partners) • Tariff system: Strongly- subsidised low tariffs • Operation and maintenance: Local community
Community Based Model	• Ownership of the power system: by Community-based entities; • Financial structure: Mix of grant and long-term soft loans, government budget and/or community contributions; • Tariff system: Break even tariffs with financial incentives; • Operation and maintenance: Local community.
Public Private Partnership (PPP) models:	
Operation-Maintenance PPP model	The Operation-Maintenance model is a partnership, in which a public partner invests in an off-grid power generating system and contracts a private partner to operate and maintain the system. The public partner retains ownership and overall management of the power system. • Ownership of the power system: by public partner • Financial structure: Public funds • Tariff system: Quasi market-based subsidised tariffs • Operation and maintenance: Private partner
Operation-Maintenance-Management PPP model	Under the Operation-Maintenance-Management model, a public partner enters a contract with a private partner to operate, maintain and manage the off-grid power system. The public partner remains the owner of the system, but the private partner may invest own capital in the system. • Ownership of the power system: by public partner • Financial structure: Public funds and private financing • Tariff system: Quasi market-based subsidised tariffs • Operation and maintenance: Private partner

Table 9: Capacity needs for different stakeholders for biomass waste project development (adapted from Cu Tran 2013)

Project stakeholders	Required skills and capacity
Policy makers and government officials	• General aspects of biomass waste projects (including policy, financial aspects, technology, impacts/benefits) • Policy frameworks for biomass waste projects • Permitting procedures for biomass waste projects • Tendering/contracting
Financial institutions and private investors	• General aspects of biomass waste projects (including policy, financial aspects, technology, impacts/benefits) • Prevalent policy frameworks and legal aspects • Project financing • Business models • Risk assessment of biomass waste technologies
Equipment manufacturers and construction companies	• General aspects of biomass waste projects (including policy, financial aspects, technology, impacts/benefits) • Prevalent technical standards • Project implementation (construction/installation, tendering/contracting, supervision/monitoring, testing/commissioning and handover)
Power plant operators and managers	• General aspects of biomass waste projects (financial aspects, technology, impacts/benefits) • Plant operation • Plant maintenance • Business management (accounting, fee collection, etc.)
Local communities/ end-users	• General aspects of biomass waste projects (financial aspects, technology, impacts/benefits) • Project design and business models • Efficient use of electricity • Productive uses of electricity
Distribution/ transmission companies	• General aspects of biomass waste projects (including policy, financial aspects, technology, impacts/benefits) • Grid codes and connection requirements • Metering of renewable energy facilities

Table 10: Assessment checklist

Category	Assessment questions	Application specific comments			Qualitative assessment		
		On-grid / larger scale		Off-grid, mini-grid / smaller scale	Clearly satisfies	Some doubts	Clearly does not satisfy
Feedstock	**Can a reliable source of feedstock for the WtE project be identified?**	Often a challenge if external to the project Can be mitigated by contracts, variety of suppliers and different feedstocks					
	Is the available biomass suitable for use?	Often more critical for larger projects where efficiency or cost is important Likely to require expert input		Characteristics for smaller projects may be less critical, perhaps with off the shelf solutions			
Technology	**Is there a WtE technology that is appropriate to the available resource and local context/needs?**	Often more critical for larger projects where efficiency or cost is important Likely to require expert input		Characteristics for smaller projects may be less critical, perhaps with off the shelf solutions			
	Is pre- or post-processing required?	Often more critical for larger projects where efficiency or cost is important (e.g. transport) Likely to require expert input					
	Is there a supplier available with appropriate technology?	Very large range. Proven, conveniently located and similar application systems are preferable Likely to require expert input		Recommended to choose quality suppliers and plan for spare parts to improve project performance and sustainability			
Logistical	**Is the distribution of feedstock amenable to my project?**	More critical for larger projects that require feedstock from a wider area					
	Can the necessary storage be provided?	More critical for larger projects that require larger volumes		Continuity of supply can be a key issue for off-grid applications, but not all feedstock can be stored longer term/seasonally			
	Is there a suitable location for the plant?	More critical for larger projects		May be an important aspect of approval for community systems			
Sustainability	**Will the project provide a reasonable mitigation impact?**						
	Will the project meet local environmental requirements?	Critical for larger projects, particularly those creating significant volumes of waste from their conversion process		Can determine local acceptance of a project over time			
	Is the project aligned to local interests?			Critical for mini-grid systems. Concerns current feedstock uses, involving the community and providing productive uses where possible			
Financial	**Is the project financially viable?**	A relatively traditional assessment of project viability, noting the particular risk associated with reliable feedstock supply		Projects will often be public, so viability is less relevant, or subsidised to improve returns			
	Is the project financially feasible, i.e. can finance be raised?	Bank willingness to lend and terms will often be critical		Public or donor budgets will be key considerations			
Regulatory / policy	**Can the necessary permits be obtained?**	A key question for large scale applications that will often have significant regulatory requirements		Less critical for more off-grid applications but needs to be checked			
	Can independent parties generate electricity and connect to the grid?	Targeted to on-grid projects that expect a revenue stream from electricity sales. A key requirement for project feasibility		Generally not applicable, but regulations for off-grid generation should be checked			
Ownership & skills	**Can a suitable ownership structure be found?**	More traditional ownership structures, often with an owner that is also the creator of the waste stream (e.g. an agro-business)		Important choices regarding public/private control over operation and different possible ownership models for implementing this. Needs to be acceptable to the project recipients			
	Is the necessary expertise available?	Capacity within financial institutions, regulators and distribution companies will be key success factors		Awareness and capacity within the project recipients (often also the owners/operators) will be a key success factor			

Section 6
Case studies

Two case studies are provided to illustrate a number of points developed earlier in the toolkit. The first considers combustion of wood residues and process waste for own-use in the South African pulp and paper industry, while the second discusses a programme in Cambodia to support gasification of waste by SMEs. Together they show:

- different feedstocks and circumstances will drive adoption of different technologies
- the ability of WtE facilities to provide reliable and competitive electricity for use by industry
- the potential role of industry organisations in stimulating the growth of bioenergy technologies
- the importance of demonstration plants
- that opportunities for waste-to-energy biomass use remains untapped in many countries.

A number of additional case studies can be found in the Bioenergy Primer from UNDP (2000).

6.1 Wood residues and process waste as energy inputs to the pulp and paper industry in Africa

Paper production is a very energy intensive process, but also one that produces a very significant amount of biomass waste that could be recovered and used as energy input.

The paper production process starts with pulping of wood to release fibrous material. The most common pulping process is known as the Kraft process and involves a combination of chemical, thermal and mechanical destruction of the fibres. Heating is often employed in both chemical and mechanical paper production processes (Ras and Lewis 2012). Paper is produced from pulp through a sequence of screening (to remove fine pulp); thickening, pressing and drying (to remove water); and refining through the addition of chemicals. Paper is finally wound, cut and trimmed into appropriate sizes and dimensions (Brown, Hamel and Hedman 1996).

In the Kraft process, steam is used in several of the processing steps, notably in the digester to supply heat for cooking; evaporators to drive off moisture; bleachers; and for drying of pulp (Brown, Hamel and Hedman 1996). Fuel is used predominantly to meet the requirements of a steam boiler and for onsite electricity production but is also used to fire a lime kiln to produce slaked lime. Electricity is used for most of the processing steps and especially for forming and pressing of pulp prior to paper production (Brown, Hamel and Hedman 1996). Indicative energy requirements for pulp and paper are shown in Table 11.

Historically, much of this energy demand was met by fossil fuels, but increasingly the industry is utilising biomass resources to meet its energy needs (Agenda 2020 2010). Biomass represents a significant opportunity for RE substitution in the pulp and paper industry and it is increasingly becoming common practice to utilise biomass to generate heat and electricity. Table 12 indicates several sources of biomass waste material available from paper and pulp processing. Residual fibres collected from the wastewater system, waste wood chips and bark (for the case where bark is removed at or close to the pulping mill rather than in the forest) and pulp mill effluents are both sources of biomass available from the pulping process. Black liquor, in particular, carries about half of the biomass material contained in the raw wood feedstock (Gavrilescu 2008). These materials may be combusted directly or converted to biogas through anaerobic digestion.

Table 11: Energy requirements for pulp and paper processes

Energy requirements	Electricity	Heat
	[kWh/tonne]	[MJ/tonne]
Kraft pulping	600 – 1,200	10 - 14
Mechanical pulping	1,000 – 4,300	
Paper mill (tissue)	500 – 3,000	
Paper mill (coated and uncoated paper)	500 – 900	
Paper mill (paperboard)	550 – 680	

Source: IFC (2007c)

Of these, black liquor is a significant biomass source from the Kraft process with heating values ranging from 13,000 to 15,500 kJ/kg of solid black liquor (Gavrilescu 2008). In developed countries, the use of biomass material, including black liquor, accounts for up to 50 per cent of total energy consumption in the pulping and paper industry (Gavrilescu 2008).

Paper mills in developing countries are increasingly exploring the potential for recovery of the energy value in their biomass wastes. The Mondi Group, which has operations in South Africa, derived more than 50 per cent of its fuel consumption across its material operations in 2012 from biomass (Mondi Group 2012a). In addition, its Richards Bay mill has declared the intention of installing a new 47 MW steam-powered turbine, to be built at a cost of some €37.8 million (Mondi Group 2012b).[25]

The mill currently has two steam turbine generators – a 38 MW extraction back-pressure steam turbine and a 34.3 MW extraction condensing steam turbine – and a 27 MW gas turbine. The mill claims its power self-sufficiency already stands at 86 per cent but the commissioning of the new turbine will increase that to 135 per cent. Production of electricity surpluses by industry is particularly valuable in South Africa, where electricity supply security remains inadequate. Mondi claims surplus electricity of between 25 to 30 MW will be available for sale to prospective buyers in the generation constrained South African market and any excess to the local municipality on a self-dispatch basis (meaning that Mondi has the option to export or not, depending on circumstances) (Mondi Group 2012b).

The new turbine will initially be powered partly by renewable energy from a combination of black liquor or lignin and coal, however, there is potential to collect more biomass from forest residue and move to only renewable sources for the turbine (Mondi Group 2012b). Mondi is also currently exploring other ways to use biomass from forest by-products and wood residues for electricity generation (Mondi Group 2012b).

Table 12: Biomass wastes in pulp and paper industry

Type of biomass	Sources of biomass wastes
Black liquor	Chemical pulp manufacture (Kraft process)
Bark and wood residues	Chemical and semi-chemical pulp processes and mechanical pulp manufacture
Rejects of screening and cleaning processes	Chemical pulp production; recycled paper processing; paper stock preparing
Mechanical chemical sludge	White water treatment and effluent treatment
Biological sludge	Biological effluent treatment
Mixed sludge	Different sources

Source: Gavrilescu (2008)

25. The new turbine was expected to become operational by November 2013, however, that has not yet happened and the delays have not been explained.

An added benefit of using biomass is the carbon avoidance due to its offset of Eskom power and of coal-powered steam. The new steam-powered turbine will decrease the carbon footprint of Mondi's Richards Bay mill by about 107,000 tCO_2 per year, after attributing an appropriate carbon portion to the sold exported electricity (Mondi Group 2012b).

There is enormous potential to replicate such energy recovery both from input waste as well as process waste in other pulp and paper production facilities across the continent. Depending on the current state of biomass use in African pulp and paper mills, there is an opportunity to increase the substitution potential to above 50 per cent of total energy demand. In future, with new technologies and process improvements, it is estimated that the pulp and paper industry could meet 100 per cent of its energy needs through biomass and be a net exporter of energy (Agenda 2020 2010). These technologies and improvements include the following:

- Moving to integrated pulp and paper mills
- Employing CHP systems
- Gasification of black liquor for use in combined-cycle gasification systems.

6.2 Designing a biomass gasification roll-out for Cambodian SMEs

In Cambodia, energy expenditure is a major constraint to growth and development of SMEs. High energy costs also continue to be an important obstacle to private sector investment, especially in rural areas not serviced by reliable, lower cost electricity services (SME Cambodia 2008). The cost of both liquid fossil fuels and electrical energy in rural Cambodia is two to five times higher than in neighbouring countries, which results in even local primary products such as Cambodian milled rice, common clay bricks and ceramic tiles having difficulty competing with products imported from Cambodia's neighbours (SME Cambodia 2008).

The local developmental organisation, *SME Cambodia,* identified biomass gasification as a possible solution to this problem, especially for smaller applications from 20 kW to 2.0 MW where no inexpensive grid electricity source or inexpensive local fossil fuel source is available. To introduce biomass gasification to SMEs in Cambodia it partnered with E+Co, a US non-profit clean energy investment organisation with whom they set out to develop an integrated set of services to promote biomass gasification technology in Cambodia. To this end, they established a jointly owned subsidiary, SME Renewable Energy Ltd. (SME-RE), a Cambodian registered company promoting gasification technology, importing and installing commercial sized units and offering financing to rural based SMEs. The ultimate objective of this partnership is to assist Cambodian rice mills and other SMEs to realise substantial energy savings (SME Cambodia 2008).

To assess the potential and possibility for the uptake of biomass gasification technology among Cambodian SMEs, SME Cambodia conducted a comprehensive survey of the following aspects critical to the introduction of this technology in rice mills and other SMEs (SME Cambodia 2008):

- **Potential fuel savings from the use of biomass gasification systems in Cambodia rice mills and other SMEs**

  Reduction in diesel fuel consumption and expenditures of 70-75per cent can be achieved by gasifying rice husks or corn cobs, wood chips, coconut shells, cane sugar residues (bagasse), peanut shells, etc. even when continuing to use their existing diesel engines. One hundred per cent replacement of diesel fuel with biomass residues is possible, but requires investment in both a biomass gasifier and replacement of the diesel engine with a 100 per cent gas engine.

- **Availability of biomass**

  25-30 per cent of the volume of paddy rice milled in Cambodian rice mills is rice husk waste. Mechanically driven rice mills using their existing diesel engines need only 25-30 per cent of the rice husk produced by the mill to replace 70-75 per cent of the diesel fuel consumed.

- **Financial capacity of Rice Mills and other SMEs**

  Accounts record keeping, accounting systems and staff capacity of rural SMEs was found to be weak. In addition, management capacity to undertake necessary financial analysis, compare and evaluate different investment streams and opportunity costs and identify potential for increasing mill and factory efficiency and productivity was found to be limited.

- **Access to financing and credit**

  Most rice mills and other SMEs rely on family and friends as sources of financing for working capital, equipment purchases and operational expenses on a short term seasonal or annual basis. Limited commercial bank credit is available to SMEs and, where it is, loan terms are very unfavourable.

- **Rice miller and other SME operator awareness and perception**

  Cambodian rice millers and other SME owners were found to be generally unaware and unfamiliar with renewable energy technologies and their application to commercial operations, energy efficiency improvements or reducing environmental impacts.

Based on the findings of the survey, SME Renewable Energy Ltd. (SME-RE) developed an integrated approach consisting of the following component services (SME Cambodia 2008):

- Evaluation of enterprise potential to use biomass gasification technology, including identifying financial and fossil fuel savings
- Specification of biomass gasification equipment and systems required to meet the SMEs' needs
- Provision of affordable loan financing schema with terms tailored to allow repayment from fuel oil savings
- Supply, installation and commissioning of biomass gasification systems at the enterprise site
- SME operator and staff training
- Equipment manufacturer warranty
- After-sales maintenance services.

SME-RE started its work by conducting market opening seminars throughout Cambodia to explain to rural entrepreneurs the potential to improve their competitiveness through reducing consumption and expenditure on fossil fuels. Initially, there was hesitation to invest in the "new" technology by most SMEs owners. To instil confidence in the technology and its application in rural enterprises SME Cambodia facilitated exposure visits to see rice mills, factories and villages in India that have used biomass gasification technology for many years.

These promotional efforts gradually yielded results and in 2006 a leading Battambang rice miller decided to invest in the new technology. SME-RE specified a rice husk burning biomass gasification system and provided a turn-key project financing package to facilitate the equipment purchase. The system was installed and commissioned in August 2006. This 200 kW gasifier, fuelled with waste rice husks, reduced diesel oil consumption of the mill's diesel engine by 75 per cent or about 5,500 litres per month (SME Cambodia 2008).

This installation provided a much-needed local demonstration of the benefits that could be realised by Cambodian SMEs and a number of orders followed from four more rice mills, a brick factory and ice making plants. SME-RE and E+Co. provided project financing loans to these SMEs with terms tailored to meet the specific needs and capacity of each enterprise. The energy savings realised by the first five SMEs to install gasification equipment was and continues to be impressive, with 70-75per cent substitution rates (SME Cambodia 2008).

In response to the success of these early adopters, and also due to the steady rise of diesel fuel prices during 2007-2008, more rice millers and other SME operators began to indicate interest in investing in gasification systems. The early adopters provided the credible demonstration that hesitant Cambodian SME operators needed to convince them that the equipment would operate successfully and provide both immediate and long-term energy savings. By the end of June 2008, 10 Cambodian SMEs had installed gasification systems and 11 more had ordered systems that were to be installed by the end of the year (SME Cambodia 2008).

Based on the success of the pilot project, SME Cambodia devised an action plan for large-scale investment in biomass gasification technology. It proposes that SME Cambodia and E+Co, through SME-RE, be provided access to additional financial resources to install biomass gasification systems in up to 100 rice mills and 50 other SMEs. It is projected that as a result of these investments, each enterprise could save, on average, 4,500 litres of diesel fuel per month, with a value of more than USD5,000. Once installed, the 150 SMEs would realise annual savings of 7.5 million litres of diesel fuel each year valued at more than USD9,000,000 (1 litre= USD1.20) (SME Cambodia 2008).

The proposed action plan includes (SME Cambodia 2008):

- establishing a loan fund/credit facility
- a technical assistance grant for staff training, technical services and financial management capacity building
- a technical assistance grant for research and preparation of biomass gasification equipment standards for implementation in Cambodia.

The pioneering work of SME Cambodia and their ambitions for the future have been incorporated in the EU SWITCH-ASIA funded project entitled *Waste to Energy for the Rice Milling Sector in Cambodia (WtE)* that SNV is now implementing in the country. The project will, over the four years between 2012 and 2015, promote sustainable production of milled rice through replication of existing WtE rice milling technologies as well as the sustainable consumption of rice by consolidating fragmented guidelines into a single operational industry standard with policy makers, SMEs and financial sector actors together in a multi-stakeholder platform (Sophorn 2012). The target beneficiaries for WtE project are the rice mill members of the Federation of Cambodian Rice Millers Association—FCMRA and rice husk gasifier (RHG) manufacturers.

Section 7

Funding sources for WtE developments

It is useful to finish this toolkit with a discussion of where project developers may look for assistance with financing of WtE projects. Although modern bioenergy has been developing quickly across the globe, developing countries still often find it difficult to finance their bioenergy projects or programmes. Financial markets in several African and Asian countries are very well developed, with multiple finance institutions offering both debt and equity finance. However, most commercial funding sources in the developing world are currently going through a similar "learning" stage on new technologies that their counterparts in developed countries went through during the first years of renewable energy market development in Europe and North America. In addition, bioenergy often has a negative connotation of representing a potential competition for food, so a number of funding sources indiscriminately refuse to fund any bioenergy developments. Unfortunately, this often reduces the ability to raise capital, even for sustainable projects, based on wastes and residues.

Having noted that, there are some institutions more willing to finance renewables in general and bioenergy in particular. This section provides an overview of possible funding sources for bioenergy developments in developing countries.

A number of international finance institutions, both banks and equity funds of various sizes and investment scope, are present in both Africa and Asia, some even with strong mandates to support renewable energy projects. In addition to private, commercial funding sources, some donor governments are also establishing a presence as funding entities by establishing own special-purpose funds, or teaming up with existing local funding institutions. Local governments also often have dedicated industrial development funds, which could be tapped for projects increasing electricity supply in the country. Finally, purely development finance is also available in those countries and often used by projects to close the financial gap of project.

For a comprehensive overview of financing options for bioenergy initiatives, covering multilateral funds, national initiatives and foundations, as well as some region-specific sources providing everything from R&D finding, to feasibility assessment support to project finance, the reader is advised to refer to the Global Bioenergy Partnership publication Financing Options for Bioenergy Projects and Programmes (GBEP 2010).[26]

The Global Bioenergy Partnership (GBEP) compilation of financing sources for bioenergy developments was developed with the aim of facilitating access to financing for bioenergy for sustainable development at the project, programme and sectoral level in developing countries. It provides a comprehensive tool for use by national governments and project developers when assessing different financing opportunities for bioenergy projects and programmes, including a clear picture of selection criteria and bioenergy project characteristics that should be fulfilled to apply for the listed financing options. The table below summarises the funding options listed by the GBEP that are still accepting financing applications for biomass waste-to-energy projects and programmes at the time of writing of this toolkit.

In addition, Table 14 presents a (non-exhaustive) overview of the main funding sources that have been established after the publication of the GBEP overview that are known to provide finance to renewable energy developments in general (but not necessarily to biomass in particular).[27]

26. http://www.globalbioenergy.org/uploads/media/1004_GBEP_-_Financing_options_for_bioenergy_projects_23april_web.pdf
27. The National Business Initiative (NBI) in South Africa (SA) has recently published a report on climate finance sources available in South Africa and barriers to accessing them, which could be of interest to projects with a strong climate mitigation element. The report also offers a more extensive list of bilateral funds available in SA. For more details, please see http://www.nbi.org.za/Pages/Publication-Details.aspx?NBIweb=e586ac5b-bcad-49be-ba41-81b0f1fa2ba3&NBIlist=baaa9251-7130-4824-a0e9-0991a4bd678f&NBIitem=307

Table 13: Summary of GBEP global and regional funding sources

Institution/Programme/ Fund	Type of funding	Notes
Global funding sources		
EUEI - Partnership Dialogue Facility (PDF)	Facilities in the range of EUR50,000 – EUR200,000 for each single activity	Projects are financed in developing countries, with special focus on Africa (sub-Saharan African countries preferable)
European Investment Bank (EIB)	Concessional loans	The EIB finances both large and small-scale investment projects
Global Environment Facility (GEF) Trust Fund - Climate Change focal area	Grants and concessional loans	The GEF operates as a mechanism for international cooperation providing funding to meet the incremental costs of projects to achieve agreed global environmental benefits in climate change (among other focal areas)
Renewable Energy and Energy Efficiency Partnership (REEEP) Programme Call	Grants or co-funding	REEEP projects concentrate small-scale interventions with potential for large knock-on effects
World Bank - Clean Technology Fund (CTF)	Concessional loans, grants, guarantees and investment plans for government programmes	CTF aims to promote scaled-up financing for demonstration, deployment and transfer of low carbon programmes and projects with a significant potential for long term greenhouse gas (GHG) emissions
World Bank - Forest Investment Programme (FIP)	Concessional loans, grants, guarantees	The fund aims to promote sustainable forest management, which is a pre-requisite for the use of forestry waste and by-products as feedstock for bioenergy
World Bank - Scaling Up Renewable Energy in Low Income Countries Program (SREP)	Concessional loans, grants, guarantees	Supports bioenergy projects or programmes that improve energy access for rural populations
AEF: Access to Energy Fund – Energy for growth	Project finance (not specified)	The Fund aims to connect 2.1 million people in developing countries by 2015 by providing financing for projects involved in the generation, transmission or distribution of energy
Development Finance Facility (FMO)	Direct investment and indirect investment (through other financial institutions) and co-financing	The FMO's Sustainable Energy Strategy supports projects that generate energy based on a renewable energy source, including biomass-to-energy projects, biomass (including biofuel) based cogeneration and waste-to-energy projects (incl. waste-based landfill and sewage gas)
develoPPP .de	Not specified	The PPP provides targeted support in involving private enterprises in those sectors where there is a particular need for action as well as special opportunities
International Climate Initiative (ICI)	Grants, loans	Part of Germany's official development assistance which aims to promote a climate friendly economy and climate adaptation
KfW Bankengruppe - DEG Invest	Loans, mezzanine finance, equity capital and guarantees	DEG's intention is to promote economic development and raise people's living standards in Germany's partner countries
KfW Bankengruppe - Initiative for Climate and Environmental Protection (IKLU)	Concessional loans and subsidies	Runs a special facility for renewable energies and energy efficiency
Shell Foundation – Climate change programme	Grants, loans, guarantees and other vehicles	Supports the growth of start-up businesses that provide electricity using bioenergy technologies such as biomass gasification and biogas
Regional funding sources		
AfDB Agency Lines of Credit (I-ALC)	Loans	I-ALC was established to support finance smaller-scale infrastructure operations that are not cost-effective
AfDB Clean Energy Access and Climate Adaptation Facility for Africa (CECAFA)	Finance intermediary	Supports AfD member countries on clean energy and climate adaptation investments
AfDB Clean Energy Investment Framework (CEIF)	Loans and guarantees	CEIF's main objectives are to address energy poverty by fostering access to certain and affordable energy supplies, to encourage clean development and promote global emissions reduction and to promote renewable energy sources
AfDB Infrastructure Lines of Credit (I-LOC)	Loans	I-LOC was established to support finance smaller-scale infrastructure operations that are not cost-effective
West African Development Bank	Loans, financing of feasibility studies	The bank will consider waste-to-energy projects that contribute to poverty reduction, economic integration and promotion of private sector activity
IDB Sustainable Energy and Climate Change Initiative (SECCI) Funds	Grants	WtE projects fall under renewable energy, which is one of the Fund's strategic pillars
ADB Asian Development Fund	Equity, loans and guarantees	ADF finances infrastructure investments that contribute to poverty reduction and regional integration

Table 14: Overview of main funding sources for renewables

Institution name	Type of funding	Notes
Clean Energy Development and Finance Centre (CEDFC)	Not clear (CEDFC still under development)	The CEDFC will provide technical and financial support for renewable energy and gas projects while promoting US private-sector participation in the sector
Green Climate Fund	Grants and concessional loans	Not yet operational; should include private sector facility that enables it to directly and indirectly finance private sector
US Export-Import Bank	Debt	Renewable energy programme with more accessible terms for renewable projects; project must include US technology import
African Carbon Asset Development (ACAD) Facility	Grants	A public-private partnership spearheaded by UNEP-Risoe in cooperation with Standard Bank; supported by the German Federal Environment Ministry
Africa Enterprise Challenge Fund (AECF)	Grants and concessionary loans	AECF is running the REACT program, which is a special funding window to incentivise private sector investment in clean energy
African Development Bank's Sustainable Energy Fund for Africa (SEFA)	Grants, equity	Aimed at enhancing commercial viability and bankability of smaller-size renewable energy and energy efficiency projects; two funding windows (dates yet to be released)

For smaller scale off-grid WtE projects, rural energy funds in individual countries should also be explored as a possible source of funding.

Renewable energy projects, including WtE projects, in developing countries can also make use of carbon finance, although several restrictions do apply. The Clean Development Mechanism (CDM) of the Kyoto Protocol is now very limited in terms of attractiveness. This is due to the fact that since 2012, new Certified Emission Reductions (CERs) can only be awarded to projects in least developed countries, and in any case the current CER price is too low[28] to provide useful support to most projects. Having noted that, small-scale projects delivering a substantial development dividend may earn a premium under an additional value-added standard (i.e. the Gold Standard[29]). This can be the case under a CDM or voluntary certification scheme. Regardless of the carbon market segment targeted, the expected revenues from climate finance should be carefully weighed with the costs associated with developing carbon certification under any chosen scheme (Korthuijs 2012).

New climate finance mechanisms are still under discussion within the international climate negotiation framework, but will most likely become operational no earlier than 2015 and include NAMAs (Nationally Appropriate Mitigation Actions), NMMs (New Market-based Mechanisms) and REDD+ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks).

Finally, the constellation of funding sources for climate mitigation and adaptation activities, which encompass WtE projects, is constantly changing. Good online resources for tracking the additions or removals of the various climate financing options available are Climate Funds Update[30] and Climate Finance Options.[31]

28. As of early 2014 the spot price for green CERs was only 0.40 €/tCO2 (EEX, 2014)
29. http://www.cdmgoldstandard.org/
30. http://www.climatefundsupdate.org
31. http://climatefinanceoptions.org/cfo/index.php

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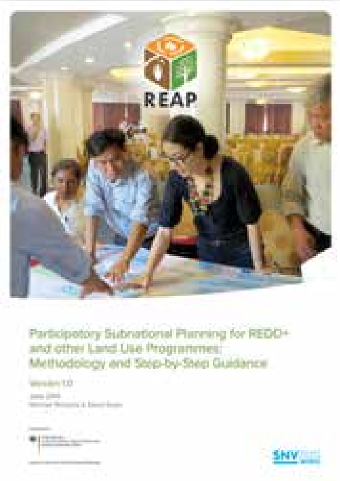

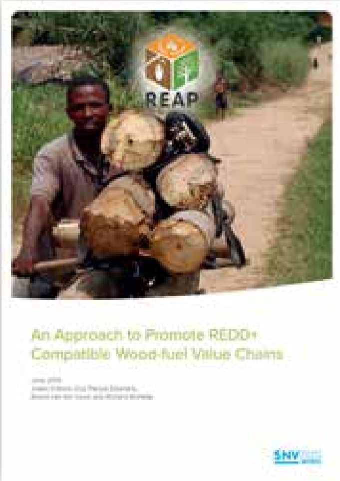

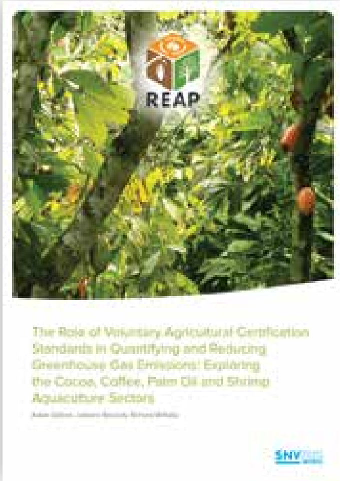

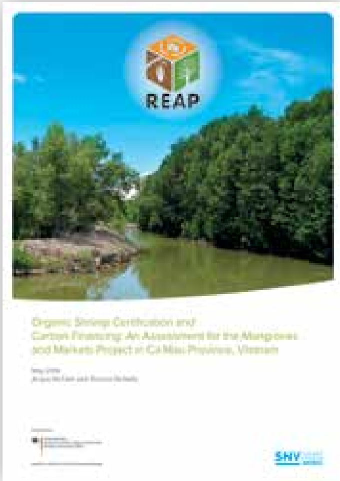

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