



# Converting Biomass to Energy

A Guide for Developers and Investors

IN PARTNERSHIP WITH





*Creating Markets, Creating Opportunities*

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2121 Pennsylvania Avenue, N.W.

Washington, D.C. 20433

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# DEFINITIONS AND ABBREVIATIONS

## DEFINITIONS:

Project owner	The developer of the project, in this case typically the owner of the small or medium industrial plant.
Project developer	The project owner or an independent and professional developer of energy projects.
EPC contractor	Engineering, Procurement, and Construction (EPC) is a particular form of contracting arrangement used in some projects. The EPC contractor is responsible for all activities from design, procurement, and construction to commissioning and handover of the project to the end-user or owner. The EPC contract is often limited to the electro/mechanical equipment.
Guide	The present guide on converting biomass to energy.
Turnkey project	A turnkey project is a package solution (including detail design, supply, and construction/erection) offered as the answer to a buyer's request for proposal. A turnkey contractor is a company or consortium that provides this type of package solution.
O&M contract	An operation and maintenance (O&M) agreement is a long-term agreement between the project company and a service contractor for the operation and maintenance of the plant.
Process steam/heat	Provision of steam at various steam pressures for industrial processes or heat and/or for district heating.

## ABBREVIATIONS:

AC	Alternating Current	CO <sub>2</sub>	Carbon Dioxide
ADB	Asian Development Bank	CPU	Central Processing Unit
AfDB	African Development Bank	DAC	Direct Air Cooling
ATEX	EU Directive 9/94/EC (Appareils destinés à être utilisés en ATmosphères EXplosibles)	DB	Design–Build
BAT	Best Available Techniques	DBFO	Design–Build–Finance–Operate
BATNEEC	Best Available Techniques Not Entailing Excessive Cost	DBOO	Design–Build–Own–Operate
BFB	Bubbling Fluidized Bed	DC	Direct Current
BIGCC	Biomass Integrated Gasification Combined Cycle	DCS	Distributed Control System
BM	Build Margin	DMC	Dry Matter Content
BOP	Balance of Plant	DSCR	Debt Service Coverage Ratio
BOT	Build–Operate–Transfer	EBRD	European Bank for Reconstruction and Development
C	Celsius	EHS	Environment, Health, and Safety
C&I	Control and instrumentation	EIA	Environmental Impact Assessment
CAPEX	Capital Expenditure (investment costs)	EIB	European Investment Bank
CDM	Clean Development Mechanism	EPC	Engineering, Procurement, and Contracting
CFB	Circulating Fluidized Bed	EPCM	Engineering, Procurement, and Construction Management
CHP	Combined Heat and Power	ESIA	Environmental and Social Impact Assessment

ESMS	Environmental and Social Management System	MJ	Megajoule
ESP	Electrostatic Precipitator	MW	Megawatt
EU	European Union	MWe	Megawatt electrical
FID	Final Investment Decision	MWh	Megawatt hour
FIDIC	International Federation of Consulting Engineers	MWth	Megawatt thermal
FRA	Frequency Response Analysis	n.a.	Not Applicable
GGF	Green for Growth Fund	NPV	Net Present Value
GJ	Gigajoule	O&M	Operation and Maintenance
GNOC	Global Nitrous Oxide Calculator	OECD	Organisation for Economic Co-operation and Development
HMI	Human Machine Interface	OEM	Original Equipment Manufacturer
IDB	Inter-American Development Bank	OM	Operation Margin
IEA	International Energy Agency	OPEX	Operational Expenditure (costs of O&M)
IFC	International Finance Corporation	ORC	Organic Rankine Cycle
IRENA	International Renewable Energy Agency	PPA	Power Purchase Agreement
IRR	Internal Rate of Return	PS	Performance Standard
IUCN	International Union for Conservation of Nature	R&D	Research and Development
KfW	Kreditanstalt für Wiederaufbau (German Development Bank)	RfP	Request for Proposal
kg	Kilogram	RCM	Reliability Centered Maintenance
kV	Kilovolt	SIA	Social Impact Assessment
kW	Kilowatt	TEWAC	Totally Enclosed Water to Air Cooling
kWh	Kilowatt hour	Ton	Metric Ton (1,000 kg)
LCOE	Levelized Cost of Electricity	UN	United Nations
LCV	Lower Calorific Value	V	Volt
LPG	Liquefied Petroleum Gas	WACC	Weighted Average Cost of Capital
MDF	Medium-density Fiberboard		

## FOREWORD

Biomass can become a reliable and renewable local energy source to replace conventional fossil fuels in local industries and to reduce reliance on overloaded electricity grids. In this perspective, many medium-to-large agricultural, wood processing, or food processing industries in developing countries and emerging economies are well placed to benefit from the successful development of biomass-to-energy.

The International Finance Corporation presents this guide as a practical tool for developers of and investors in biomass-to-energy projects. The target audience is medium-to-large agricultural, food and beverage, or wood processing companies in developing countries. Most likely, they have a biomass resource on-site in the form of a byproduct or waste from their core business that may be used for energy production and hence used to replace existing energy sources.

The development of a biomass-to-energy project requires careful preparation, and it is hoped that this guide will help project developers and investors prepare successful projects, adopting industry best practices in the development, construction, operation, and financing of biomass-to-energy projects. To facilitate this, the guide provides reference knowledge for key types of biomass-to-energy projects on technical, financial, and environmental aspects as well as issues related to grid access, offtake agreements, biomass availability, sustainability, and the supply chain.

This guide is written mainly for developers and investors in energy production from bio-waste generated from the agricultural, food and beverage processing, and wood processing sectors in developing countries and emerging economies. However, much of the technical content is equally relevant to broader applications and is likely to be helpful to readers who are keen on deepening their understanding of the biomass-to-energy sector.

We hope that you find this guide useful.



**Milagros Rivas Saiz**

*Global Head of Cross-Industry Advisory*

International Finance Corporation

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# EXECUTIVE SUMMARY

The International Finance Corporation presents this guide as a practical tool for developers of and investors in biomass-to-energy projects to help them assess the technical and financial feasibility of the different biomass-to-energy options available to their businesses and industries.

The guide specifically covers modern biomass-to-energy technologies where the biomass is derived as residues from the agricultural (including livestock and biomass from any crop), food and beverage processing, and wood processing sectors.

The guide discusses three general types of proven technologies for producing steam/heat and electricity from biomass: steam technology (combustion), Organic Rankine Cycle (ORC) technology, and biogas technology. The technologies differ by plant capacity and target different types of biomass (see Table A).

The project owner and/or the project developer need to have a detailed overview of the various options when initiating a biomass-to-energy project. These options relate to both the technologies and the actions necessary to take the project from conceptualization to a successfully completed and operating biomass project.

The project development and implementation can be broken down into the following stages:

<b>1. Project development</b>	<b>2. Project implementation</b>
1.1 Project idea	2.1 Design
1.2 Pre-feasibility study	2.2 Construction
1.3 Feasibility study	2.3 Commissioning
1.4 Contracts and financing	2.4 Operations
	2.5 Decommissioning

A project owner must carefully consider a number of issues that present potential barriers before proceeding with development. The most important concerns are:

- Is biomass available at a guaranteed quality, quantity, and price?
- Is a site with proper access and size available at reasonable costs?
- Is there sufficient biomass project development experience and financial strength?
- Is financing available at reasonable terms and conditions?
- Is a well-defined market available for the export of energy (electricity and/or steam/heat), offering long-term secure prices to make the project financially feasible?
- Is a grid connection available within a short distance, and is connection possible at reasonable terms (in case

**Table A:** Overview of Proven Biomass-to-Energy Technologies and Plant Capacity\*

Technology/Range	1–5 MWe (4–20 MWth)	5–10 MWe (20–40 MWth)	10–40 MWe (40–160 MWth)
Combustion plants using a water/steam boiler	●	●	●
Combustion plants using ORC technology	●	●	n.a.
Biogas production with gas engine	●	n.a.	n.a.

Source: COWI.

\* Steam technology and ORC technology apply to fuels with a moisture content below approximately 60 to 65 percent, whereas biogas technology (anaerobic digestion with gas engine) applies to fuels with a moisture content above 60 to 65 percent.

the project is not developed solely for self-supply of electricity and/or heat/steam)?

- Is national (and any regional or international) legislation in favor of this type of project, and can planning and environmental approval be expected?

Furthermore, the project owner should identify and mitigate any potential regulatory risk to the project. The most common regulatory risks are:

- Availability of policy support measures necessary for project viability
- Changes in political priorities that may reduce attractiveness of regulatory regime
- Planning and environmental permits are not obtained in a timely manner.

When initiating a biomass project, the amount, quality, and availability of the biomass is essential for the success of the project. This guide includes a characterization of 35 different types of biomass, including their calorific value (energy content of the fuel), biogas potential, chemical composition, ash content, and moisture content. The guide also explains the elements needed to secure biomass availability, including supplier agreements, realistic transport distances, and acceptable costs of collection, transport, and storage. It provides the approximate amounts of biomass necessary for different plant sizes and technologies (based on certain criteria for calorific value, load profile, etc.) (see Table B).

Once the technology has been chosen and sufficient amounts and quality of biomass are confirmed, procurement and contracting of the biomass plant becomes relevant. There are several ways of transferring the responsibility from the

owner of the plant to the contractor(s), listed below in order of increasing responsibility for the contractor:

- Traditional contracts with division of the plant into a number of partial contracts with separate detailed designs
- DB (Design–Build) / EPC (Engineering, Procurement, Construction) / Turnkey contract with one contractor being responsible for the design and construction for the entire plant
- DBO (Design–Build–Operate) / BOT (Build–Operate–Transfer) type contracts where the contractor also operates and maintains the plant
- DBFO (Design–Build–Finance–Operate) where the contractor takes full responsibility for the provision of a biomass-based power plant and is remunerated through the sale of heat and power.

The decision of the type of contract will depend on the degree to which the biomass plant is integrated with the owner’s existing facilities and the owner’s ability and willingness to transfer design decisions, operational control, and project risks to the contractor.

During the construction phase, special attention must be given to the time schedule and follow-up on progress, the handling of claims for extra work, the handling of risks related to the project, and the environment, health, and safety (EHS) aspects.

When the construction of the plant is completed, it is time for the commissioning phase, which includes training, cold testing, hot testing, functional testing, and trial operation.

A financially viable business case is essential for securing financing for any project. To support the business case

**Table B:** Overview of Needed Biomass Quantities

Technology/Range	1–5 MWe	5–10 MWe	10–40 MWe
	Minimum input (GJ/day)*		
Combustion plants using a water/steam boiler	20 tons/day–100 tons/day	100 tons/day–200 tons/day	200 tons/day–900 tons/day
Combustion plants using ORC technology	50 tons/day–200 tons/day	200 tons/day–500 tons/day	n.a.
Biogas production with gas engine	40 tons/day–200 tons/day	n.a.	n.a.

Source: COWI.

estimates, this guide provides indicative estimates of the capital expenditures (CAPEX) and operational expenditures (OPEX) for the different technologies and for different sizes of plants (see Table C).

Another important factor when securing financing is formalizing of the agreements with biomass suppliers and heat/power buyers. Once the terms of these agreements have been established, the project developer will have concrete knowledge of the input and output of the plant. This will enable the developer to conduct a realistic financial analysis, which is the basis for a bankable feasibility study to be used for ensuring financing.

Before initiating the search for finance, the project developer should bear in mind the following:

- The process of acquiring finance can be time consuming.
- The technical, contractual, and permitting aspects of a biomass-to-energy project all affect the opportunities for securing financing.
- Project lenders will carefully assess all aspects of the project, with specific attention to the risks involved. Therefore, attention to detail, risk mitigation, and anticipation of lender concerns are very important.

When addressing financial institutions, it is a prerequisite that the project developer be able to present a financial viable business case. This is important for both small and large-scale biomass projects. A financial business case should be conducted with the following issues in mind:

- Be seen from the investor’s perspective
- Be based on market prices (include taxes, tariffs, and subsidies, but not externalities)

- Reflect the underlying project risks and the identified mitigation measures.

There are many different ways of securing financing for a biomass-to-energy project. The most common ways are:

- Own funds (equity)
- Bank loans (from international commercial banks, local banks, and development banks or multilateral financing institutions)
- Investment by technology supplier
- Investment by biomass supplier (could be cooperatives of farmers or biomass processing companies with significant bio-waste quantities)
- Build–Operate–Transfer (a third party takes the responsibility of financing, designing, building infrastructure, and operating the plant for a fixed period)
- Private equity funds.

This guide focus primarily on secondary and tertiary bio-residues, as the social and environmental risks associated with using primary biomass for energy purposes are much higher. It is therefore important that the main biomass input is bio-residues to ensure environmental and social sustainability.

The development of a biomass-to-energy project requires careful preparation. It is hoped that this guide will help project developers and investors prepare successful projects that adopt industry best practices in the development, construction, operation, and financing of biomass-to-energy projects, thereby paving the way for an increase in these projects.

**Table C: Typical Investment Costs, Best Available Techniques (CAPEX)**

Plant Size (MWe)	Steam Cycle CAPEX* (\$/kW)	ORC CAPEX (\$/kW)	Biogas CAPEX (\$/kW)
1–5	5,000–10,000	3,000–8,000	3,500–6,500
5–10	4,000–8,000	2,000–5,000	n.a.
10–40	3,000–6,000	n.a.	n.a.

Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.

\* Capital expenditure: European basis, indicative minimum and maximum costs. For other geographical areas, see Figures 12–2, 12–3, and 12–4.



Source: COWI.

Biomass resources are found almost everywhere and can become a reliable and renewable local energy source to replace fossil fuels. Energy produced from biomass can reduce reliance on an overloaded electricity grid and can replace expensive fuels used in local industries.

The International Finance Corporation (IFC) presents this guide as a practical tool to help developers of and investors in biomass projects assess the technical and financial feasibility of the different biomass-to-energy options available to their businesses and industries.

The target audience is medium-to-large enterprises for which biomass is a byproduct, including, but not limited to, the food and beverage industry, the wood processing industry, and forestry and agriculture in developing countries. Most likely, these enterprises already have identified a biomass resource as a byproduct or waste from their core business and can use the energy for captive purposes, with grid sales as a secondary goal. The focus here therefore is not on primary biomass sources, except to supplement the on-site biomass.

## 1.1 BACKGROUND

Solid biomass—including fuel wood, charcoal, agricultural and forest residues, and animal dung—traditionally has been used for energy in rural areas of developing countries, alongside traditional technologies such as open fires for cooking, kilns, and ovens for small-scale agricultural and industrial processing. Often, the use of traditional biomass-to-energy technologies has been beneficial to local communities, but this approach continues to lead to high pollution levels, forest degradation, and deforestation.

The present guide concerns modern biomass-to-energy technologies where electricity and steam/heat are derived from the combustion of solid, liquid, and gaseous biomass fuels in high-efficiency and low-emission conversion systems.

The guide also includes biogas, where organic matter (such as agricultural residues, animal wastes, and food industry wastes) is converted into biogas through anaerobic digestion. The raw biogas can be combusted to produce electricity and/or steam/heat, or it can be transformed into bio-methane and used as a substitute for natural gas in internal combustion engines. This guide does not cover biofuel technologies such as liquid fuel ethanol and biodiesel intended for use as transport fuel in vehicle engines.

Biomass-to-energy is a sustainable solution that can reduce greenhouse-gas emissions to the atmosphere, assuming the use of secondary and tertiary biomass to substitute the use of fossil fuels. Agricultural and forest-based industries in developing and emerging economies generate a substantial amount of biomass residue and waste that could, in principle, be used for energy production.

However, the development of a biomass project is complex and requires careful preparation. The absence in many developing countries and emerging economies of high-quality project documentation that substantiates the technical, financial, and socioeconomic feasibility of biomass projects is a key barrier for access to funding for these projects.

Against this background, IFC has requested COWI to develop this guide for developers and investors. The guide provides reference knowledge for key types of biomass-to-energy projects on technical, financial, and environmental aspects as well as issues related to agreements for the sale of steam/heat and electricity and grid access, in addition to biomass availability, sustainability, and the supply chain.

The overall objective of this guide is to build competence among key stakeholders. Improved knowledge of the technical and financial feasibility of the different biomass-to-energy technologies available to business and industry may lead to



Source: COWI.

an expansion of biomass-to-energy projects in developing countries and emerging economies, as well as elsewhere.

This guide is written mainly for developers and investors in energy production from biomass surplus or waste generated from small, medium, and large-sized firms that operate in the agricultural, food and beverage processing, and wood processing sectors.

## 1.2 SCOPE

The scope of this guide is to provide project developers in developing countries with an approach and methodology for developing a biomass project, while at the same time giving them the ability, on an initial level, to assess the quality of their biomass and the corresponding most-suitable technologies.

To assess the quality of the available biomass, this guide includes a characterization of 35 of the most common types of biomass available in developing countries. The biomass included in this guide is primarily waste products from the agricultural and forestry sectors and from industry. The main focus is on secondary and tertiary biomass types; primary biomass is included only as a supplemental energy source, if other sources are unavailable.

Once the available biomass has been assessed, a suitable technology has to be selected. This guide presents three general types of technologies to provide the project developer with the insight to perform an initial project assessment and development. The three technologies in focus are:

- Combustion plants using a water/steam boiler
- Combustion plants using Organic Rankine Cycle (ORC) technology
- Biogas technology using a gas engine.

This guide furthermore distinguishes between plant sizes, as biomass-to-energy projects are subject to significant economies of scale. The projects are divided into the following ranges:

- Small (1–5 MWe)
- Medium (5–10 MWe)
- Large (10–40 MWe).

Table 1–1 provides an overview of the key technologies and the typical plant sizes in which they are applied.

Technology descriptions in this guide are based on Best Available Techniques (EU BAT Reference Documents

**Table 1-1: Overview of Technologies and Plant Sizes**

Technology/Range	1–5 MWe (4–20 MWth)	5–10 MWe (20–40 MWth)	10–40 MWe (40–160 MWth)
Combustion plants using a water/steam boiler	●	●	●
Combustion plants using ORC technology	●	●	n.a.
Biogas production with gas engine	●	n.a.	n.a.

Source: COWI.

(BREFs) and BAT Conclusions (IPCC, 2015)). International standard prices as of early 2016 are applied, scaled to the specific world regions based on their typical relative price level differences. Local conditions, specific local context, and the market situation at the time of procurement may influence actual procurement prices, so these cost estimates should be used with caution.

### 1.3 GUIDE STRUCTURE

This guide describes all the necessary steps in the development of a biomass-to-energy project. Following this introductory chapter, we present an overview of the entire project development process, so that project developers have an idea of the overall process they are about to enter. Next, the guide describes biomass resources and how to secure biomass supply. This is followed by several in-depth chapters covering the technology aspects, plant design, plant procurement, construction, and operation. After the more technical aspects, the guide focus on framework conditions, investment costs, financial and economic analysis, and securing financing. Finally, the guide presents potential environmental and social considerations and concludes with a chapter on the lessons learned from implemented biomass-to-energy projects.

#### The guide structure:

- Chapter 1: Introduction to Biomass-to-Energy
- Chapter 2: Project Development Process
- Chapter 3: Biomass Resources
- Chapter 4: Securing Biomass Supply
- Chapter 5: Energy Conversion Processes
- Chapter 6: Plant Design and Permitting
- Chapter 7: Procuring the Biomass Plant
- Chapter 8: Construction and Commissioning
- Chapter 9: Operation and Maintenance of Biomass Plants
- Chapter 10: Regulatory Framework
- Chapter 11: Commercial Aspects
- Chapter 12: Typical Investment and Operation and Maintenance Costs
- Chapter 13: Financial and Economic Analysis
- Chapter 14: Financing Biomass Projects
- Chapter 15: Environmental and Social Considerations
- Chapter 16: Lessons Learned from Biomass Projects
- Appendix A: Screening List
- Appendix B: Characterization of Biomass
- Appendix C: References



Source: COWI.

This chapter presents an overview of the development process from the point of view of both project owners and professional project developers. It begins with the concept of a biomass project, describes the complexity of such projects, presents the stakeholders involved, and discusses the stages of project development and implementation.

## 2.1 PROJECT CONCEPT

### 2.1.1 HOW IS THE PROJECT IDENTIFIED?

A biomass project can provide many advantages, such as:

- Offering a cheaper and more stable energy supply (electricity, steam, heat) for an industrial process
- Improving the economy of the industrial business by exporting surplus electricity, heat, or steam produced from biomass residues
- Providing an environmentally friendly solution to the energy needs of an industry or a local community (district heating or cooling)
- Reducing greenhouse-gas emissions by substituting fossil fuels such as oil, gas, or coal with biomass
- Reducing a potential industrial or agricultural waste disposal problem.

One or more of these reasons may lead to the idea to develop a biomass project. The owner of an industrial enterprise or a professional project developer may identify an opportunity for a potential biomass project. It will then take the combined efforts of a larger group of stakeholders to bring the idea to fruition in the form of a successfully operating project.

### 2.1.2 ENERGY DEMAND

A successful biomass project brings together a source of biomass with an energy demand. This may result in different plant types and sizes.

Two types of energy use:

1. Electricity generation and/or heat/steam for in-house consumption
2. In-house consumption plus export of electricity/heat/steam/district heating

#### *ELECTRICITY GENERATION AND/OR HEAT/STEAM FOR IN-HOUSE CONSUMPTION*

All industrial plants use electricity for processing, and many need heat in the form of steam or hot water. If the proper match exists between available biomass resources and energy demand at the plant (power and heat), a cogeneration plant may be developed. If biomass resources are limited and there is a process demand for steam/heat, it may be preferable to design the plant for heat production only. The technology is simpler, operation and maintenance are easier, and the capital cost is less.

#### *IN-HOUSE CONSUMPTION PLUS EXPORT OF ELECTRICITY/HEAT/STEAM/DISTRICT HEATING*

When biomass resources exceed the energy demands of the industrial plant, this may become a local energy center based on biomass as fuel. The plant may export surplus energy to nearby industries in the form of electricity and heat (steam or hot water). In cooler climates, biomass also may feed a district heating system for the surrounding community. This type and size of project will demand careful planning, as the technology is more complicated, the time and cost of the project development is more demanding, and the risk is greater.

## 2.1.3 BIOMASS RESOURCE

### Two types of biomass sources:

1. Energy production units using biomass residues from industrial production
2. Energy production units based on available residues from agricultural crops and forestry wastes

### *ENERGY PRODUCTION UNITS USING BIOMASS RESIDUES FROM INDUSTRIAL PRODUCTION*

Industrial facilities may develop energy plants using their own biomass residues. The biomass may consist of, for example, waste from wood processing industries, distillery waste, ethanol production waste (lignin), bagasse from sugar production, etc.

As a starting point, the biomass plant produces electricity and/or steam/heat for the industry's own use, but it may also export excess electricity and/or heat.

In case of seasonal industrial production, such as a season or campaign at a sugar mill, the energy production plant may be used outside the campaign to export electricity and heat. This will require that the plant be designed for off-season operation (typically the turbine needs to be an extraction/condensing type instead of a backpressure turbine).

Supplementary fuels will be needed outside the campaign, so it is important to secure that the biomass plant is able to operate fully on the two different types of biomass.

### *ENERGY PRODUCTION UNITS BASED ON AVAILABLE RESIDUES FROM AGRICULTURAL CROPS AND FORESTRY WASTES*

This option represents projects based on the recovery of residues from the forestry and agricultural sectors. In this case, there may not be an existing industrial facility to use the electricity, steam, or heat produced. An exception could be an industry owning, for example, fields for sugarcane production, wheat grain production, oil plantations, or fruit plantations (mango, pineapple, etc.).

The residues from forestry and agriculture also may be used as a supplementary fuel source for industrial biomass plants.

If no suitable industrial facility exists to use the available forestry and agricultural residues, a new biomass plant may be established to supply electricity and/or district heating for a local community.

This is outside the scope of this guide, but many considerations and recommendations of this guide are relevant and may be useful for that purpose.

## 2.1.4 IS ENOUGH BIOMASS OF PROPER QUALITY AVAILABLE?

The most important question to ask is whether sufficient biomass (at guaranteed long-term quality, quantity, and price) is available from the industrial facility's own production, perhaps supplemented by local agricultural or forestry biomass wastes.

Before investing in a biomass plant, the project owner must be certain that sufficient biomass is available to keep the plant running and to ensure a financially viable project. If the project owner fails to convince the potential investors of the project's financial viability, the project is unlikely to obtain financing on reasonable terms.

Table 2–1 shows the minimum amount of biomass necessary for the project to be technically viable.

**Table 2-1: Biomass Amounts and Plant Sizes**

Technology/Range	1–5 MWe	5–10 MWe	10–40 MWe
	Minimum input (GJ/day)*		
Combustion plants using a water/steam boiler	20 tons/day–100 tons/day	100 tons/day–200 tons/day	200 tons/day–900 tons/day
Combustion plants using ORC technology	50 tons/day–200 tons/day	200 tons/day–500 tons/day	n.a.
Biogas production with gas engine	40 tons/day–200 tons/day	n.a.	n.a.

Source: COWI.

\* Biomass tonnages at an average caloric value of 10 megajoules per kilogram, assuming 100 percent load.

## 2.2 MOVING FROM IDEA TO CONCEPT

The project owner must carefully consider a number of issues before proceeding with the development. Aside from having sufficient biomass of the proper quality, the most important barriers are listed below.

### Important project barriers:

1. Is a site with proper access and size available at reasonable cost?
2. Does the project owner have sufficient strength to close the project?
3. Is financing available at reasonable terms and conditions?
4. Is a well-defined market available for export of energy (electricity and/or steam/heat), offering long-term secure prices and making the project feasible?
5. Is a grid connection available within a short distance, and is connection possible at reasonable terms? (This is not relevant if the project is developed only for self-supply of electricity and/or heat/steam.)
6. Is national (and any regional or international) legislation in favor of this type of project, and can environmental approval be expected?

Additional questions to be considered are also listed below. To support these considerations, Appendix A provides a screening list to be used by project owners and/or project developers.

### SITE IDENTIFICATION

The use of biomass residues requires a proper site adjacent to the industrial facility with sufficient space for the storage, potential processing, and feeding of the biomass residue. Additional space must be available for the biomass plant itself and for the residues from the combustion process. If supplementary biomass fuel is needed from outside sources, proper access roads are important.

Potential plant sites must be identified if space is limited at the industrial site or if the project is planned for the use of forestry or agricultural residues. In this respect, the following considerations are necessary:

- What is the cost of suitable and available sites?
- Are there any restrictions on their use?
- Is the potential site large enough for the biomass plant and for the necessary biomass storage area?
- How is the infrastructure of the area? For example, connection to grid (if relevant), connection to heat/steam customers (if relevant), road/railway access (if relevant), power supply, sewer connection, raw water supply, etc.
- What is the distance from the biomass resource?
- Is sufficient storage space available to accommodate interruptions in external fuel supply (rainy season, blocked roads, etc.)?

### PROJECT DEVELOPMENT

The development of a biomass project may take long and be complicated and costly. The success of the project depends entirely on the strength of the project owner/ project developer in terms of available time, technical and economical insight, and access to sufficient funds to develop the project.

### IMPORTANT QUESTIONS

- The development process may require substantial assistance from specialists with experience in engineering, architecture, environment, legal issues, and economy/finance. What can the project owner do, and when will external assistance be needed from

consultants and advisers? Are the necessary advisers available, and what would be the associated costs at each stage of the project development?

- What would be the timeline for project development, and is this realistic in terms of authority approvals, etc.?
- Are potential government incentives or subsidies available within the timeframe of the project?

#### *BIOMASS SOURCING (SUPPLEMENTARY FUEL OR FORESTRY/AGRICULTURAL PROJECTS)*

- Is sufficient biomass available, and from whom/where?
- Is seasonality or the rainy season an obstacle?
- How is the biomass stored until delivery to the plant (at the biomass supplier's place)?
- Who delivers the biomass, and what is the contractual setup?
- How is the quality of the biomass verified?
- What is the price and the payment mechanism (weight, moisture content)?

#### *TECHNICAL ISSUES*

- Is the biomass waste appropriate as a fuel for energy production?
- Is potential corrosive behavior of the fuel acceptable for technology providers?
- If supplementary biomass fuels are needed, can the biomass plant operate without limitations on both on-site and off-site sourced fuels? (Fuel handling, steam boiler, and flue gas cleaning are important points to consider.)
- Is it technically and economically feasible to convert the biomass waste to electricity/heat?
- Is sufficient biomass fuel available, and, if not, are supplementary fuel sources available, and at what cost and terms?
- Is a connection to the grid possible at the correct voltage (if export of power is relevant)?
- Is a connection for the supply of steam and/or heat to nearby industries or district heating networks accessible (if export of heat and/or steam)?

- Who will pay for the transmission line to the grid connection point and for the heat/steam connection?
- How is biomass handled and stored at the site?
- How is backup energy supply secured (in case of plant breakdown, lack of biomass supply, etc.)?

#### *OPERATION AND MAINTENANCE*

A biomass plant is a technically complex setup that requires staff with sufficient skills unless operation and maintenance is outsourced to an operation and maintenance operator under a long-term contract.

- Will the plant's own staff carry out maintenance, or will it be outsourced?
- Are staff with required skills locally available to manage and operate the plant?
- Will the plant have a high degree of automation, thus reducing the need for manpower? (This may require more highly skilled staff.)
- Are disposal routes for ashes available?

#### *LEGISLATION*

- Is national (and any regional or international) legislation in favor of this type of project, and can planning and environmental approvals be expected?
- Does legislation allow such facilities?
- What are the local and national emission limits that need to be met? What is the associated cost?

#### *FINANCING*

- Who will be the owner and operator of the project?
- Is the project financially viable, and are potential risks identified and adequately mitigated?
- Does the project have access to sufficient financing from internal sources, or will external financing from financial institutions be necessary for implementation?
- Is financing available at acceptable terms and costs?

## PROJECT ECONOMY

- Is the project dependent on external sale of energy? If yes, is there a market for the sale of electricity, process steam, or heat to outside customers?
- What terms can be obtained for connection to and sale of electricity to the grid, including available support mechanisms for renewable energy such as feed-in tariffs, clean energy certificates, etc.?
- Is there a tariff for the sale of heat and/or steam?
- Can the feed-in tariff be guaranteed, and what are the commercial terms and timeframe?
- Is the anticipated project revenue sufficient to generate a return on investment commensurate with project risks?

A thorough discussion and assessment of energy demand, biomass resources, site selection, and many of the other issues stated above is crucial in order to continue the development of a biomass project.

Some issues may still be left open, but the more important questions must be resolved with a favorable answer if the project development shall proceed and the time and money be spent.

The size and complexity of a project will guide the development process. Is the proposed project small or large; will it supply energy for a single industry only or will it export to others; will energy be produced as electricity or steam/heat, or perhaps energy cogeneration?

These considerations and the approach to take are discussed in more detail in the following.

## 2.3 COMPLEXITY OF THE DEVELOPMENT PROCESS

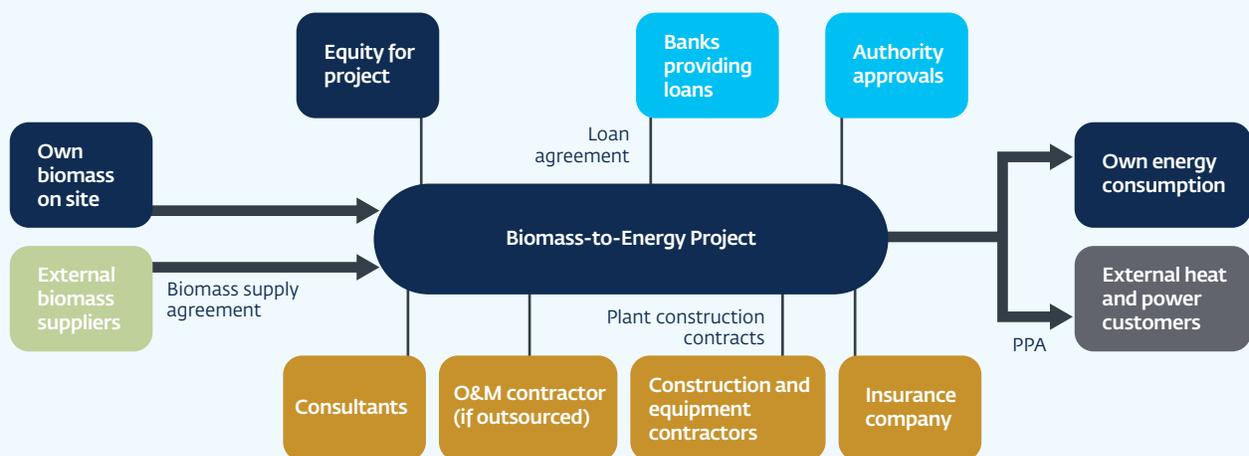
### 2.3.1 MEDIUM-SIZED, COMPLEX PROJECTS

When a biomass project has been identified, more-thorough studies and considerations must be made in order to develop the project.

The development of a biomass project is complex and requires careful preparation with the support and involvement of several stakeholders. The development of a project, including all necessary permits from the environmental authorities, may take as many as one to three years depending on the location, financing, and procurement process—potentially leading to high project development costs. It is therefore of utmost importance to know the route to follow and the barriers and constraints that need to be managed in order to achieve a project that is technically well functioning and financially viable. This section defines the stages and details the requirements for key initial considerations, studies, and documents.

Figure 2–1 shows the main agreements for a biomass project. The agreements concern biomass supply, financing, contractors/consultants, and energy sales—all aspects vital for a financially sustainable project. If these agreements are missing, the project developer faces large risks.

**Figure 2-1:** Main Contracts for a Biomass-to-Energy Project



Source: COWI.

Plant procurement may take place in various ways,

- As a turnkey/EPC contract
- As EPC/turnkey for the electro/mechanical equipment
- In multiple lots with separate contracts (e. g., for the turbine/generator, steam boiler, etc.).

Likewise, the civil construction can be split into several contracts. This is discussed in more detail in Chapter 7.

An operation and maintenance contractor is relevant only if operation and maintenance are outsourced instead of the plant having its own operation and maintenance personnel.

External heat and power customers are not relevant if the biomass plant only produces electricity and/or process steam/heat for own-consumption by the industrial plant.

### 2.3.2 SMALL AND LESS-COMPLEX PROJECTS

Small plants are often developed to serve a single industry, producing the quantity and quality of biomass residue to meet the industry's own energy requirements. The energy could be in the form of electricity and/or heat (steam). This type of project is usually less complex, less controversial, and less costly than many larger projects; as such, development may proceed more quickly.

An example of this is the owner of a small industrial plant who wishes to develop an energy production unit using biomass as the fuel. The owner has access to the necessary funds for the development, and biomass fuels of acceptable quality and sufficient quantity are available in the area. The energy needed could be in the form of electricity and/or heat (steam).

The owner should still ensure that the basic requirements for a successful project are observed with respect to:

- Financing available at acceptable terms
- Permits (planning, environment and community relations, etc.)
- Infrastructure (access roads, utilities, etc.)
- Fuel supply (quality, quantity, transport, storage, cost, contract terms, etc.)

- Technology (fuel preparation, combustion, energy recovery and use, etc.)
- Staffing (quality of personnel for operation and maintenance, etc.)
- Energy backup
- Contractors/consultants
- Project risk evaluation.

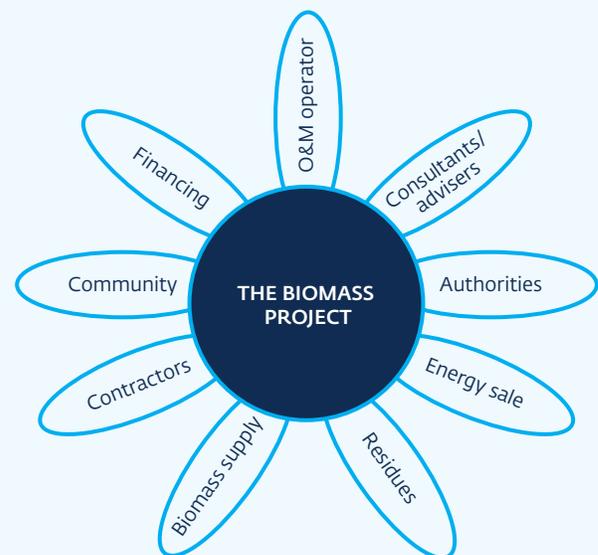
If the owner's evaluation of the issues listed above is favorable and the owner is capable of financing the project from his or her own funds or from local banks, the owner may be able to develop and procure the project locally and complete the project quickly.

## 2.4 STAKEHOLDERS

The success of a biomass project often depends on the attitude of various stakeholders, including the authorities, biomass suppliers, energy customers, and local stakeholders (among them nongovernmental organizations and various community groups).

Figure 2–2 gives an overview of the many different stakeholders that may influence or be involved in the development of a biomass project. The text below describes their different roles.

**Figure 2-2:** Stakeholders of the Biomass Project



Source: COWI.

**The Biomass Project** represents the proposed scheme and its developer/owner. If the biomass plant is established as an SPV (Special Purpose Vehicle), the owner becomes a stakeholder as the SPV is an independent legal entity.

The stakeholders are presented in alphabetic order below:

**Authorities** include national bodies that will examine the project from a national statutory and planning position as well as from an environmental and a working environment/health point of view. Authorities also include local authorities (which may include the municipality) with the mandate to issue local planning and construction permits, traffic regulations, fire certificates, licenses to connect to wastewater sewers (and to the electricity grid, if applicable), etc.

**Biomass supply** represents an agreement (if necessary) with outside biomass suppliers. In the case of a project using waste material produced from the manufacturing process of the owner's industrial plant, such agreement probably will not be required. This may, however, be the case if the in-house production of biomass residues is insufficient to meet the industrial plant's need for energy. Biomass supply agreements will be required if the project is designed for the use of external agricultural or forestry biomass wastes (for example, as supplementary fuel due to seasonal variations of the primary biomass or to achieve economies of scale).

**Consultants/Advisers.** In addition to the capabilities of their own organization, the owner may need outside advice and support from consultants within technical, environmental, legal, commercial, and financial areas.

**Contractors.** At some point, a decision should be made on whether to use a turnkey contractor or to rely on separate contracts for the process plant and a civil contractor for building and civil construction work. Further contract breakdown may include, for example, separating the turbine/generator and the fuel-handling equipment from the steam generator and the flue gas cleaning. There are variations to these two main options, and all will require a different set of contract agreements.

**Community.** Well-managed, early community engagement is an important factor to decide the success or failure of

a project. Local citizen groups may support the project but also will be concerned about potential negative environmental and social impacts. It will be essential to consult with communities on their concerns and to incorporate results of the consultation in the design of the environmental and social risk and impact mitigation strategy.

Project-related traffic could be an important issue to manage if external biomass is necessary, as many trucks will enter the biomass plant every day. On the other hand, transport creates job opportunities that may benefit the local economy.

**Energy sale** represents the necessary agreements with the buyers of electricity and/or heat/steam.

Power may be used by the industrial company that owns the biomass plant (captive power). Alternatively, it may be sold to another industrial consumer or it may be sold to a utility company.

A power purchase agreement (PPA) with the national or local (as may be) power company or agency or with an industrial user/consumer will stipulate the terms and price for taking and paying for any surplus electricity from the biomass plant. It may include a commitment on the part of the biomass plant to produce power for a minimum number of hours during the year.

Energy sale also may include the sale of any surplus heat in the form of hot water or low-pressure steam to adjacent industries or to a district heating/cooling company.

**Financing.** The source of finance for this type of project could be company- or investor-owned funds, but usually it involves a financial institution. Lenders are typically international commercial banks, local banks, and development banks or multilateral financing institutions (for example, IFC). Owner equity or third-party investors, such as technology suppliers, also may be an option.

**O&M operator.** Three options may be relevant. The biomass plant may be operated from the industrial plant's control room or from a control room at the biomass plant with its own personnel. Another option is to engage an O&M contractor, who is responsible for operation and maintenance on a long-term contract. A third option is to enter into



Source: TGM, 2016, [www.grupotgm.com.br](http://www.grupotgm.com.br); COWI A/S, [www.cowi.com](http://www.cowi.com).

<b>Name and location:</b>	Tres Valles, Mexico
<b>Project:</b>	Power plant at sugar mill in the province of Veracruz in Mexico
<b>Description:</b>	Grate-fired boiler producing process steam and electricity for the sugar mill. Surplus electricity is exported to the owner (soft drink producer) via the grid.
<b>Boiler data:</b>	65 bar / 510 °C / 250 tons of steam per hour
<b>Turbine output:</b>	40 MW gross power output + 50 tons of extraction steam per hour (28 bar, 392 °C)
<b>Fuel:</b>	Sugarcane bagasse

a Design–Build–Own–Operate (DBOO) contract for the biomass plant. This is a joint, long-term contract with one counterpart to design, build, finance, and subsequently operate and maintain the biomass plant.

**Residues** represent an agreement with a waste hauling/disposal contractor to remove and dispose of all residues from the plant in accordance with local and national environmental rules. Disposal of residues also may be included in a biomass supply agreement or handled by the industry owner.

There may be opportunities to use the residues as fertilizer, which could provide cost savings and/or an additional revenue stream.

## 2.5 OVERVIEW OF PROJECT STAGES

The development and implementation process for a biomass project can be broken down into development and implementation of the project.

### PROJECT DEVELOPMENT (PREPARATION)

- 1.1 Project idea
- 1.2 Pre-feasibility study
- 1.3 Feasibility study
- 1.4 Contracts and financing

### PROJECT IMPLEMENTATION

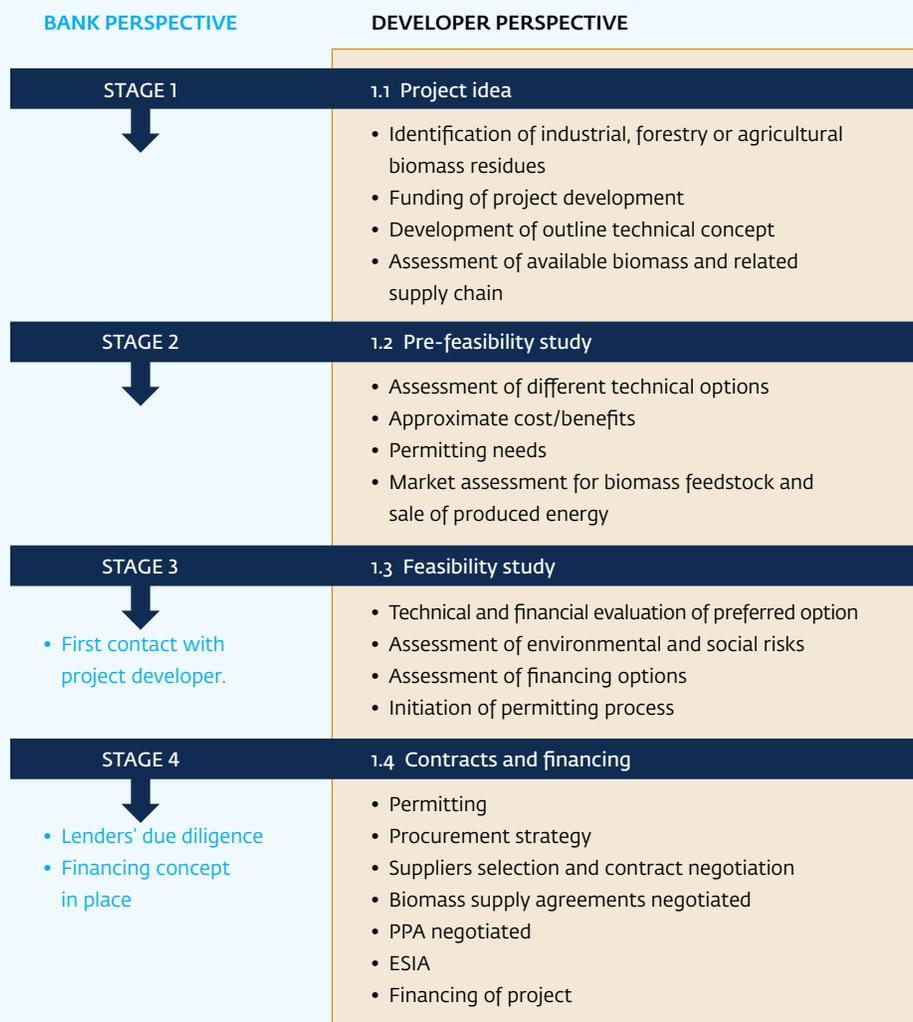
- 2.1 Design
- 2.2 Construction
- 2.3 Commissioning
- 2.4 Operations
- 2.5 Decommissioning

Project development stages 1.1 to 1.4 take the project from the conceptual ideas/thoughts until the final investment decision (FID) is taken by the owner. At the end of stage 1.4, due diligence is conducted by the financial institutions, and the financing concept is finalized. Figure 2–3 shows the entire route to follow for project development (from the perspectives of project developers and of banks) and highlights the main activities. The development stages are described in more detail in Section 2.6.

Figure 2–3 shows the “standard procedure” for new projects, especially if external financing is involved. If the project is fully owner-financed, many of the steps may be avoided or reduced. This may be the case for many industrial biomass projects.

Figure 2–4 shows the entire route to follow for project implementation, from the perspectives of project developers and of banks.

**Figure 2-3: Project Development Stages**



Source: IFC, 2015; COWI.

Implementation stages 2.1 to 2.3 take the project from financial investment decision to start of operation of the biomass plant. The implementation phase is described in more detail in Section 2.7.

It should be noted that mandatory requirements stipulated by the banks (signed power purchase agreement, environmental impact assessment in place, etc.) must be met in order to make the loan agreement effective (financial close).<sup>1</sup>

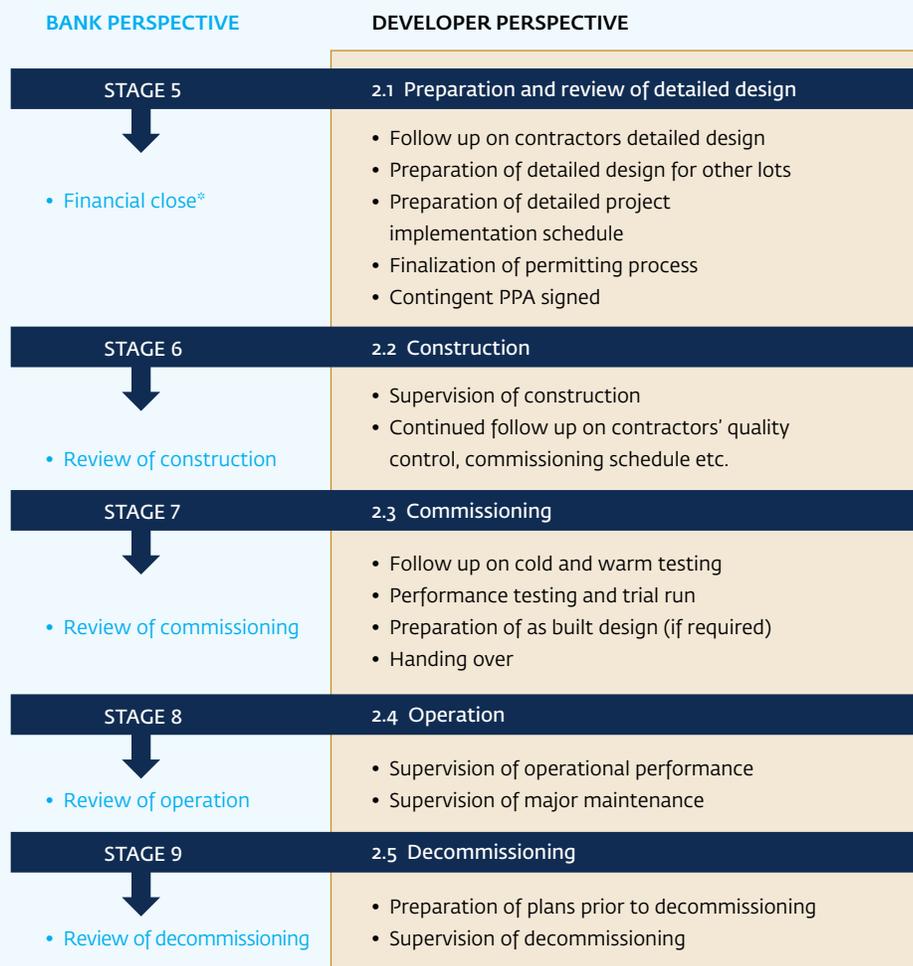
The owner may decide to start the design stage by signing the prepared contract with the EPC contractor. This,

however, is done at the owner's own risk, and the contract therefore must include a clause concerning pending approvals. Typically, a design agreement is signed with the EPC contractor allowing the contractor to start the design but not to order any materials. Reservation of special materials, such as boiler tubes, may be necessary, and this often involves payment of a reservation fee.

Note that a project development and implementation process may not always follow the simple linear progression as shown in Figures 2-3 and 2-4.

<sup>1</sup> Financial close may be reached when the project is already under construction or even in operation.

**Figure 2-4: Project Implementation Stages**



Source: IFC, 2015; COWI.

\* Financial close may be reached when the project is already under construction or even in operation.

## 2.6 PROJECT DEVELOPMENT

### 2.6.1 PROJECT IDEA

An opportunity for a potential biomass project may be identified by the owner of an industrial enterprise or by a professional project developer. This stage is described in more detail in Section 2.1.

### 2.6.2 PRE-FEASIBILITY STUDY STAGE

The pre-feasibility study is the first assessment of the potential project. It is a high-level review of the main aspects of the project, and the purpose is to decide if it is worth taking the project forward and investing further money and time.

The typical pre-feasibility study may cover the following issues:

- Description of the biomass fuel resource (amount, characteristics, price, transport, logistic, need for supplementary fuel, etc.)
- Barriers for the project
- Potential technical concepts (several concepts may be identified and briefly assessed)
- Calculation of expected energy production (electricity, steam, heat)
- Preliminary layout

- Possibility to connect to the electrical grid (distance to grid, voltage level, costs for connection, etc.)
- Preliminary assessment of energy sales (PPA, electricity price, heat price, steam price, etc.)
- Preliminary assessment of alternative sites (access to site, size, connection to grid, sewer, etc.)
- Preliminary assessment of alternative locations
- Preliminary assessment of environmental and social risks and impacts
- Preliminary assessment of construction costs (CAPEX) and operating costs (OPEX)
- Preliminary financial analysis
- Preliminary risk assessment
- Preliminary assessment of necessary permitting and licensing
- Planning and project implementation, including tentative time schedule.

Figure 2–5 shows a typical table of contents for a pre-feasibility study for a biomass project.

**Figure 2-5: Typical Contents of a Pre-Feasibility Study**

1.	Introduction
2.	Conclusion and recommendations
3.	Description of the project
4.	Expected energy production
5.	Power and heat demands
6.	Preliminary environmental impact assessment
7.	Assessment of alternative sites
8.	Layout
9.	Civil engineering design
10.	Electro-mechanical equipment
11.	Grid connection
12.	Cost estimation (CAPEX/OPEX)
13.	Permitting and licensing process
14.	Planning and project implementation
15.	Preliminary financial analysis
16.	Preliminary risk analysis
17.	Appendices

Source: COWI.

#### Time and Cost Implications

Depending on the size and complexity, the associated costs and the time needed may vary substantially. The authorities normally are not involved in a pre-feasibility study, and it therefore can be conducted quite quickly, typically in two to six months.

The associated cost also may vary substantially but is typically between \$20,000 (for a small and less-complicated project) and \$100,000 (for a large and complicated project).

### 2.6.3 FEASIBILITY STUDY STAGE

If the outcome of the pre-feasibility study is favorable, a detailed feasibility study will follow. This feasibility study consists of a significantly more detailed assessment of all aspects of the project. The purpose of the feasibility study is to explore the project in enough detail for the interested parties and stakeholders to make a commitment to proceed with its development.

Financial Institutions involved may require the preparation of a “bankable feasibility study.” The bankable feasibility study may include an environmental and social impact assessment (ESIA).

A well-detailed technical description, rough layout, plant main data, etc. are needed in order to estimate the CAPEX/OPEX and to conduct, for example, a detailed environmental assessment. Consequently, a conceptual design study is necessary.

#### CONCEPTUAL DESIGN

The conceptual design typically comprises:

- Definition of fuel characteristics, such as composition and heating value
- Description of applied technology
- Evaluation of suitable technologies, including fuel handling, combustion system, boiler, ash handling and disposal, flue gas treatment technologies to meet applicable and relevant air emission standards, energy recovery system, etc.
- Assessment of potential plant location(s) following an evaluation of technical, environmental, and economic aspects, and local acceptability

- Initial assessment of capital costs (CAPEX) and operational expenditures (OPEX)
- Assessment of potential use of steam and/or heat. Is it possible to use the heat for industrial purposes, perhaps as steam? Is there a market for district heating/cooling?
- Examination of the connections to the electrical grid, other external offtake customers, water and wastewater services, etc.

A preliminary business case, including cash flow for the project's depreciation period, can be prepared based on the information collected above and on the budgetary figures for CAPEX and OPEX.

### BANKABLE FEASIBILITY STUDY

International financial institutions normally require a full bankable feasibility study to be conducted before financing concepts can be finalized. The following items could be included in a bankable feasibility study, but the exact scope will be determined for each project, since different investors will have different demands for the study. The basis is the data determined under the conceptual design, but normally some items will have to be investigated more thoroughly:

- The conceptual design and required investment
- Secured long-term supply of biomass (volume, heating value/properties, and price)
- Financial and economic analysis including cost-benefit calculations, calculations of net present value (NPV) and internal rate of return (IRR), and similar analyses (see Chapter 13)
- Overview of current regulatory and policy framework relevant to the project
- Assessment of potential additional sources of financing, sensitivity analyses, and risk analyses important to financing institutions (see Chapter 14)
- Assessment of potential risks to the financial viability of the project and suggestions of mitigation measures
- Environmental and social impact assessment, including identification of mitigation measures
- Organization studies of potential O&M service companies
- Procurement plan and identification of potential equipment suppliers and contractors
- Implementation plan, including time and financing schedule.



Source: TGM, 2016, [www.grupotgm.com.br](http://www.grupotgm.com.br).

<b>Name and location:</b>	Mondi Richards Bay, Republic of South Africa
<b>Project:</b>	The replacement of coal (fossil fuel) by biomass residues in an existing co-fired boiler that produces steam at the Mondi operation
<b>Description:</b>	The project activity was designed to increase the use of self-generated bark and to enable the introduction of third-party-generated biomass residues as feed into a co-fired boiler for the generation of steam
<b>Boiler data:</b>	83 bar / 483 °C, chain-grate boiler originally designed for coal
<b>Turbine output:</b>	49 MW + various steam extractions
<b>Fuel:</b>	Biomass residues from chipping facilities, plantagen, and bark

## AUTHORITY PERMITS

Although the permitting process differs by country, there are some similarities, and investors normally seek to obtain all important permits before the final investment decision (FID) is made. At that point in time, detailed design and procurement can start unless the owner intends to proceed at her or his own risk with the planning before FID. This may optimize and reduce the project time schedule (if this is important).

The following elements are normally part of the permitting process:

- Environmental permit based on the environmental impact assessment prepared as per regulatory requirements
- Planning permission
- Building permit
- Power grid connection approval, if relevant
- District heating system, if relevant
- Approval for wastewater discharge, if any.

If the feasibility study indicates that the project is viable, the next stage of the project can be started.

The content of a feasibility study is, in principle, outlined as the pre-feasibility study shown in Figure 2–5.

### Time and Cost Implications

A full bankable feasibility study, including an environmental and social impact assessment, may take as long as 12 to 18 months, depending mainly on the demands for the assessment by the local authorities.

The associated cost also may vary substantially but is typically between \$100,000 for a small and less-complicated project and \$300,000 for the bankable feasibility study.

Depending on the size and complexity, the associated costs and the time needed may vary substantially.

## 2.6.4 CONTRACTS AND FINANCING STAGE

The contracts and financing stage takes the project from the feasibility study to FID by the project owner. This involves moving the project forward on a number of fronts, including outline design and selection of contractor(s).

Selection of contractors can be done several ways via public procurement, including competition among qualified potential bidders, or via a dialogue-based procurement process with one or several potential contractors. The outcome of stage 1.4 is typically an EPC contract ready for signature that allows the project owner to prepare a fairly accurate investment budget.

The time needed for procurement is typically 5 to 12 months.

The procurement process is further described in Chapter 7, and financing is further described in Chapters 13 and 14.

## 2.7 PROJECT IMPLEMENTATION

### 2.7.1 DESIGN STAGE

The key systems and structures will be designed in detail. The completion is generally done by one or several contractors and/or a consultant.

Considerations concerning the design are outlined in Chapter 6.

### 2.7.2 CONSTRUCTION STAGE

The physical construction of the project includes follow-up on the contractor and site supervision.

Chapter 8 outlines the construction issues.

### 2.7.3 COMMISSIONING AND TESTING STAGE

The commissioning stage includes a cold and hot test, a functional test, a trial run, a performance test, and handing over to the owner.

Chapter 8 describes commissioning in more detail.



Source: COWI.

This chapter identifies the most important types of biomass residues and waste streams available for bioenergy production globally and provides an overview and introduction to these different sources of feedstock for biomass-to-energy projects.

The availability, amount, and type of biomass will determine the types of technologies appropriate for the specific biomass project. This approach reflects that a number of generic supply chains will dominate for each type of project based on the availability of biomass and choice of technology. Section 3.2 characterizes the relevant feedstock. Section 3.3 presents the classification of biomass types, and Section 3.4 presents potential resource constraints and how to identify these.

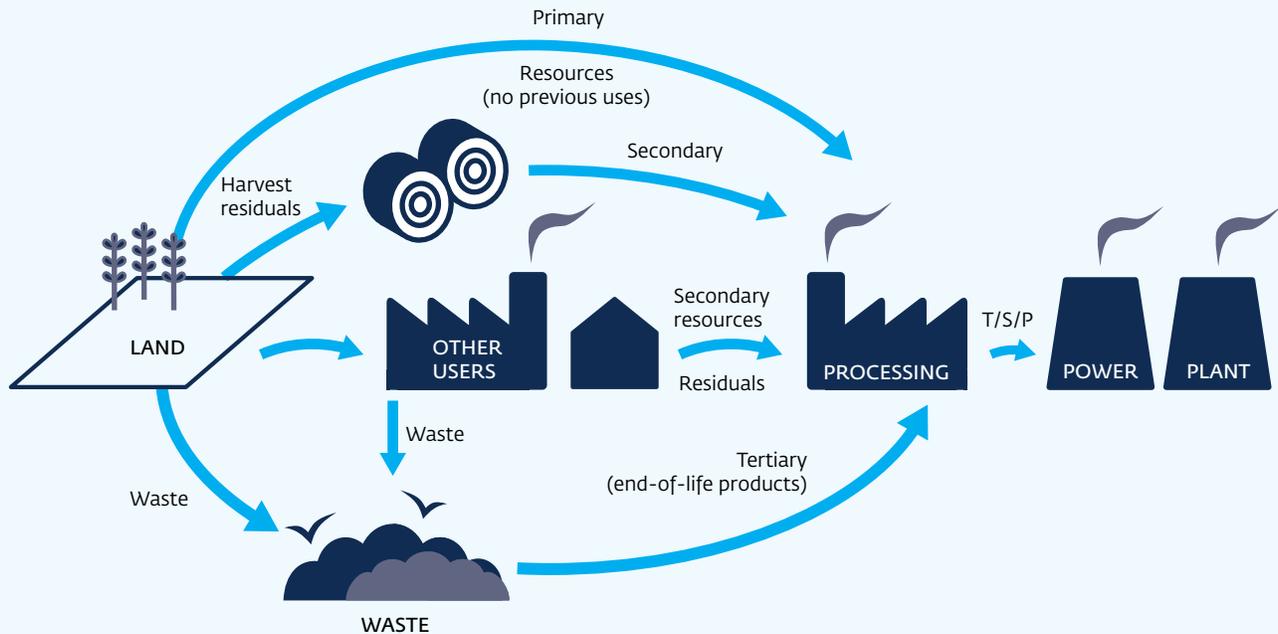
## 3.1 TYPICAL BIOMASS RESOURCES AND SUPPLY CHAINS

Figure 3–1 shows the most suitable biomass types (primary, secondary, and tertiary) and their supply chains.

The figure provides a flow chart for biomass waste and residues available for energy production in developing countries and emerging economies across the globe.

This guide focuses on biomass types that are secondary and tertiary outputs from production. Primary biomass sources for energy production (that is, dedicated energy crops) are another option that can be economically or environmentally feasible in some situations; however, they are not the focus of this guide.

**Figure 3-1:** Flow Chart of Biomass, from Field to Plant



Source: COWI.

For each of the typical biomass types, this chapter presents the following information:

- Industry (agriculture, forestry, food production)
- Type (primary, secondary, tertiary)
- Feedstock (wood, agricultural)
- Characteristics (calorific value, biogas potential, chemical composition, moisture content)
- Energy conversion process applicable (boiler, gasification).

Table 3–1 provides a cross-cutting overview of the different types of biomass available from primary, secondary, and tertiary sources. Primary sources refer to energy crops harvested for the purpose of energy generation; no other use of the crop is foreseen. These include woody biomass, such as plantation trees (for example, eucalyptus), and herbaceous biomass, such as energy grass or grain (for example, for biofuel production).

Secondary crops refer to byproducts used for energy production. As such, the main crop harvested (for example, grain for food and feed) is not used for energy generation, but any residues (straw, husks, shells) are. Similarly, for woody biomass, the main crop is not used for energy generation (for example, wood is harvested for use as planks or in paper production), while logging byproducts are used for energy

generation. Secondary sources also refer to any byproducts from production, such as black liquor from paper production.

Tertiary sources refer to end-of-life materials, such as discarded wood products or household waste and other biological waste.

## 3.2 CHARACTERIZING BIOMASS AND FEEDSTOCK

Biomass and feedstocks can be characterized in several ways, including in terms of inherent physical and chemical properties, such as bulk density and moisture content, and in terms of origin and type. For the latter, it is important, in order to assess a number of environmental and socioeconomic issues, whether the biomass is primary, secondary, or tertiary. Answering a number of questions on sourcing and value chain linkages can help identify the biomass type.

### 3.2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

When the selected biomass resources have been identified, it is relevant to clarify their characteristics. Identifying the chemical and physical properties of the selected biomass resource is essential for assessing the energy output when applying different technologies and estimating the associated investment and O&M costs.

	Woody Biomass	Herbaceous Biomass	Biomass from Fruits and Seeds	Other (Including Mixtures)
	Wood fuels	Agro-fuels		
<b>Primary (Energy crops)</b>	<ul style="list-style-type: none"> <li>• Energy forest trees</li> <li>• Energy plantation trees</li> </ul>	<ul style="list-style-type: none"> <li>• Energy grass</li> <li>• Energy whole cereal</li> </ul>	<ul style="list-style-type: none"> <li>• Energy grain</li> </ul>	
<b>Secondary (Byproducts)</b>	<ul style="list-style-type: none"> <li>• Thinning byproducts</li> <li>• Logging byproducts</li> </ul>	<b>Crop production byproducts</b>		<ul style="list-style-type: none"> <li>• Animal byproducts</li> <li>• Horticultural byproducts</li> <li>• Landscape management byproducts</li> </ul>
	<ul style="list-style-type: none"> <li>• Wood processing industry byproducts</li> <li>• Black liquor</li> </ul>	<ul style="list-style-type: none"> <li>• Straw</li> </ul>	<ul style="list-style-type: none"> <li>• Stones, shells, husks</li> </ul>	
<b>Tertiary (End-use materials)</b>	<ul style="list-style-type: none"> <li>• Used wood</li> </ul>	<ul style="list-style-type: none"> <li>• Used fiber products</li> </ul>	<ul style="list-style-type: none"> <li>• Food processing industry byproducts</li> <li>• Used products of fruits and seeds</li> </ul>	<ul style="list-style-type: none"> <li>• Bio-sludge</li> <li>• Slaughter byproducts</li> </ul>

Source: COWI.

The characterization of the biomass feedstock includes its chemical and physical properties (for example, trading form, calorific value, biogas potential, bulk density, ash content, and moisture content). Table 3–2 describes and presents these properties for each feedstock. Appendix B provides

a thorough characterization of the biomass feedstock, including pictures of the biomass and detailed chemical composition (percentage of lignin, cellulose, hemi-cellulose, and extractives).

**Table 3-2: Characterization of the Biomass Feedstock**

No	Feedstock	Most Common Trading Form	Choice of Energy Conversion Technology	Net Calorific Value (MJ/kg)	Biogas Potential (milliliters of methane/grams of volatile solids)	Bulk Density (kg/m <sup>3</sup> )	Ash Content (% dry bulk)	Moisture Content (%)
1	Coniferous stem wood, without bark	chips	combustion	19.1 (18.5–19.8)	n.a.	330 (310–350)	0.4 (0.3–0.6)	30–55
2	Logging residues, coniferous	chips	combustion	18.5–20.5	n.a.	300 (270–360)	3 (1–10)	35–55
3	Wheat straw	bales	combustion/ fermentation	16.6–20.1	240–440	20–40 (loose)	no data	no data
4	Used wood (postconsumer wood, recycled wood, untreated)	20–80 (chopped)	combustion	18.6–18.9	n.a.	200 (140–260)	0.5–2	15–30
5	Bark, coniferous (debarking residues)	110–200 (baled)	combustion	17.5–20.5	n.a.	240–360	1–5	50–65
6	Delimed broadleaved stem wood with bark	560–710 (pelletized)	combustion	15.0–19.2	n.a.	220–260	0.3–1.5	10–50
7	Poplar	hog fuel	combustion	18 (17.3–20.9)	n.a.	340 (320–400)	1.2 (0.2–2.7)	5–15
8	Cereal straw	shredded	combustion/ fermentation	14.8–20.5	245–445	20–40 (loose)	6.7 (1.3–13.5)	15 (8–25)
9	Pruning from olive trees	chips	combustion	16.3 (16.0–18.5)	n.a.	250 (220–270)	3.5 (4.5–5.5)	25 (10–50)
10	Eucalyptus	chips	combustion	18.5 (17.0–21.6)	n.a.	250 (220–260)	1.2 (0.2–6.1)	10 (5–50)
11	Paulowina	bales	combustion	18.6 (18–20)	n.a.	250 (220–260)	1.1 (0.5–3.5)	10 (5–30)
12	Willow (Salix)	20–80 (chopped)	combustion	19.8 (19–21)	n.a.	330 (300–390)	1.5 (1–3)	40 (35–50)
13	Reed canary grass	110–200 (baled)	combustion/ fermentation	16.6 (14.6–17.5)	280–410	150–200 (bales)	8 (3–22)	15 (5–35)
14	Barley straw	560–710 (pelletized)	combustion/ fermentation	18.9	240–320	20–40 (loose) 20–80 (chopped) 110–200 (baled) 560–710 (pelletized)	4.5–9	15 (5–35)
15	Empty fruit bunch	chips	combustion/ fermentation	11.5–14.5	264	100–200	1.3–13.7	61–72

(Continued)

**Table 3-2: Characterization of the Biomass Feedstock (continued)**

No	Feedstock	Most Common Trading Form	Choice of Energy Conversion Technology	Net Calorific Value (MJ/kg)	Biogas Potential (milliliters of methane/grams of volatile solids)	Bulk Density (kg/m <sup>3</sup> )	Ash Content (% dry bulk)	Moisture Content (%)
16	Bamboo	chips	combustion	16.9	n.a.	200	7.7	15 (5–30)
17	Sugarcane bagasse	chips	combustion/ fermentation	16.7 (15–19.4)	72–200	130 (120–160)	9 (4.5–25)	50 (48–53)
18	Corn cobs	chips	combustion/ fermentation	14	330	160–210	15 (1–40)	8–20
19	Rice husk	bales, chopped	fermentation/ combustion	12–16	49 (49–495)	100	17–24	10
20	Rice straw	bales	fermentation/ combustion	14.5–15.3	280–300	20–40 (loose) 20–80 (chopped) 110–200 (baled) 560–710 (pelletized)	14–16	10–20
21	Switch grass	20–80 (chopped)	fermentation/ combustion	15.7	246	49–266 (chopped)	4.3	8–15
22	Chicken manure	110–200 (baled)	fermentation/ combustion	9–13.5	156–295	230	24	6–22
23	Dairy manure	560–710 (pelletized)	fermentation/ combustion	no data	51–500	depends on moisture content	25.2	10–75
24	Swine manure	bales, briquettes	fermentation/ combustion	no data	322–449	depends on moisture content	27.6	10–85
25	Palm kernel shells	chips	combustion	15.6–22.1	n.a.	450	3.2–6.7	no data
26	Banana peel	chopped	fermentation	no data	223–336	depends on moisture content	11.4	no data
27	Cassava peels	chopped	fermentation	no data	272–352	depends on moisture content	4.5	29–66
28	Tobacco leaves	bulk	fermentation/ combustion	18	289 (calculated)	depends on moisture content	17.2	~10 (dried)
29	Tobacco stalk	bales	fermentation/ combustion	19	163	depends on moisture content	2.4	6 (dried)
30	Recycled paper	20–80 (chopped)	combustion	12.8	n.a.	431 (compacted)	89.2	5
31	Sewage sludge	110–200 (baled)	fermentation/ combustion	no data	12–35	depends on moisture content	12–35	55–97

*(Continued)*

**Table 3-2:** Characterization of the Biomass Feedstock (continued)

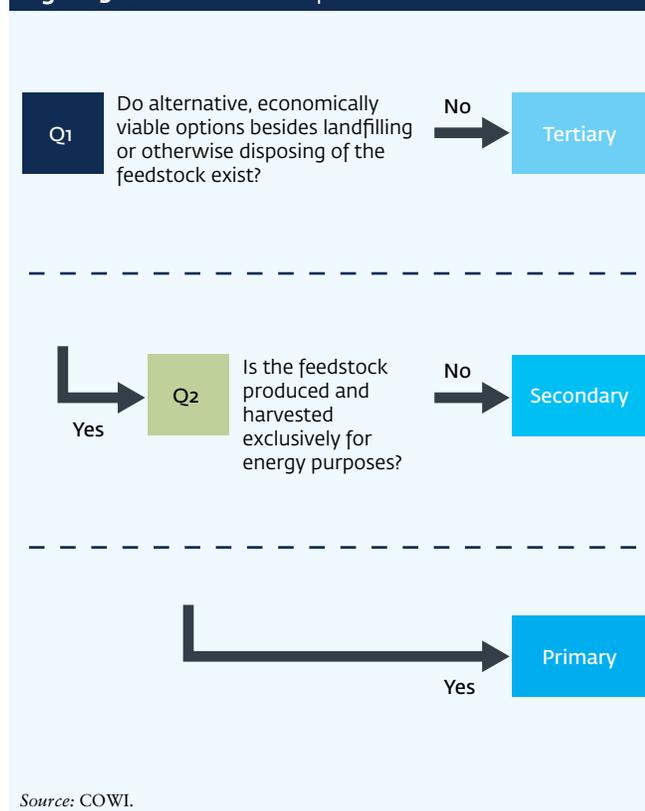
No	Feedstock	Most Common Trading Form	Choice of Energy Conversion Technology	Net Calorific Value (MJ/kg)	Biogas Potential (milliliters of methane/grams of volatile solids)	Bulk Density (kg/m <sup>3</sup> )	Ash Content (% dry bulk)	Moisture Content (%)
32	Residuals from slaughterhouses	bulk	fermentation	no data	no data	depends on moisture content	no data	no data
33	Residuals from dairies	bulk	fermentation	no data	no data	depends on moisture content	no data	no data
34	Residuals from breweries	bulk	fermentation	12–27.8	no data	no data	no data	no data
35	Palm oil mill effluent	bulk	fermentation	0.5	no data	no data	no data	no data

Source: See Appendix B.

### 3.3 BIOMASS TYPE

To decide on the type of a given biomass or feedstock, the key below may be used. It introduces a number of questions, mainly concerning alternative uses of the biomass and feedstock, that can help classify this material. All biomass and feedstock should first be evaluated posing the questions in Figure 3–2 below.

**Figure 3-2:** Biomass Classification



Source: COWI.

### 3.4 BIOMASS POTENTIAL AND BARRIERS

#### Guidance: "Biomass of Sufficient Quality"

- When this guide discusses the importance of biomass of a "sufficient quality," it is important to remember that this term depends on the technology chosen.
- The quality of the biomass can be improved through pretreatment; thus, quality is not a fixed term, but it will have an effect on CAPEX. An example of this is drying the biomass.
- Biomass with undesirable qualities, such as a high ash content, likewise can be bypassed, for example by improving the technology. This also will have an effect on CAPEX.
- If the fuel is very wet, usually above 60 to 65 percent, a combustion process is out of the question, and biogas is the relevant option.

The availability of biomass for energy production is affected by different factors on various spatial scales. On a global scale, it is dependent on land availability and productivity. These features are, in turn, shaped by macro-drivers, such as global population, food consumption and diet, yield growth and potentials, and economic development (Slade et al., 2011; Bauen and Slade, 2013). On a regional scale, political and economic factors, such as market accessibility, policy development, and trade patterns affect the size of the resource. Local access is restricted by infrastructure, natural components such as climate and water availability, and economic aspects, such as competition for resources and opportunities for handling, processing, or storing resources, as well as by general

infrastructural aspects, such as road access, port facilities, railways, and other transport corridors.

### 3.4.1 ASSESSMENT OF POTENTIAL RESOURCE CONSTRAINTS

Further to the technical description of the biomass or feedstock, each combination of a supply chain with a biomass or feedstock will result in a number of potential constraints that should be considered. All of the constraints essentially relate to the question: Can the given biomass feedstock be supplied in sufficient amount and quality and with sufficient supply stability and reliability? For example, for a crop

residue for which production is seasonally determined (such as where crop harvesting takes place only in the summer), no residues will be available for the rest of the year.

Identifying any potential constraints at this stage of the project includes assessing the climatic factors (for example, precipitation or average temperature) and biogeographical factors (for example, biodiversity, water supply, altitude, and nutrient availability) that influence the production of a given biomass or feedstock (Table 3-3). Some biomass types will thrive only in very specific climates, while others are more generalist and can grow in a range of different climates.

Factor	Typical Questions	Aspects to Consider
<b>Water</b>	<p>Are sufficient water resources available locally to meet any increased water demand because of the project?</p> <p>Is the water requirement for the project sustainable in the long term?</p> <p>What impact will the project have on community water uses?</p>	<p>Look up data on water needs and, for example, drought or flooding resilience of relevant crops or trees.</p> <p>Many types of bioenergy crops and trees are highly dependent on water availability for their growth. If the water resource becomes scarce, so will the biomass resource.</p>
<b>Climate zone</b>	<p>Are weather hazards or adverse climatic conditions present in the project sourcing region that can put the necessary production and supply of biomass at risk, permanently or in certain periods?</p> <p>Are the crops, forests, or animals needed for the supply of biomass or feedstock suited for the local climate?</p>	<p>Search for a local climate or weather risk assessment and compare it to the production systems on which the project's supply chain depends.</p> <p>Search for a map or digital tool showing growing conditions in the sourcing area, chiefly water availability (rainfall and evaporation), radiation, and, if relevant, growing degree days. Aspects such as slope and pests also may be relevant.</p> <p>Consider that every crop will have its ideal growing conditions. For example, crops such as sugar cane do not grow in colder temperate and boreal regions but primarily in subtropical and tropical regions.</p>
<b>Soil and land</b>	<p>Is enough productive land with suitable soil types available to grow the needed biomass?</p> <p>Can the available land—and its soils—deliver biomass or feedstock of sufficient and stable quality for the project?</p> <p>Is the productive land that will supply biomass or feedstock for the project in a state and condition to withstand weather hazards or climate change without significant disruption of production?</p>	<p>If the sourcing region for the biomass or feedstock is high-intensity productive land, any major shift in demand for a particular biomass or feedstock may induce changes in land use.</p> <p>In mountainous regions, in regions with much degraded land, and in areas with waterlogged soils or permafrost, land can be of limited use and thus can become a constraint.</p> <p>Some crops or trees have specific requirements as concerns soil type. Consider if the biomass or feedstock have particular issues in this regard.</p>
<b>Biodiversity</b>	<p>Will the biodiversity of the area be negatively affected by the sourcing of biomass or production of energy?</p> <p>Is the source area for the biomass home to endangered or rare, endemic species?</p>	<p>Conflict could arise, for example, in land areas where biodiversity is the basis of local income generation, such in national parks that benefit from tourism.</p> <p>If agricultural production is dependent on rich biodiversity (such as in low-input, extensive grazing-dependent farming systems), changes in land management intensity may result in loss of biodiversity, reduced climate resilience, or erosion, leading to social consequences for farmers.</p>

Source: COWI.

Table 3–3 presents some important factors to consider in relation to feedstock availability and quality. Environmental or socioeconomic concerns related to sourcing of biomass should be considered as part of a broader environmental screening in a feasibility study. Guidance on this can be found in Chapter 15.

For the project developer to select the best biomass available, it is necessary to screen the area with regard to supply chain aspects, such as whether the right infrastructure, technical knowledge, and economic opportunities exist in the area.

In the second phase of project development, the developer should perform a pre-feasibility study (see Figure 2–3 in Chapter 2). This includes initiating an investigation of the availability of biomass in sufficient amounts and quality. Table 3–4 presents an overview of the typical questions a project developer must ask during investigation of the feedstock.

**Table 3-4: Supply Chain Questionnaire**

Supply Chain	Biomass Growth and Harvesting	Storage	Transport	Conversion
<b>Harvesting</b>	Does the infrastructure exist to enable harvesting of the biomass?	Does the infrastructure exist for storage of the biomass?	Does the infrastructure exist for transport of the biomass?	Does the infrastructure exist for conversion of the biomass to the required type?
<b>Technical knowledge</b>	Does the technical knowledge exist on how to harvest the biomass, and is the technology (for example, machines) available?	Does the technical knowledge exist on how to store the biomass, and is storing capacity available?	Does the technical knowledge exist on how to transport the biomass?	Does the technical knowledge exist on how to convert the biomass to the required type?
<b>Economic opportunities</b>	Is harvesting of the biomass economically feasible?	Is storing the biomass economically feasible?	Is transporting the biomass economically feasible?	Is conversion of the biomass to the required type economically feasible?
<b>Energy</b>	Will energy be needed for harvesting, and is it available (at the right cost)?	Will energy be needed for storage, and is it available (at the right cost)?	Will energy be needed for transport, and is it available (at the right cost)?	Will energy be needed for conversion, and is it available (at the right cost)?

Source: COWI.



Source: COWI.

Establishing a secure biomass supply is a precondition for a successful biomass project. Securing a year-round, stable supply of biomass of a sufficient quality depends on both the availability of the biomass and the effectiveness and stability of the supply chain. This chapter discusses the concepts of biomass availability and biomass supply chain and provides the tools for analyzing them.

## 4.1 ASSESSING BIOMASS AVAILABILITY

This section provides an assessment of the minimum amounts of biomass needed for a biomass project to be technically feasible (Table 4-1). The section also discusses security of supply, including supplier risks, seasonal variation, and the possible need for supplementary purchase of other types of biomass residues or wood pellets in case of shortage of supply.

### 4.1.1 MINIMUM SUPPLY OF BIOMASS

When investing in a biomass plant, a project developer must be certain that the plant will receive sufficient biomass to keep the plant running and keep the project financially viable. If the developer fails to convince potential investors of the project’s financial viability, the project is unlikely to receive financing on reasonable terms.

### 4.1.2 AMOUNTS AND QUALITY

A documented constant supply of biomass of sufficient quantity and quality is vital for realizing a biomass project.

Mapping the biomass availability therefore is a prerequisite for securing the technical and financial viability of the project, as explained in Chapters 13 and 14.

For biomass that is available on-site (industrial waste products), an important aspect to be assessed is the generation of waste products by production process (including possible seasonal variations, which may be significant).

When charting off-site biomass resources, the following aspects should be investigated:

- Area (in hectares) of the crop or vegetation type where the biomass is obtained
- Annual production of the main product obtained from this area (in metric tons “as harvested” for crops, in cubic meters processed for wood logs)
- Yield, in metric tons harvested per hectare (green tons per hectare) or in cubic meters per hectare for wood
- Ratio of residual biomass to main product (a coefficient)
- Dry matter content (DMC) in the residual biomass:

$$DMC = 1 - \left( \frac{\text{Moisture content}}{100} \right)$$

**Table 4-1: Biomass Amounts and Plant Sizes**

Technology/Range	1–5 MWe	5–10 MWe	10–40 MWe
	Minimum input (GJ/day)*		
Combustion plants using a water/steam boiler	20–100 tons per day	100–200 tons per day	200–900 tons per day
Combustion plants using ORC technology	50–200 tons per day	200–500 tons per day	n.a.
Biogas production with gas engine	40–200 tons per day	n.a.	n.a.

Source: COWI.

\* Biomass tonnages at an average calorific value of 10 megajoules per kilogram assuming 100 percent load.

- Accessibility coefficient (fraction of the area where residual biomass produced can be collected)
- Harvest coefficient (fraction of residual biomass accessible that can be recovered)
- Unused fraction (the part of recoverable biomass that is not currently used for other purposes).

The answers to these questions will enable more accurate calculation of the biomass potential available for energy production. Figure 4–1 illustrates a rough example of the calculation methodology.

Once the biomass potential has been estimated, it is necessary to take into account seasonal variations. A biomass plant requires a stable supply of biomass to ensure good capacity utilization. If the preferred biomass is available only eight months of the year, supplementary biomass may need to be identified and sourced. Section 4.1.3 explains the issues related to seasonal variation, and Section 4.1.5 explains aspects of supplementary biomass.

### 4.1.3 SEASONAL VARIATION

If the energy production depends on waste or residues from agricultural or forestry production, the seasonal variation of the primary source of biomass becomes a determining factor in its availability. It therefore is essential to map the seasonal variation for the most common crops that deliver secondary or tertiary biomass suitable for energy production.

For example, in the case of Mexico, the most common agricultural crops were mapped to identify their seasonal variation, and their potential availability for energy production across the year. Figure 4–2 illustrates that wheat, sorghum, and maize/corn are strongly seasonal, while coffee, sugarcane, and rice have partial seasonality.

This case example illustrates a mapping of agricultural crops where some crops have a stable output year-around, whereas others are subject to seasonal variation. Note that the seasonality of crops will vary across continents and climate zones and also is subject to regional conditions.

**Figure 4-1:** Calculation Methodology for Biomass Availability



Source: COWI.

#### Calculating the Available Biomass

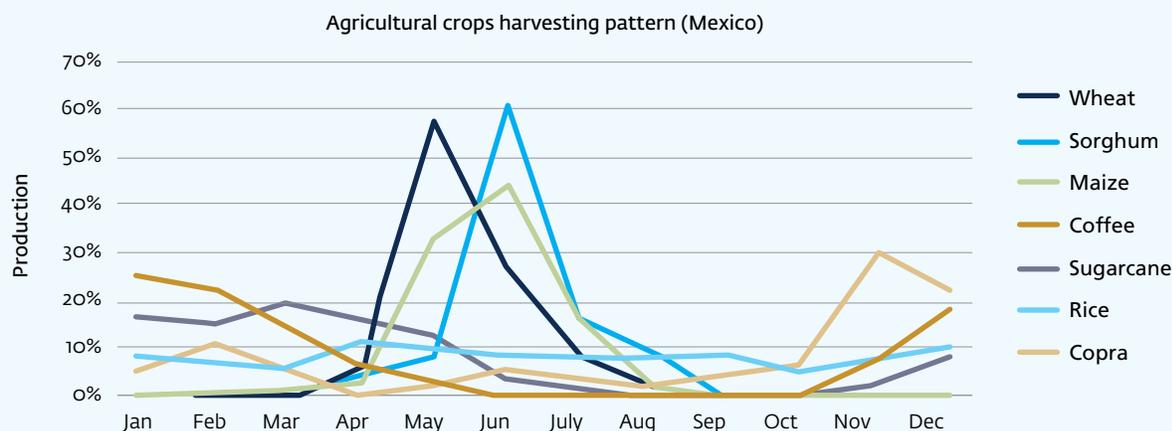
Biomass availability is essential for a biomass-based energy project. The example below illustrates how to estimate the amounts of biomass available for energy production, based on residues from primary crop production.

$$50,000 \times 0.30 \times 0.95 \times 1 \times 0.80 = 11,400$$

	Amount
Annual production of primary product (tons)	50,000 tons per year of sugarcane
Ratio of residual biomass to main product (%)	30%
Accessibility coefficient (%)	95%
Harvest coefficient (%)	100%
Unused fraction (%)	80%
Biomass available for energy production (tons)	11,400 tons of sugarcane residues

Source: COWI.

**Figure 4-2:** Seasonality of Agricultural Crops



Source: COWI.

If the available biomass has seasonal variability, it is important to assess whether the available amounts at any time during the year are below the optimal and minimum biomass amounts needed for the plant.

If available biomass amounts drop below the amount needed to secure optimal energy production, it will be necessary to supplement with other biomass types. If the available biomass drops below the minimum amount necessary for keeping the plant running, this could constitute a serious risk to the project. A reliable supplementary biomass supplier should then be located before proceeding with project development, provided that other mitigation options are not available. The compatibility of the supplementary biomass with the preferred biomass should be assessed before proceeding with procurement.

The risk of seasonality can be mitigated through the availability of proper storage facilities on-site or locally. If sufficient quality can be stored post-harvest until the biomass is needed for energy production, seasonality becomes less problematic. However, storage of large quantities of biomass can be costly, and the need for storage facilities can affect the viability of a biomass project.

#### 4.1.4 DISTANCE

Besides determining the amounts and availability of the biomass, it is important to map its location and proximity to

the plant. If a large share of the necessary biomass is located far from the plant, significant transport costs must be taken into account. The further the transport distance, the higher the risk of delays or lack of supply.

Thus, the security and costs of supply is linked to the distance between the plant and the biomass source.

Figure 4–3 presents an example of a mapping of the available biomass and distance from the biomass to plant.

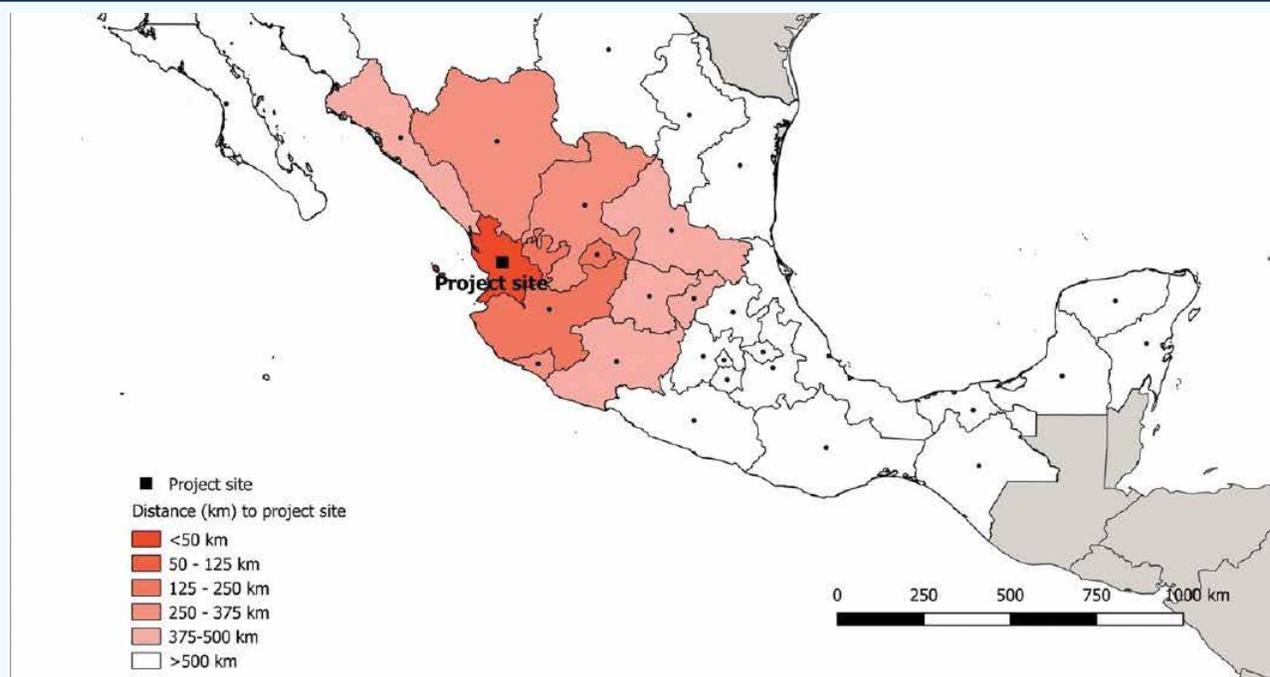
#### 4.1.5 NEED FOR SUPPLEMENTARY BIOMASS

A biomass plant may require supplementary biomass for several reasons:

- Insufficient biomass availability
- Insufficient biomass quality
- Significant seasonal variation in the biomass stock.

If supplementary biomass is needed for the plant, the developer should commence a mapping of other available biomass residues in the region. If no other biomass residues are available, the developer should investigate if any secondary biomass is available for import, or if suitable primary biomass is available in the region. As a final solution, the developer should consider the possibilities for imported primary biomass. This, however, could compromise the financial viability of the project, as the price for biomass could significantly increase.

**Figure 4-3:** Map of Distance from Biomass Resource to Project Site



Source: COWI.

#### 4.1.6 BIOMASS SUPPLY CHAIN

When an acceptable supply of biomass has been located, a supply chain should be established. This includes identifying the owners of the biomass, agreeing on prices (which frequently are assumed to be zero, but this often is not the case), settling supplier contracts, and arranging transport and storage of the biomass, all within the constraints of maintaining a financial viable project.

The project developer should complete the following steps to secure a stable and reliable biomass supply chain:

##### Owners of the biomass:

- The owners shall be identified
- The price of the biomass must be determined
- Contractual arrangements for biomass supply must be negotiated.

##### Transport:

- How will the biomass be collected?
- How will the biomass be transported?
- What types of trucks/machinery are available and suitable?

- Who will be in charge of transport of the biomass?
- What related contractual arrangements are needed?

##### Storage:

- What are the requirements for on-site storage (volume, safety, dry storage, etc.)?

When setting up the supply chain, the developer should keep in mind the financial viability of the project. The plant needs the best-quality biomass possible, at the lowest possible costs.

The contractual agreements must be set up to secure the project developer a long-term, stable supply of biomass of a certain quality. The agreements of supply and transport should include incentives for the counterpart to uphold their part of the agreement. Chapter 11 goes in-depth into the contractual relations.

##### Indicative supply chain costs:

- Costs of biomass: \$35 per ton
- Costs of storage: \$11.5 per ton
- Costs of loading: \$5 per ton
- Costs of transport by truck: \$0.12 per ton per kilometer

### Calculation example of the impact of the transport distance

To supplement the on-site supply of biomass, the project owner will buy 10,000 tons of logging residues. The logging residues have to be transported 25 kilometers to the biomass-to-energy plant.

The cost of transport totals \$93,000, or \$9.30 per ton. The transport cost is a little less than 10 percent of the operational expenditure (including maintenance).

If the distance were instead 200 kilometers, the total cost of transport would be \$336,000, or \$33.60 per ton. In this case, the transport cost is around 30 percent of the operational expenditure (including maintenance).

The cost of transport is not correlated linearly with the distance, as there are fixed costs related to the handling of the biomass volume. The handling cost for transport is \$5 per ton.

Source: COWI.

A main risk when seeking to establish a supply chain for biomass projects is that many developing countries lack a well-functioning biomass supply market, including the necessary transport, storage, and handling facilities. An investor planning a biomass project may not be able to find a reliable supplier who can guarantee a specified amount, quality, and price for the biomass feedstock for a reasonable length of time (for example, 10 years).

The key issues relate to infrastructure and logistics (collecting, storing, handling, and delivering biomass), lack of incentives (financial or otherwise), and available low-cost alternatives (for example, burning the biomass in the field). Another risk is the absence of enforcement of the agreed contracts. If enforcement is not realistic, the risk to the project owner increases significantly.

## 4.2 SOCIAL AND ENVIRONMENTAL SUSTAINABILITY ISSUES

When procuring and using biomass for energy generation projects, numerous social and environmental issues can arise. It is important that these concerns are considered when securing biomass supply. Some of these factors are summarized below, providing a brief introduction to the information presented in Chapter 15.

- Transport can result in significant emissions, especially for biomass that contains large amounts of water, meaning that the dry matter content (DMC) is low.

Biomass with low DMC generally should be procured near to the plant or the DMC should be increased prior to transport (for example, by drying). Note that the greenhouse-gas emissions profile and the emission reductions achieved by the biomass-to-energy project can be compromised if transport distances are increased.

- Care should be taken that procured biomass is not currently used by local communities, whose livelihood, food security, or other social aspects could be put at risk by the use of this biomass. This is a particular concern for primary and agriculturally related biomass resources that can be used as food or feed (such as crops or straw). Procuring significant amounts of a given biomass also can affect local markets, increasing prices of the biomass and related commodities, which can have an impact on local livelihoods.
- The impact on the local environment should be taken into account before procuring biomass. It is essential to ensure that procured biomass does not lead to increased local production through clearing of forested land or unsustainable intensification of production.

In general, procuring primary biomass constitutes larger social and environmental impacts than the use of secondary and tertiary feedstocks.

Regardless of the type of feedstock, whether local or imported, it is important to note that procuring biomass can have environmental and social risks and impacts that would need to be properly assessed and appropriately addressed before project implementation.

If *primary* biomass is chosen as the input for energy generation, in-depth analysis of the environmental, social, and financial consequences should be conducted. The use of primary biomass for energy production could easily have the following implications:

- Increase in greenhouse-gas emissions (also compared to the use of coal)
- Increase in food and/or feed prices, with possible negative impact on livelihoods
- High and fluctuating costs of biomass, compromising the financial viability of the project
- Significant land conversion
- Impact on biodiversity and ecosystem services.



Source: COWI.

The conversion of biomass to energy can happen through various processes and by using different technologies. This guide focuses mainly on proven technologies appropriate for projects in developing countries. This chapter presents an analysis of the selected technologies.

## 5.1 OVERVIEW OF APPROPRIATE TECHNOLOGIES

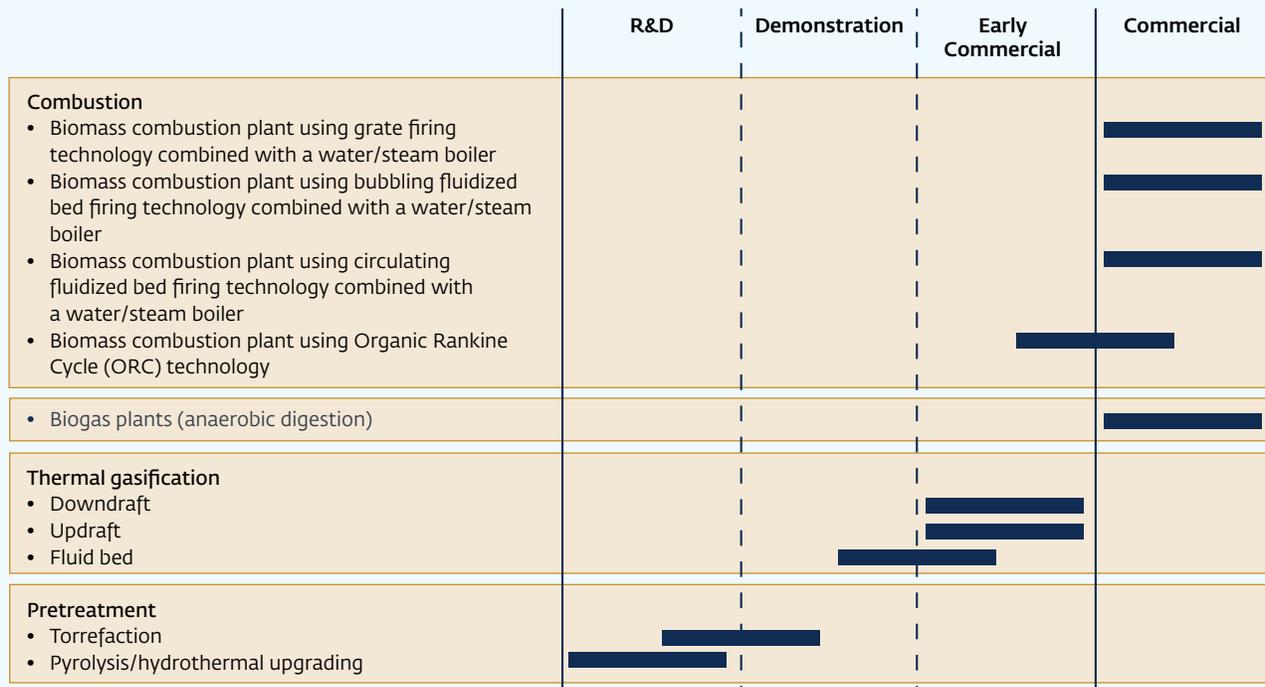
One of the most important aspects for plant owners is whether the chosen technology is commercial and proven, as this is crucial for securing a reliable and stable production of electricity and/or heat/steam. The use of proven and commercial technology is also very important for the financial viability and robustness of the project and thus affects the possibilities for securing financing.

Due to this aspect, only technologies considered as proven and commercial are considered in this guide.

These technologies are:

- Biomass combustion plant using grate technology combined with a water/steam boiler
- Biomass combustion plant using bubbling fluidized bed (BFB) technology combined with a water/steam boiler
- Biomass combustion plant using circulating fluidized bed (CFB) technology combined with a water/steam boiler
- Biomass combustion plant using Organic Rankine Cycle (ORC) technology
- Biogas plants (anaerobic digestion + gas engine).

**Figure 5-1:** Overview of Biomass Conversion Technologies and Their Current Development Status



Source: COWI.

Finally, in Section 5.5, some promising emerging technologies are presented briefly. These technologies are:

- Thermal gasification
- Torrefaction
- Pyrolysis/hydrothermal upgrading.

## 5.2 TECHNOLOGY SELECTION

Selection of a preferred technology is complex and requires careful consideration of the type of biomass, fuel flexibility, load ramping capability, investment cost, plant size, etc. However, the very early and most important selection relates to the moisture content in the fuel. If the fuel is very wet, usually above 60 to 65 percent, the calorific value of the biomass is too low for combustion and a biogas plant is the only relevant option, unless drying of the fuel is considered.

Table 5–1 lists selected biomass residues suitable for combustion and anaerobic digestion in a biogas plant (production of biogas to be used in a gas engine), respectively.

The selected technologies are applicable in different plant sizes, and Table 5-2 highlights their relevance in the three approximate size ranges 1–5 MWe, 5–10 MWe, and 10–40 MWe. Note that there is not a sharp distinction between the groups and that overlaps might occur. Furthermore, combustion plants using a water/steam cycle also are applicable for plant sizes above 40 MWe.

## 5.3 BIOMASS COMBUSTION PLANT

A biomass combustion plant consists of a number of more or less standardized systems that can normally be supplied by several suppliers. Figure 5–2 shows the different systems described in the following sections.

Biomass	Typical Humidity	Technology Selection
<ul style="list-style-type: none"> <li>• Manure from animals</li> <li>• Organic waste material from food industries</li> <li>• Sludge from flotation plants and other</li> <li>• Vegetable and fruit waste from agriculture</li> <li>• Other organic waste materials from industries</li> </ul>	> 65%	Biogas technology
<ul style="list-style-type: none"> <li>• Wood</li> <li>• Various straw</li> <li>• Rice straw and husk</li> <li>• Other</li> </ul>	< 60%	Combustion technology

Source: COWI.

Range	1–5 MWe (4–20 MWth)	5–10 MWe (20–40 MWth)	10–40 MWe (40–160 MWth)
Combustion plants using a water/steam boiler (steam technology)	X	X	X
Combustion plants using ORC technology	X	X	n.a.
Biogas technology	X	n.a.	n.a.

Source: COWI.

Note: The biomass combustion plants using a water/steam boiler include three types of technologies: grate, bubbling fluidized bed (BFB), and circulating fluidized bed (CFB).

**Table 5-3: Steam-cycle Technologies According to Size**

Technology	1–5 MWe	5–10 MWe	10–40 MWe
Grate technology	X	X	X
Bubbling fluidized bed (BFB) technology		X	X
Circulating fluidized bed (CFB) technology			X

Source: COWI.

The description follows the flow through the plant, starting with the fuel reception, the fuel handling, and the fuel storage system (called the fuel yard), followed by the combustion system (grate, BFB, and CFB systems). Next is the energy conversion process, where a boiler converts the energy in the hot combustion flue gases into high-pressure steam, which finally is transformed into electrical power and process heat. The steam circuit is closed when the condenser returns the condensate back to the boiler feed pumps. This is described in Section 5.3.3, and the circuit is shown in Figure 5–13.

Section 5.3.4 describes the emissions and flue gas cleaning, including the types of equipment normally used, such as cyclones, baghouse filters, electrostatic precipitators, and scrubbers. This is followed by a section on residues and the ways to handle these.

This technical description of a biomass combustion plants is followed by two chapters describing electrical and distributed control systems (DCS).

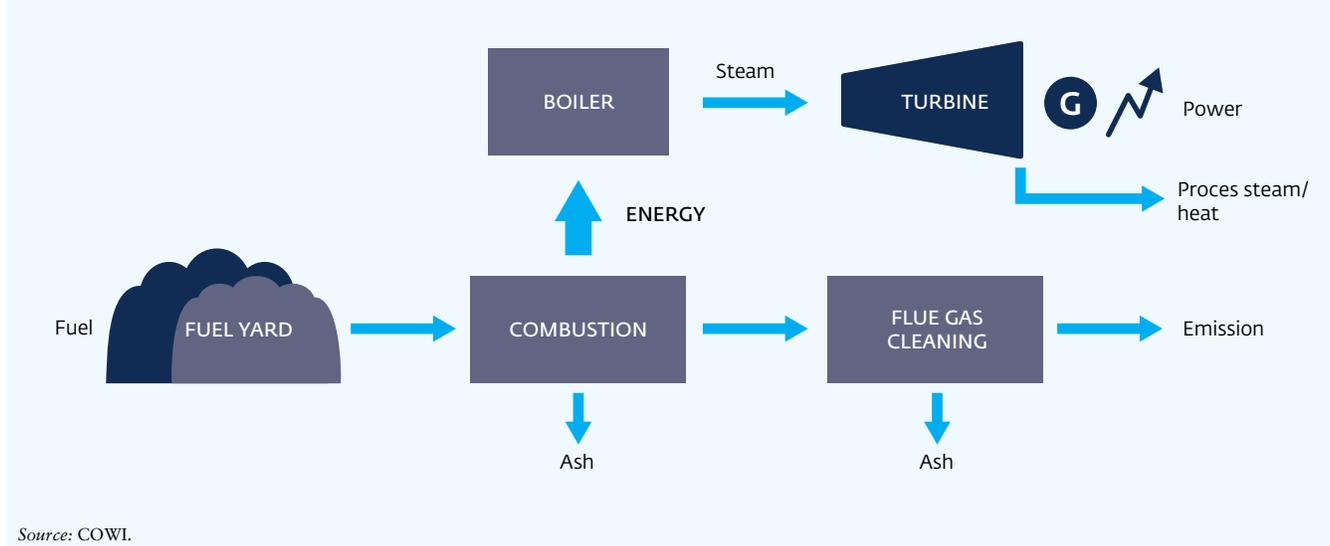
### 5.3.1 FUEL HANDLING, STORAGE, AND PREPARATION

Fuel handling, storage, and preparation will differ depending on the origins of the biomass fuel (whether it is residue from an industrial process, such as bagasse from sugar production; supplementary biomass fuel from a fuel supplier, such as wood chips; or locally produced straw/wood).

In terms of proper fuel handling, the following issues should be considered carefully:

- Fuel reception, including weighing, general quality control, and moisture control
- Storage, including fuel yard management
- Potential preparation of the biomass fuel, including drying, shredding, and grinding.
- Fire risk and strategy, including explosion risk and fire extinguishing means

**Figure 5-2: The Biomass Combustion Plant**



Source: COWI.

- Environmental issues, such as dust, fungal spores, noise, odor, etc.
- Boiler feeding
- Flexibility in handling various fuels.

### *FUEL RECEPTION*

If the biomass fuel originates from the owner's industrial process, a reception control is normally not needed.

For external fuel supplies, it is necessary to measure and register the weight and moisture content of each fuel delivery, as this information forms part of the payment to the fuel supplier. Weight can be registered on a scale/weigh bridge or in a crane. Registration of moisture content can be done either manually with a portable instrument, in a crane with radar sensors, or with other online equipment based on microwaves, radioactivity, light absorption, etc. Finally, moisture content can be detected via manual sampling followed by local laboratory testing, drying the sample for a minimum of 17 hours at 103°C. The weight loss equals the moisture content in the biomass sample. This test is normally used in small facilities.

Furthermore, a random visual inspection is important, especially in the initial period of external biomass supply, in order to discourage suppliers from trying to deliver a poorer quality than agreed in the contract.

A biomass plant must establish rejection criteria for the fuel supply to be used if fuel deliveries are outside the range agreed in the fuel supply contract.

### *FUEL MANAGEMENT AND STORAGE*

An important aspect that greatly influences the investment cost is the storage volume of the fuel yard, especially if covered by a roof/wall. It therefore is important to assess the need for a fuel buffer of up to perhaps two weeks. This depends quite a lot on the security of supply from the biomass supplier.

The logistics and management of the large biomass quantities necessary is a very important issue that must be considered carefully.

### *FUEL PREPARATION*

For certain applications, it may be necessary or advantageous to prepare the fuel before combustion. This may include:

- Drying
- Pelleting
- Shredding and/or grinding.

Because the moisture content affects the value of biomass as a fuel, the basis on which the moisture content is measured must always be mentioned. This is particularly important because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from less than 10 percent for cereal grain straw up to 50 to 70 percent for forest residues. Very wet fuels (typically above 60 percent) may be difficult to combust properly, and drying is therefore needed. This is very costly, however, as additional energy is needed for the drying process (this is typically done with auxiliary steam or flue gas).

Pelleting also is an expensive method of fuel preparation and normally is not needed. Commercial pelleting is used only for wood pellets.

Shredding of fuel may be necessary due to the size or the feeding equipment.

Further grinding of the fuel is needed if the boiler requires fuel in pulverized form. In this case, a hammer mill or similar equipment may be needed. Hammer mills however, consumer large amounts of electricity and require extensive maintenance.

Both shredders and hammer mills are noisy, and necessary precautions must be taken.

### *FIRE AND EXPLOSION RISK*

Cereal grain straw with very low moisture content has a high potential fire risk, but experience shows that fuels such as wood chips with a higher moisture content also might cause a fire. The necessary precautions must be taken to avoid a serious fire risk with potential for personnel injuries and production stoppage.

Typical installations used to protect against fire and explosion may be sprinkler systems above conveyors and handling/unloading areas, points where the conveyor changes direction, etc. A sprinkler system will require large pumps and large firewater storage, as the local water system may be insufficient.

When using very dusty fuels, explosions become a latent risk. An assessment should be made to evaluate the explosion risk and how to reduce this risk.

### 5.3.2 COMBUSTION TECHNOLOGIES

This section describes the three combustion technologies that are used most commonly for biomass-to-energy plants: grate (including an introduction to the most common types of grates), bubbling fluidized bed (BFB), and circulating fluidized bed (CFB).

#### GRATE TECHNOLOGY

Grate-fired combustion in a furnace is often called “fixed-bed” technology. Generally, grate-fired units are suitable for fuels with high moisture, high ash content, and varying particle sizes, but with a lower limit for fine particles. The grate technology is used on biomass-fired power plants up to 50 MWe.

The actual type and size of grate and furnace to be selected will depend on the biomass type, woody or herbaceous fuels, combustion behavior, moisture content, ash melting point, and particle size.

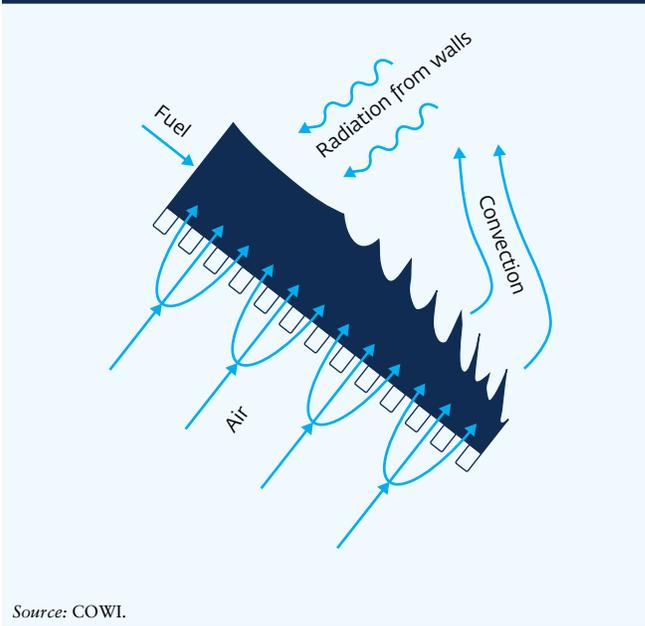
For the combustion process, and thus the efficiency of the boiler, it is essential that the fuel or fuel mixture is well distributed in the fuel bed on the grate. The fuel feeding system is normally designed to control this.

In all grate-fired boilers, the same process takes place in and above the fuel bed:

- Drying of moisture
- Pyrolysis and combustion of volatile matter
- Combustion of char particles.

Primary air is supplied to the fuel bed from under the grate. Heated primary air will boost the drying of wet fuels. The

**Figure 5-3:** Combustion Process on a Sloping Grate



Source: COWI.

primary air should be distributed, divided into sections, so that each part of the grate will receive the air needed for its part of the different processes (drying, pyrolysis, char burnout).

Secondary air is supplied to the furnace above the grate for burning out volatiles and fuel dust particles.

Tertiary air can be supplied to the upper furnace, with staged combustion, for reduction of nitrogen oxide emissions. The lower part of the furnace can then be operated with a low stoichiometry.

Secondary air is supplied to the furnace above the grate for the burning out of volatiles and fuel dust particles. Tertiary air can be supplied to the upper furnace, with staged combustion for reduction of the nitrogen oxide emissions. The lower part of the furnace can then be operated with a low stoichiometry.

The size and combustion quality of the biomass particles must be taken into consideration when deciding the type of grate firing. The large particles should have sufficient time to burn out before the ash is removed at the end of the grate. The small particles, when released from the fuel bed, can cause a higher amount of fly ash, with unburned particles and carbon monoxide emissions. The operation control of

the grate (bed layer, grate travel velocity, primary air) should serve to integrate and optimize the combustion process.

A blend of different wood fuels is acceptable, but normally a blend of woody fuels with straw-like fuels is not recommended (except for vibrating grates).

The melting temperature of the fuel ash, the ash content, and the furnace gas temperatures also should be taken into consideration. High gas temperatures and low ash melting temperatures can cause severe slagging in the char burnout zone.

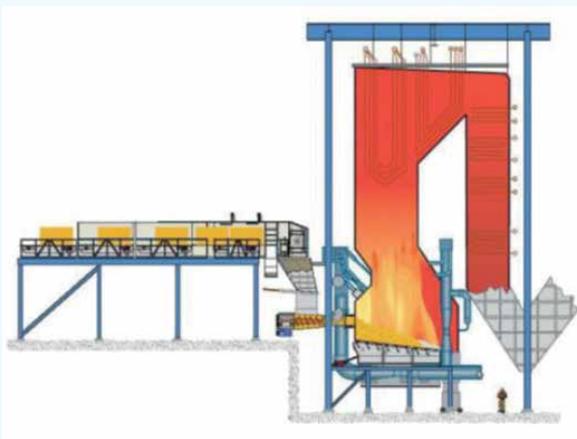
The ideal type and size of grate firing selected should take into account the fuel type, size, and energy output (heat, power). The performance of the industrial biomass unit can thus be optimized, ensuring a continuous, trouble-free operation.

The most commonly used grates are:

- Traveling grate
- Vibrating grate
- Step grate.

In small package boilers (<1 MWe), traveling grates are used for biomass firing. The fuel should be homogeneous to ensure ignition and burnout within a short distance. For larger capacities (up to 50 MWe), traveling grate boilers are used for power and heat production.

**Figure 5-4:** Straw-fired CHP plant: 35 MWe and 50 MJ Per Second of Heat



Source: Babcock & Wilcox Vølund A/S.

Vibrating grates are used for loose-density biomass fuels (loose straw, etc.) but also for blends of fuels with different densities (straw, wood chips). Different parts of the sloping grate are vibrated successively.

Step-fired boilers are equipped with a step-like grate alternating back and forth to move the fuel through the combustion zone. Step firing is used for “difficult” biomass fuels and is commonly used in solid waste incinerators.

### TRAVELING GRATE

In a traveling grate-fired boiler unit, the fuel bed is moved continuously from fuel inlet to ash outlet on a belt with “hinged” cast iron grate bars, attached to chains, and moved by a drive system. Fuel is supplied to the grate by screw conveyors (stokers) to give an evenly distributed fuel layer on the grate.

At the back end of the grate, the bars are cleaned for ash and slag. On the way back, the “loose” bars are cooled by the primary air to the grate.

The combustion process on the grate is controlled by the height of the bed layer, the grate velocity, and the combustion air (primary air) to ensure a complete burnout of the char without slagging or overheating the grate.

A too-high content of fine fuel particles will increase the amount of fly ash with uncontrolled burnout.

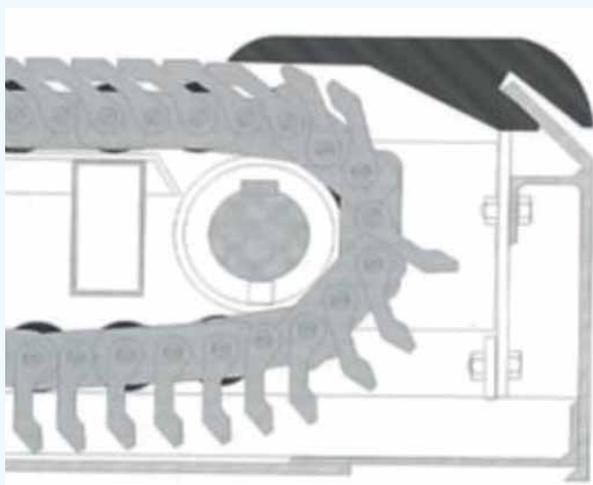
Blends of different biomass fuels should be evenly distributed across the grate, not leaving openings in the fuel bed layer that will allow primary air to “leak” directly into the furnace.

The maintenance cost for this type of grate is normally higher, as the traveling grate chain requires regular maintenance.

The traveling grate principle is well suited for:

- Wet biomass fuels
- High ash fuels
- Fuels with different sizes.

**Figure 5-5:** Traveling Grate Principle



Source: Loo and Koppejan, 2008.

### VIBRATING GRATE

Vibrating grates are used for various biomass fuels, such as wood chips, loose straw, etc., as this is a cost-effective solution.

The grate can consist of one or more sections, each designed as a membrane wall with air nozzles in the fins. The grate cooling water is integrated with the boiler water/steam system, and the water cooling protects the grate against overheating.

The grate sections are individually vibrated in cycles and can thus regulate the stages of the combustion process. The vibration also prevents large slag formations, and the fuel ash and slag will gradually move down to the ash conveyor.

Vibrating grates can also be designed with cast iron grate bars, attached to a frame that vibrates on an alternating basis.

The primary air is injected from under the grate, and secondary/tertiary air is supplied to the furnace through nozzles located above the grate.

Vibrating grates are used especially for straw firing, in which several lines of straw bales are conveyed to the boiler feeding system. Knives cut the twine, and straw shredders are used to loosen the fuel before feeding the straw onto the grate.

Vibrating grates are used in biomass-fired power plant units with a capacity of up to 40 MWe.

**Figure 5-6:** Vibrating Grate



Source: COWI.

A disadvantage with vibrating grates is the high peaks of carbon monoxide emissions produced during the vibration of the grate. The maintenance cost for this type of grate is normally considered to be low as there are no moving parts inside the combustion chamber that require regular maintenance.

### STEP GRATE

Step grates are commonly used in waste-to-energy incinerators, but they are also used with difficult biomass fuels. Moving grates are commonly used in small, heat-only biomass boilers (10 to 20 MW fired capacity).

The fuel is fed onto the top of the grate and moves down the grate as it burns. The step-like cast iron hydraulic grates alternate back and forth to push the fuel through the combustion zone. At the bottom of the grate, the ash is dumped into the water-filled ash conveyor.

The complete grate can consist of more parallel moving grate sections (lanes). Each section is cooled with water or air.

The maintenance cost for this type of grate is normally higher, as the moving parts of the step grate require regular maintenance.

### FLUIDIZED BED TECHNOLOGY

Fluidized bed combustion is used widely for biomass fuels. Two fluidized bed combustion technologies are available: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). Both are proven technologies. BFB boilers are often

**Figure 5-7: Step Grate**



Source: Justsen Energiteknik A/S, 2016.

preferred in small-scale applications, with fuels having low heating value and high moisture content. CFB boilers are normally used in larger applications.

Both types can be used for a wide range of biomasses and are especially suitable for fuels with high moisture content and high ash content. Fluidized bed boilers are used for fuels with a high alkaline content, such as straw.

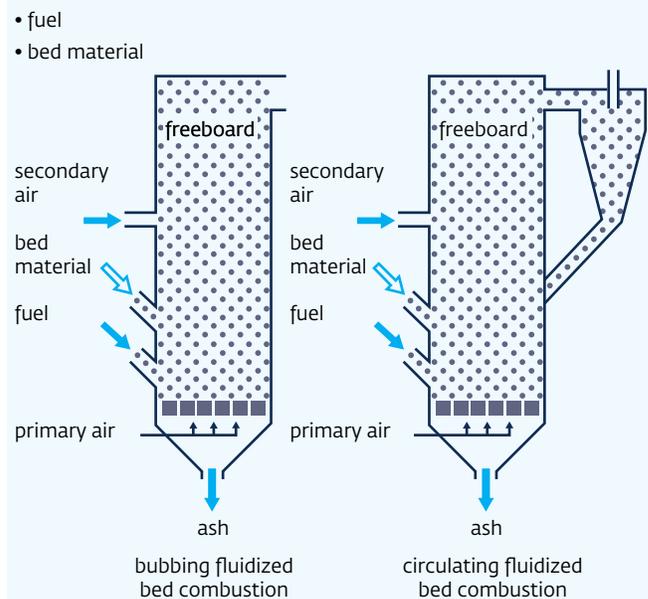
### BUBBLING FLUIDIZED BED (BFB)

The core of the BFB boiler is the combustion chamber or furnace. It features water-cooled walls and bottom. The bottom has a full refractory lining, and the lower portion of the water wall is also refractory lined. The bed is fluidized by means of an arrangement of nozzles at the bottom of the furnace, which create turbulence that enhances the mixing of the fuel and its conversion into char. Solid materials stay mostly in the well-stirred bed, although small particles will leave the bubbling bed and be thrown up into the freeboard region.

The bed is usually formed by sand mixed with a small quantity of fuel. Fluidization of the solids occurs when

a gaseous stream (primary air) passes through a bed of solid particles at a velocity sufficient (above the minimum fluidization velocity) to overcome the particles' gravity force.

**Figure 5-8: Principle of BFB and CFB**



Source: COWI.

## Case Story: Biomass Project for the Paper Industry in Pakistan



### PROJECT DESCRIPTION

The large paper manufacturer Bulleh Shah Packaging Ltd., in Kasur, near Lahore in Punjab, Pakistan, has commissioned a new biomass power plant based mainly on wheat straw, corn stover, and cotton stalks. The new biomass boiler substitutes an existing fossil fuel-fired boiler, but natural gas/oil is still used for startup and as auxiliary fuel.

The new power plant, commissioned in 2015, is reducing Bulleh Shah's operating costs by substituting fuel oil and gas with biomass. The plant contributes to the region's economic development, as it uses locally grown biomass residues, available in large quantities, as fuel. Furthermore, the new biomass-fired plant is reducing the carbon dioxide emissions.

The integration between the new biomass boiler and the existing power plant has been thoroughly investigated to find an optimal size of the new boiler together with the existing steam turbine and the process steam consumption.

Based on the conceptual design, a bankable feasibility study for external financing was carried out, followed by the overall design, tender specifications, contract negotiations, and finalizing of the turnkey contract.

### APPLIED TECHNOLOGY

The project includes a new biomass boiler, a new flue gas cleaning system, and civil construction.

The grate-type boiler is equipped with a steam superheater for the turbine, a feed-water economizer, and an air preheater.

The flue gas from the boiler is cleaned for dust emissions in the baghouse filter, located prior to the stack.



### PLANT PERFORMANCE

The plant capacity is 120 MWth, and the plant generates up to 35 MWe electricity in addition to process steam for the paper mill.

The capacity of the grate-fired boiler unit is 150 tons of steam per hour, 525°C, 100 bar.

### FUEL TYPE AND HANDLING

The plant is designed for a variety of biomass fuels such as wheat straw, corn stover, cotton stalks, and rice straw and husk.

The power plant includes outdoor fuel storage (bales), shredding facilities (maximum particle size of 100 millimeters), indoor storage with shredded fuel for automatic operation during night hours and weekends, and automatic conveying of fuel from storage to the boiler unit and feeding into the boiler.



Source: COWI.

Limestone might be added to the bed to reduce and remove sulfur and/or chlorine. Coarse bed material is withdrawn from the bottom of the bed to maintain high sulfur-capture capacity and to avoid ash contamination that might cause bed agglomeration.

Primary air is about 30 percent of the combustion air and varies according to the moisture content of the biomass. The

remaining air is injected through the secondary and tertiary air ports above the furnace, enhancing staged combustion.

BFB operation range is between the minimum fluidization velocity and the entrainment velocity at which the bed particles would be dragged by the passing gas. Since the combustion chamber is protected with refractory load changes, cold start capability is relatively slow compared to the grate technology.

Combustion temperature is normally between 800°C and 950°C, with 850°C as a typical bed temperature.

The maintenance cost for BFB boilers is normally considered to be high as the refractory in the bed and at the boiler walls requires regular maintenance and the bed technology requires a relatively high primary air pressure that is costly. Further bed material (sand) needs to be added continually, and hence the ash residue amount is high and generates costs.

### CIRCULATING FLUIDIZED BED (CFB)

CFB boilers are normally used in larger applications. A CFB configuration includes solid separators that isolate the entrained particles from the flue gas stream and recycle them to the lower furnace. The collected particles are returned to the furnace via the loop seal.

Fluidizing velocity is higher than in a BFB and can be between 4.5 and 6.7 meters per second. The entrainment velocity is the point that defines the transition from a BFB to a CFB. The CFB operation range is fixed over that entrainment velocity. Beyond this velocity, the bed material becomes entrained and the solids are distributed throughout the furnace with a gradually decreasing density from the bottom to the top of the furnace. A distinction between the bed and the freeboard area is no longer possible. A large fraction of the particles rises up from the bed and is recirculated by a cyclone. The circulating bed material is used for temperature control in the boiler.

CFB boilers are used in large combined heat and power (CHP) plants or power plants, with a capacity of hundreds of MWe, but they also are applied in small-scale power generation, using fuels or fuel mixtures that are less reactive and require longer residence time for full conversion.

The maintenance costs for CFB boilers are normally considered to be high as the refractory in the bed and at the boiler walls requires regular maintenance. The operation costs for CFB boilers are likewise considered to be high, as the bed technology requires a relatively high primary air pressure that is costly. Further, bed material (sand) needs to be added continually and hence the ash residue amount is high and generates costs.

**Figure 5-9:** Bubbling Fluidized Bed Boiler



Source: Foster Wheeler, 2016.

## 5.3.3 BOILER TECHNOLOGIES

### WATER AND STEAM BOILER PLANTS

This section describes how the boiler converts the energy in the hot flue gas from the combustion into steam/heat. The section introduces the thermodynamical concept of a steam cycle and presents the main boiler types.

### WATER AND STEAM BOILER

The purpose of a steam generator or boiler is to generate steam at a desired rate, temperature, and pressure by transferring heat from the combustion of fuel into water, which is then evaporated into steam. The steam can be used for different applications, such as power generation, district heating, industrial processes, or combinations thereof, depending on the steam pressure/temperature.

A boiler can be either a fire-tube boiler, where hot flue gases flow through tubes surrounded by water in a shell, or a water-tube boiler, where the water flows through tubes and the hot flue gases flow over the tubes. In high-pressure applications, such as power generation, it is an advantage (in terms of metal stress) to have the high-pressure water/steam inside relatively small-diameter tubes. Hence, the water tube configuration is preferred. For small hot water or process steam boilers, the fire tube boiler is often used.

Boilers that use a drum and recirculate water for changing into steam are called drum boilers.

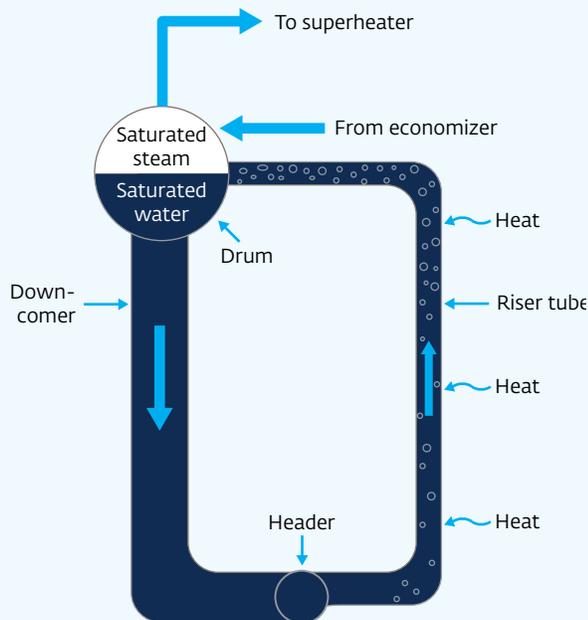
## PROCESS

The heat transfer from the hot flue gases to the feed water in a drum boiler is divided into three sections: an economizer, an evaporator, and superheaters.

Feed water pumps pump the feed water into the economizer, which heats it to saturated water and feeds it into the evaporator. The evaporator consists of a number of down-comer pipes and riser tubes (membrane wall) in a loop connected to a header in the bottom of the boiler and a drum in the top of the boiler. The saturated water enters the drum, falls through the down-comer tubes into the bottom header, and moves up through the riser tubes, where it is heated by the hot flue gases and led back into the top of the drum as steam.

In the riser tubes, the saturated water will boil partially and will form bubbles of saturated steam. The saturated steam is taken from the top of the drum to the primary superheater, while the saturated water repeats the loop (see Figure 5–10). In the superheaters, the steam is further heated by the hot flue gases to superheated steam and led to a steam turbine where it is expanded, delivering work to generate power.

**Figure 5-10:** Evaporator Circulation System, P.K. Nag, Power Plant Engineering



Source: COWI.

Figure 5–11 shows a schematic of a typical drum boiler arrangement. The evaporator riser tubes constitute the walls of the furnace area, mainly absorbing heat by radiation. Finally, the remaining heat from the flue gases is used to preheat the combustion air. The flue gases then leave the boiler through the flue gas treatment systems to the flue gas stack.

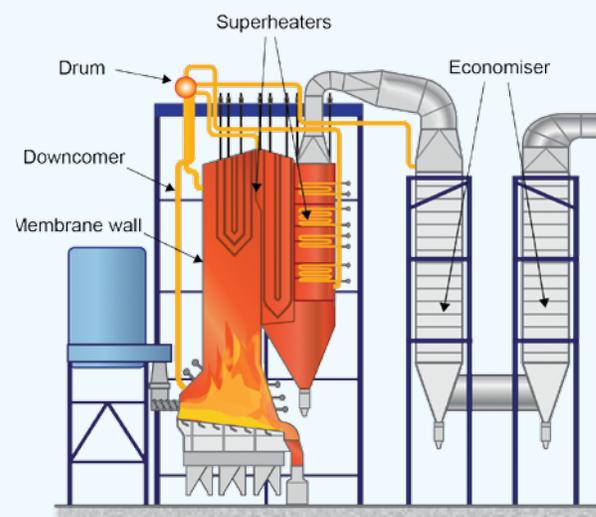
## WATER-STEAM CYCLE

As described in the previous section, a boiler converts the energy from the biomass combustion into high-pressure steam. The steam is transformed into electrical power in a steam turbine, which drives a generator that produces electrical power. After the steam has passed through the turbine, it is condensed into water in a condenser and recycled back to the boiler, where it is heated into steam again. The use of a water-steam cycle as described above, including a boiler and a steam turbine, is the most widely spread and commonly used technology to produce electric power from a fuel, including biomass.

The water-steam cycle also is termed a Rankine Cycle, and Figure 5–12 shows this in its most basic form.

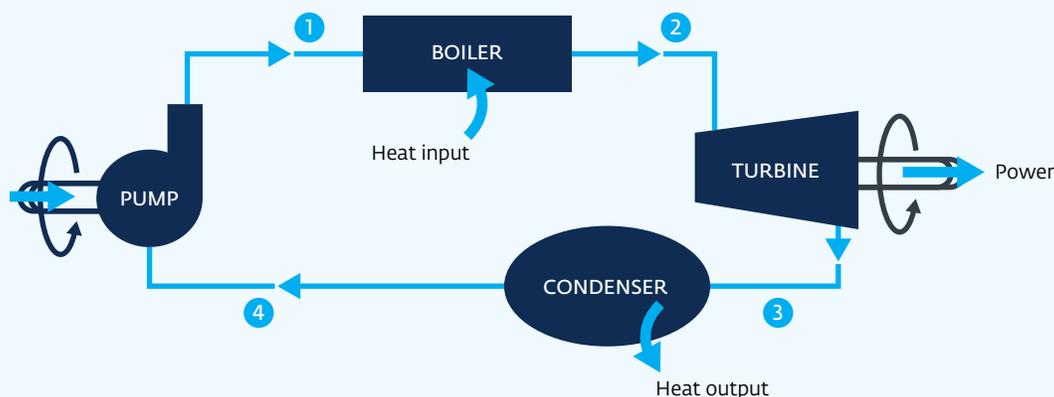
**Steps 1–2:** The heat released from combustion of the fuel is used to evaporate water to steam in the boiler. The steam is superheated to a temperature above the boiling point.

**Figure 5-11:** Typical Water Tube Boiler Arrangement, P.K. Nag, Power Plant Engineering



Source: COWI.

**Figure 5-12:** Water-Steam Cycle



Source: COWI.

**Steps 2–3:** The steam flows through the turbine, expanding along the way, and thus transfers mechanical energy to the rotating turbine shaft. The turbine shaft drives a generator, which produces the electrical power. Figure 5–13 shows an example of a steam turbine.

**Steps 3–4:** When the steam exits the turbine, it is left with an amount of residual heat that cannot be used for electricity production in the turbine. This heat has to be removed, and the steam is condensed in order to be recirculated into the boiler. This happens in a heat-exchanging condenser that transfers the residual heat to cooling water, either from a natural source such as river or sea water or to air coolers.

**Steps 4–1:** The condensed steam (water) is then pumped from the condenser to a reservoir or feed water tank, from

where it is again pumped to the boiler for steam production. The pump used for this purpose is termed the feed water pump and is usually a multi-stage pump suitable for handling large pressure heads.

#### ELECTRICAL EFFICIENCY

The electrical efficiency of the cycle is highly dependent on the steam temperature and the condensing temperature. The efficiency will increase with higher steam temperature and lower condensing temperature. Higher steam temperatures require the use of more expensive steel alloys in the boiler and steam pipes.

#### COMBINED HEAT AND POWER (CHP) PLANT

For a combined heat and power (CHP) plant, where heat in the form of steam or hot water can be used, it is most often the heat output from the condenser that is used. The amount of heat that can be recovered from the condenser is normally about 40 to 60 percent of the energy from the fuel. Often, the heat is in the form of water at a temperature between 70°C and 100°C or low-pressure process steam. Higher temperatures can be obtained; however, this will have a negative effect on the electrical power production.

#### HEAT-ONLY BOILER

There are many cases where there is a need for heat (steam or hot water) without a demand for power production. For plants up to around 30 to 40 MW<sub>th</sub>, a large number

**Figure 5-13:** Illustration of a Steam Turbine



Source: COWI, 2016.



### PROJECT DESCRIPTION

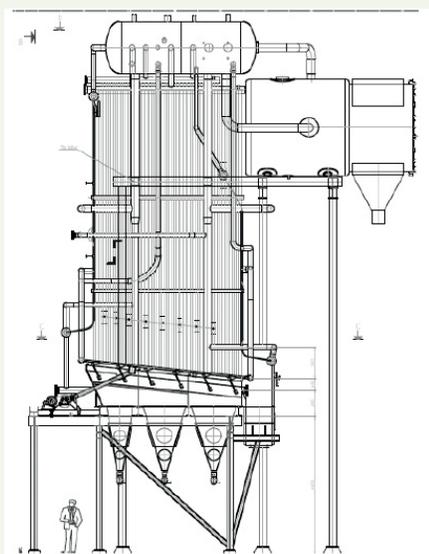
Bentong Biomass Plant is a privately owned energy plant located in Pahang, Malaysia, a region where many industries using natural resources are gathered.

The plant is fired with waste products from nearby industries, thereby making use of waste products for energy production. Two types of fuel are used: wood chips and empty fruit bunches. The wood chips are left over from furniture production that takes place at a nearby plant. The empty fruit bunches are residues from palm oil production, after the palm oil has been extracted.

Both waste products are pretreated upon arrival at the Bentong plant. Both fuel types are shredded to obtain a homogenous size, which enables smoother operation of the plant and the combustion process.

Bentong Biomass Plant produces steam, which is sold to a nearby paper factory 24 hours a day, 7 days a week. A multiyear agreement between Bentong Biomass Plant and the paper factory has secured the biomass plant a guaranteed price for steam, while securing the paper factory a guaranteed rate of supplied steam.

The plant is shut down for maintenance one to three times per year for one to three weeks at a time. However, in some years, no maintenance has been required at all. The plant was commissioned in 2007 and is staffed by three shifts of six operators each. The plant was built by a Malaysian contractor specializing in biomass plants and using combustion technology from a Danish boiler supplier.



### APPLIED TECHNOLOGY

Boiler capacity and parameters:

- 32 tons of steam flow per hour
- 29 bar / 218°C

Typical costs for biomass plants fired by empty fruit bunches:

- **Fuel cost:** 72–80 Malaysian ringgit per ton of fuel (including transportation, pretreatment)
- **Operation and maintenance cost:** 240 Malaysian ringgit per MWh.

### PLANT PERFORMANCE

The project includes the entire plant as well as pretreatment for waste. The drum-type steam boiler, fired from the grate, is equipped with steam superheaters.

The vibrating grate is designed as water-cooled membrane wall panels and is connected to the boiler by means of flexible pipes. The vibrating movement of the grate is provided by two vibration drives, and the intervals for vibration can be set according to fuel quality.

### IMPORTANT LESSONS LEARNED

The plant was originally designed with air spout fuel feeding. Due to variations in fuel quality, however, the feeding system was subsequently changed to screw feeding, a more robust feeding system.

Source: Babcock & Wilcox Vølund A/S, [www.volund.dk](http://www.volund.dk).

of suppliers offer standardized boilers that can operate on the most common types of biomass. Larger plants, or plants with special requirements (e.g., in relation to steam parameters) will need a tailor-made boiler to be designed for the actual case. Many boiler suppliers are specialized

in delivering tailor-made biomass boiler plants that can meet special requirements for a certain flow, pressure, or temperature for the process heat.

## RETROFIT OF EXISTING FOSSIL FUEL BOILERS

In some cases, it can be interesting to investigate the possibilities for a complete or partial conversion of fossil fuel-fired boilers to burn biomass fuels.

Both the technical options and the economic viability of such projects will be very specific for the individual case. There are a number of examples of conversion projects for various boiler types, including:

- Coal-fired grate boilers converted to biomass grate
- Coal-fired pulverized fuel boilers converted to biomass BFB.
- Natural gas/ liquefied petroleum gas (LPG)/ light oil-fired boilers converted to biogas.

A number of projects are under development, mainly in Europe and the United States, for the conversion of large utility-size, coal-fired power stations up to 600 to 800 MWe, mainly by substituting coal with wood pellets.

These projects demonstrate that technical solutions can be found, but they are outside the scope of this guide.

Many small to midsize coal-fired utility and industrial boilers, up to about 200 MWth, exist around the world. The majority of these boilers are either grate-fired boilers (the smaller sizes) or pulverized fuel-fired boilers (the larger). Converting such plants from coal to biomass fuels can use locally available fuels and reduce greenhouse-gas emissions. A conversion also may be a way to reduce sulfur emissions as an alternative to installing a desulfurization system.

Converting a relatively small grate-fired boiler from coal to biomass will require modifications to the stoker system in order to handle the larger volume of fuel. Preferably, the new biomass fuel should have a relatively low moisture content, thus avoiding a capacity reduction due to larger flue gas flow. In addition, the fuel should not be of a high alkaline type (such as straw) due to risks of fouling and corrosion of heating surfaces.

For a typical pulverized fuel-fired boiler (up to 200 MWth), an option may be to replace the original boiler bottom with a new BFB-type bottom, including air nozzles and bottom

ash removal. A BFB-type boiler may be able to handle fuels with moisture content up to 50 to 60 percent. However, an increase in flue gas flow may reduce the boiler capacity or require changes of the flue gas path and the fans.

The technical considerations for a conversion project will also include:

- New installations for fuel handling and storage
- New installations or modifications of filters for particle removal
- New installations or modification of ash handling.

Boilers designed for natural gas, LPG, or light fuel oil may be converted to use biogas from a nearby new biogas plant. Such conversions will require change of burners and possibly combustion air systems. All the biomass fuels mentioned have relatively low contents of sulfur and ash, so the flue gas path often will require no or only small changes.

## 5.3.4 ORC TECHNOLOGY

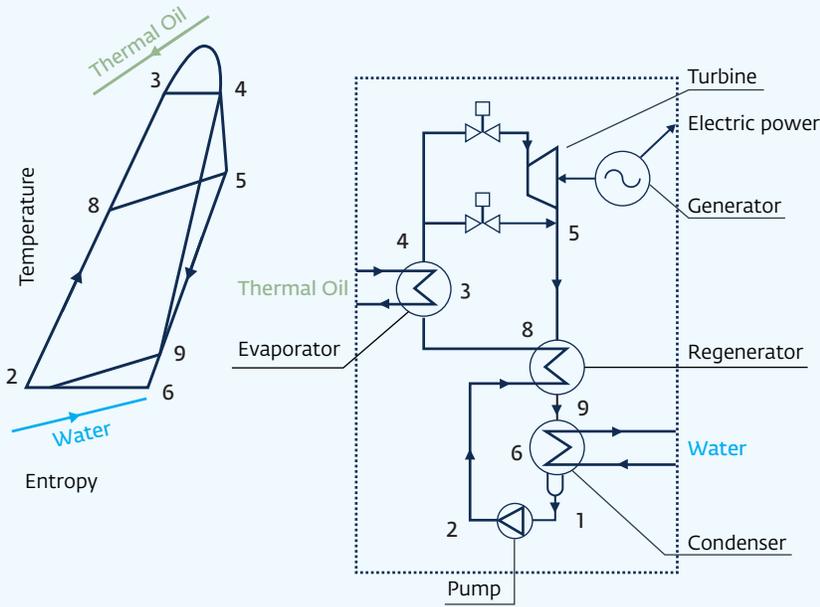
### PRINCIPLE OF ORC

The Organic Rankine Cycle (ORC) is, as the name implies, a technology based on the Rankine Cycle, which is the basic thermodynamic cycle also used in the conventional water-steam cycle, as shown in Figure 5–14. The working fluid in ORC is an organic, high-molecular-mass fluid. This fluid has a liquid-vapor phase change (or boiling point) occurring at a lower temperature than for water-steam. ORC can be used to convert thermal energy from a relatively low-temperature heat source to electricity. Typical heat sources are industrial waste heat, geothermal heat, and heat from a relatively simple biomass combustion system.

Typically, the temperature of the heat input to an ORC cycle is up to 300°C to 350°C, compared to the 500°C to 600°C steam temperature often applied in water-steam cycles. The efficiency of the heat to electricity conversion depends thermodynamically on the heat source temperature. ORC therefore will have a theoretically lower efficiency than a water-steam cycle operating at higher temperatures.

Because design temperatures and pressures applied in an ORC unit are lower than in a typical water-steam plant, the costs

**Figure 5-14:** Principle of a Typical Organic Rankine Cycle



The plant uses the hot-temperature thermal oil to preheat and vaporize a suitable organic working fluid in the evaporator (8→3→4). The thermal oil is cooled in the evaporator and returned to the boiler or other heat source for reheating. The organic fluid vapor powers the turbine (4→5), which is directly coupled to the electric generator through an elastic coupling. The exhaust vapor flows through the regenerator (5→9) where it heats the organic liquid (2→8). The vapor is condensed in the condenser (cooled by the cooling water flow) (9→6→1). The organic fluid liquid is finally pumped (1→2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

Sources: COWI; Turboden, 2016.

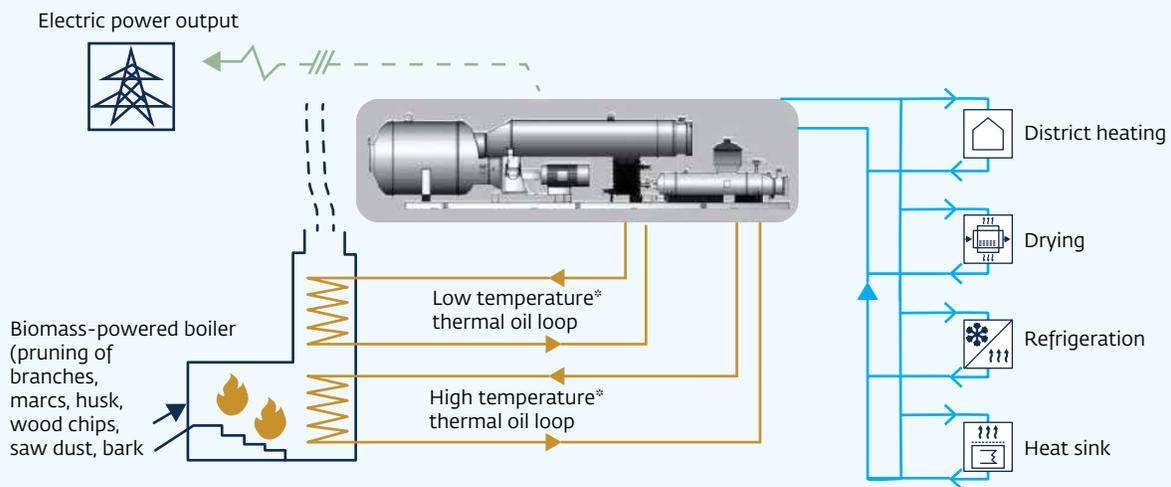
of components can be reduced by using less costly materials, smaller wall thicknesses, and comparatively simple designs.

This will improve the economic feasibility for smaller plants compared to water-steam plants. Generally, the lower temperatures and pressures in an ORC plant also simplifies operation and maintenance and reduces the skills needed

by the operating staff, and therefore may reduce the direct O&M costs.

The basic ORC thermodynamic cycle and the coupling of the main components are illustrated in Figure 5–15. The core ORC unit must be connected to the high-temperature heat source, the low-temperature heat sink, and the

**Figure 5-15:** Principle of Connections to an ORC Unit



Source: Turboden, 2016.

\* Turboden ORC units can be also fed with saturated vapor or superheated water.

electrical grid. Figure 5–15 illustrates the principle of these connections.

A closed-circuit thermal oil heat transfer system is often used to transfer the driving heat from the combustion unit (for example, a biomass combusting boiler or waste heat source) to the ORC unit. These systems use a special oil-based thermal fluid as the heat carrier. The main advantage of these systems is that they can be designed and operated at much lower pressures than needed for a water-steam based system. However, extreme care is needed in the design and operation of thermal oil systems, as the fluids normally are combustible and leaks may cause a fire.

The energy converted to electricity via the turbo-generator must be transferred to the electrical grid or to an industrial consumer, as for any other electricity-generating plant.

The energy not converted to electricity must be transferred from the ORC condenser to a low-temperature heat sink. For a plant designed for the sole production of electric power, the heat is transferred to a cooling water system or to a dry or wet cooling tower. The electrical efficiency of an ORC plant will depend on the temperature of the cooling system, as illustrated in Figure 5–16.

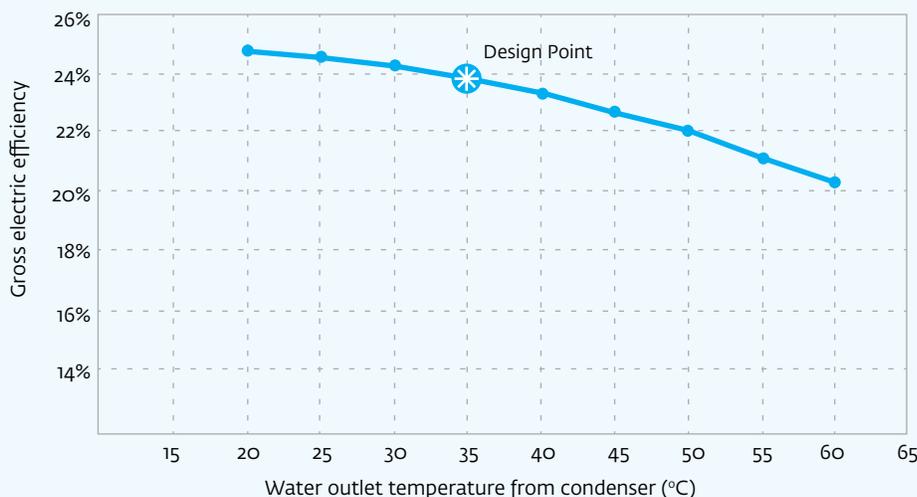
ORC plants can also be configured as combined heat and power plants, where the energy not converted to electric power is used for district heating or as industrial process heat. A CHP plant will have a lower electrical efficiency than a power-only plant, because the temperatures needed for heat application generally will be higher than the temperatures in cooling circuits. The combined efficiency (electricity plus heat) will, however, be much higher for a CHP plant than for a power-only plant. Overall efficiencies can be more than 90 percent if all low-temperature heat from the ORC unit can be made useful.

Although CHP projects have a higher CAPEX, CHP projects usually have a stronger and more robust economy due to income streams from sale of both power and heat.

### ORC PLANT CONFIGURATIONS AND LAYOUT

ORC plants are available in unit sizes from a few hundred kWe up to 10–15 MWe. For smaller plants, the core ORC unit is typically a factory-assembled unit, simplifying the on-site installation and commissioning. Larger plants are typically partly factory-assembled and transported to the construction site in modules, requiring final connection and testing on-site. Figures 5–17 and 5–18 show examples of the layout of ORC units.

**Figure 5-16:** Illustration of Electrical Efficiency as a Function of Cooling Water Temperature



GROSS PERFORMANCE OF THE TURBODEN HRS MODULES AT VARIOUS CONDENSATION WATER TEMPERATURES

\* Value of gross electrical efficiency calculated as the ratio of electric power output at generator terminals to the thermal power input to the ORC at the design point

Source: Turboden, 2016.

**Figure 5-17:** Layout of a 1 MWe ORC Unit



Source: Turboden, 2016.

**Figure 5-18:** MWe Biomass-driven ORC Unit



Source: Turboden, 2016.

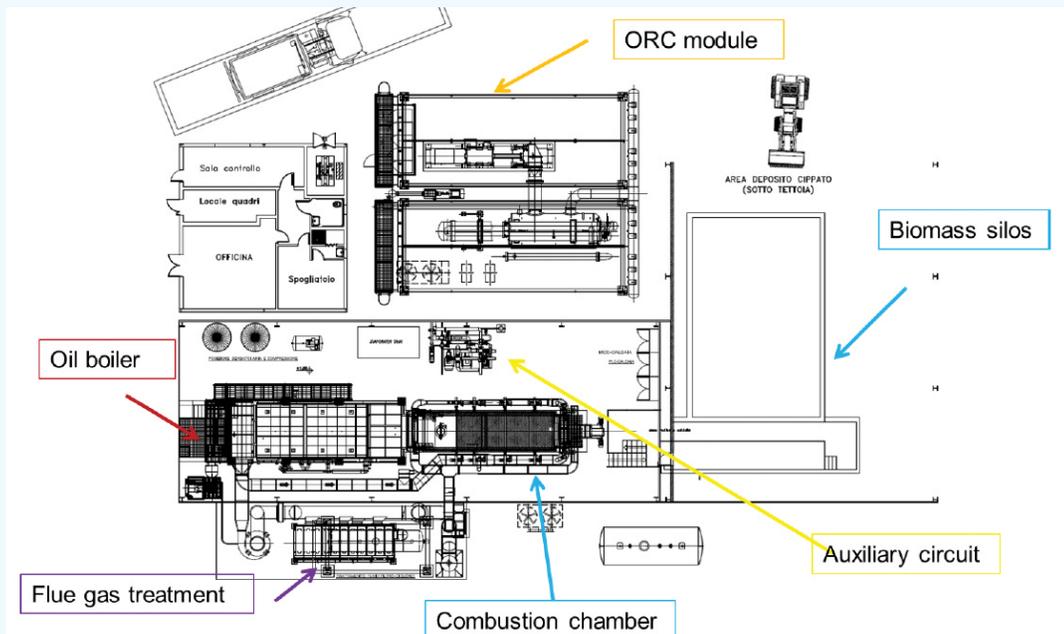
A biomass-to-energy ORC plant includes a number of sections and systems, for example:

- The core ORC unit
- Biomass fuel reception, storage, and handling
- Biomass boiler with flue gas cleaning and ash handling
- Thermal oil heat transfer system
- Cooling water system and/or low-temperature heat recovery system

- Internal electricity supply and control system
- Electrical grid connection
- Civil works and buildings.

The core ORC module may represent only 20 to 30 percent of the total investment cost (CAPEX) for a complete biomass plant. During project development, it is very important to focus on all necessary parts of the complete plant.

**Figure 5-19:** Illustration of the Layout of a Biomass ORC Plant Including Biomass Boiler, Fuel Silo, and Some Auxiliary Systems



Source: Exergy, 2016.

### 5.3.5 EMISSIONS AND FLUE GAS CLEANING

This section describes the different measures available for reducing emissions from the combustion of biomass. The emissions can be reduced by either primary measures (combustion process integrated measures) or secondary measures (post-combustion cleaning).

#### PRIMARY MEASURES

The primary measures improve the combustion process and minimize the production of pollutants. A combustion temperature above 850°C for at least 1.5 seconds secures a complete combustion; lower temperatures or lower residence time increase the emissions of complex hydrocarbons (tars), carbon monoxide, etc.

If the combustion air is preheated and the moisture content in the fuel is less than 50 to 60 percent, an adequate combustion temperature can normally be reached.

Emission of nitrogen oxides is due either to the nitrogen content in the fuel or to the formation of thermal nitrogen oxide (that is, oxidation of atmospheric nitrogen gas). Oxidation of nitrogen gas is only a problem at combustion temperatures above 1,400°C, and it therefore presents little problem in biomass-fired boilers, where the combustion temperatures range from about 900°C to about 1,200°C.

The nitrogen content in biomass covers a wide range from 12 percent in hardwood to 2 percent or more in some agricultural waste products, which potentially can lead to very high nitrogen oxide emissions. These emissions can be reduced by staged combustion, where the initial combustion is sub-stoichiometric, whereby the fuel nitrogen is converted to nitrogen gas. Excess secondary air is subsequently added to secure complete burnout of carbon monoxide, hydrocarbons, etc.

Inappropriate boiler operation may cause large emissions, so the plant should preferably be equipped with a control system that automatically adjusts the air/fuel ratio, both at steady operation and during load changes.

Uniform size and moisture content of the biomass fuel parts also will improve the combustion process.

Figure 5-20: A 1 MWe Biomass ORC Plant in Italy



Source: Turboden, 2016.

Measures to enhance the combustion process are summarized below:

- **Fuel quality:** uniform size and (low) moisture content
- **Staged combustion:** to reduce fuel nitrogen oxide formation
- **Combustion temperature** >850°C; >1.5 seconds to secure complete burnout
- **Adequate control system:** to adapt to changes in load and fuel quality.

#### SECONDARY MEASURES

Secondary measures are flue gas treatment systems placed between the combustion zone and the stack to remove unwanted pollutants. Depending on the boiler and the biomass fuel, nitrogen oxides, carbon monoxide, hydrogen chloride, sulfur dioxide, volatile organic compounds, and particulates could pose a problem.

For biomass-fired boilers, dust or particulate removal is the most frequent and important process. Systems for dust removal are:

- Multicyclones
- (Venturi) scrubbers
- Electrostatic precipitators
- Baghouse filters.

## MULTICYCLONE

A multicyclone is a battery consisting of 8 to 16 or more single cyclones (see Figure 5–21). In cyclones, particles are separated by centrifugal forces. Multicyclones are simple and can resist high temperatures, but they are less efficient for small particles. They are often used for upstream pretreatment.

## SCRUBBERS

Several types of wet scrubbers can be used for particulate removal. Among the most efficient are the venturi scrubbers (see Figure 5–22). A venturi scrubber consists of three sections: a converging section, a throat section, and a diverging section. The inlet gas stream enters the converging section, and, as the area decreases, the gas velocity increases.

### Case Story: Biomass Project for the Wood Processing Industry in Turkey



#### PROJECT DESCRIPTION

Kastamonu Entegre is a large integrated company specialized in the production of wood-based panels (particle board and MDF). In its facility in Gebze (in northwestern Turkey), the company burns wood residues from its own production in order to use the heat, mainly for thermal-oil presses and dryers.

Because the company had a surplus of both biomass and thermal capacity in the existing boilers, it decided to install an ORC unit in order to produce electricity. The plant startup occurred in 2014.

#### APPLIED TECHNOLOGY

The company decided to install a Turboden 10-CHP unit, which produces both electricity and hot water at 90°C.

The input of the unit is hot oil at about 300°C (about 5.5 MWh thermal). The oil circuit was already present in the facility (used mainly for the presses), so the company installed a three-way valve to redirect part of the flow to ORC heat exchangers.

#### PLANT PERFORMANCE

Outputs of the ORC unit:

- Electricity totaling 955 kWh electrical at nominal conditions.
- Thermal power totaling about 4.5 MWh thermal in the form of hot water at 90°C. The hot water is integrated in the production system and used to heat the buildings and dryers.

#### OUTCOME OF THE PROJECT

The ORC project at the MDF board producer in Gebze, Turkey, is an interesting example of the realization of opportunities for integrating ORC technology with the particle board and MDF manufacturing industry. Low-price biomass fuel is available, combined with a need for both thermal energy and electrical power for the production processes.

Thermal energy is used in the process for:

- Low-pressure steam for fiber preparation
- Hot gases for hot fiber drying in direct contact dryers
- Thermal oil for hot process and other heat consumers.

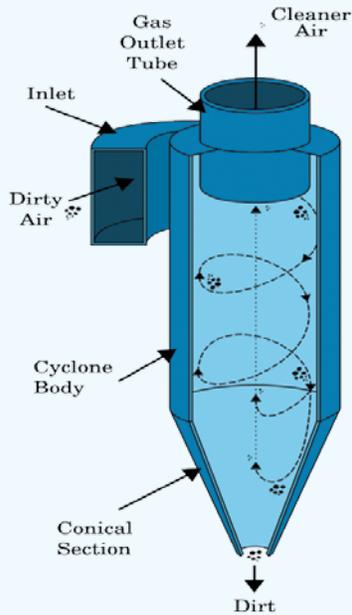
Electrical power is used for:

- Hammer mill
- Sawmill
- Hot compression of the presses
- Auxiliaries.



Source: Turboden, 2016.

**Figure 5-21:** Illustration of a Multicyclone



Source: Cburnett, Wikipedia, 2016.

Liquid is introduced either at the throat or at the entrance to the converging section.

The inlet gas, forced to move at very high velocities in the small throat section, shears the liquid from the scrubber walls, producing an enormous number of very tiny droplets.

Particle and gas removal occur in the diverging section as the inlet gas stream mixes with the fog of tiny liquid droplets. The inlet stream then exits through the diverging section, where it is forced to slow down.

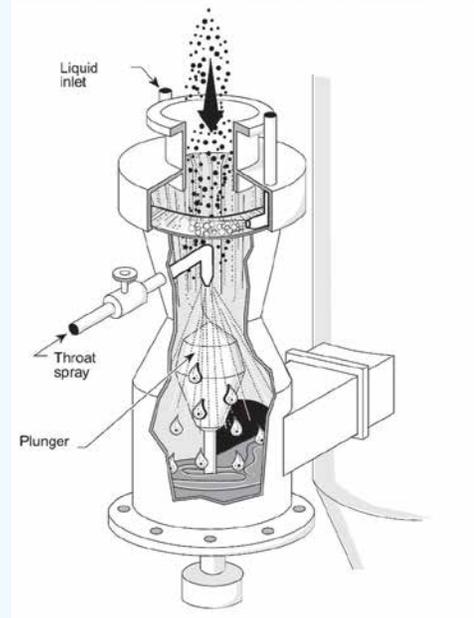
### ELECTROSTATIC PRECIPITATORS

An electrostatic precipitator (ESP) (see Figure 5-23) is a particle control device that uses electrical forces to move the particles out of the flue gas stream and onto collector plates.

In the ESP, the particles are given an electrical charge by forcing them to pass through a corona, a region in which gaseous ions flow. The electrical field that forces the charged particles to the walls comes from electrodes maintained at high voltage in the center of the flow lane.

Once the particles are collected on the plates, they must be removed from the plates without re-entraining them into

**Figure 5-22:** Illustration of a Venturi Scrubber



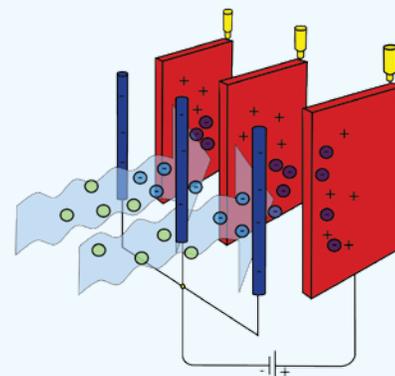
Source: Wikipedia, 2016.

the gas stream. This is usually accomplished by knocking them loose from the plates, allowing the collected layer of particles to slide down into a hopper from which they are evacuated. Some ESPs remove the particles by intermittent or continuous washing with water.

The efficiency of an ESP depends primarily on particle size distribution and resistivity of the dust particles.

The electrical force to move the particles out of the gas stream depends on the number of electric charges per mass

**Figure 5-23:** Detail of an Electrostatic Precipitator



Source: Egmason, Wikipedia, 2016.

unit. For small particles (<1 micron), removal efficiency is rather poor as the available space (on each particle) for electron charges is limited. An ESP is therefore mediocre for aerosol particles, although better than a multicyclone.

The resistivity of the dust particles should be neither too low nor too high. If the resistivity is too low, the particles lose their charges when they hit the collecting plate and will re-entrain back into the gas stream. If the resistivity is too high, the particles will not be charged at all and therefore will not be affected by the electric field.

### BAGHOUSE FILTERS

A baghouse filter (see Figure 5–24) contains bags of textiles or membrane-coated textiles through which the flue gas passes and leaves a layer of dust to accumulate on the filter media surface. When sufficient pressure drop is reached, the cleaning process begins.

Cleaning can take place while the bag house is online (filtering) or is offline (in isolation). When the compartment is clean, normal filtering resumes.

The cleaning cycle can be either mechanical shaking, reverse air, or jet pulses of compressed air. In all cases, the collected dust cake will crack and fall into the hopper below, from which it is evacuated.

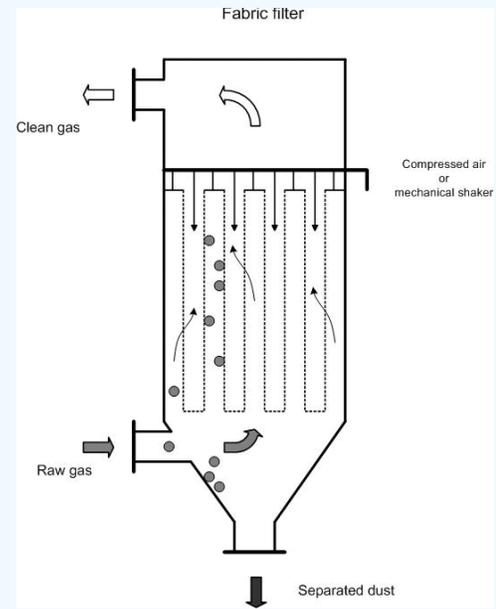
Baghouse filters are very efficient at removing all particle sizes, and operation is reliable when the flue gas is dry and the particles are non-sticking. However, the baghouse filter is sensitive to the risk of fire caused by sparks in the flue gas stream.

### EMISSION OF GASEOUS SUBSTANCES

Most emissions (carbon dioxide, nitrogen oxides, tars, volatile organic compounds, etc.) are best handled by primary measures; however, in some cases, nitrogen oxides need to be reduced by secondary measures.

In principle, both selective and non-selective catalytic reduction systems based on ammonia can be used. The non-selective process takes place in the boiler at temperatures between 850°C and 950°C. Due to the high temperature, most of the ammonia ends up as nitrogen gas, and therefore a high excess of ammonia is needed. Depending on the location

Figure 5-24: Baghouse Filter



Source: emis.vito.be.

of the superheaters and on a sufficient temperature window, it is realistic to achieve a 30 to 50 percent reduction in nitrogen oxides. The superheaters often are located in the desired temperature window, and this will spoil the option of using non-selective catalytic reduction.

The selective catalytic reduction process takes place at a catalyst surface at 320°C to 380°C, a temperature range often reached just before the economizer, but the potassium content in biomass poses a serious risk for fast degradation of the selective catalytic reduction catalyst.

Secondary measures for nitrogen oxide removal are CAPEX and OPEX intensive and should be implemented only if deemed necessary by legislation and by the Environmental and Social Impact Assessment outcomes / consideration of potential sensitive receptors / degraded airshed.

### 5.3.6 RESIDUES AND THEIR HANDLING

All extraction of biomass from the forests and fields removes nutrients and acid-buffering capacity from the soil.

During combustion of biomass fuel, nutrients and acid-buffering substances are concentrated in the ash. This makes the ash suitable as a compensatory fertilizer to replace the

lost nutrients and acid-buffering capacity in forest soil. Only nitrogen is missing, as it is eliminated with the flue gases.

The amount of ash depends on the biomass type and the amount of residual soil attached to the fuel. Hardwood logs produce the lowest amount of ash, whereas byproducts from annual crops (such as straw and corn stover) collected directly from the fields have the highest amount. The typical amounts are between 1 percent and 4 percent of the dry fuel.

### THE WASTE HIERARCHY

Ash from biomass combustion should be treated according to the waste hierarchy (see Figure 5–25). In relation to ash, there are three relevant options: reduce, recycle, or landfill.

Ash production can be reduced to some extent by using clean logs for wood chip production, etc., and by storing the biomass fuel on paved ground. However, a limited production of biomass ash is unavoidable; the primary goal therefore will be to recycle the ash to prevent depletion of minerals in the fields and forests.

The biomass ash preferably should be returned to the same type of field/forest that the fuel came from, and approximately in the same amount. A rule of thumb is to limit the amount of ash to less than 3 tons per hectare.

In addition to the macro constituents, biomass ash—especially from annual crops—could contain high concentrations of,

for example, cadmium, lead, or zinc. Ash analysis therefore should be carried out to ensure that ash recycling complies with local regulations.

In addition to its probable heavy metal content, biomass ash has a very high pH. The option to recycle ash therefore should be dependent on the sustainable conditioning of the soil. Ash recycling should not result in an uncontrolled pH shock, hence the biomass ash could be stored (for example, for a season) to allow atmospheric carbon dioxide to react and neutralize the ash.

If recycling of ash is impractical for either environmental or economic reasons, the ash may be disposed of at an approved landfill.

The macro constituents (the valuable ones are primarily manganese, magnesium, potassium, phosphorus, and sulfur) in a number of biomass ashes are summarized in Table 5–4.

Ash collected from a biomass plant should preferably be separated into bottom ash from the boiler and fly ash from the filter. This will enable the owner to apply for recycling of the bottom ash, whereas the fly ash with most of the heavy metals of the fuel may be landfilled. If permitted by the local authorities, the fly ash also may be recycled, resulting in a much lower cost.

### 5.3.7 COOLING PRINCIPLES

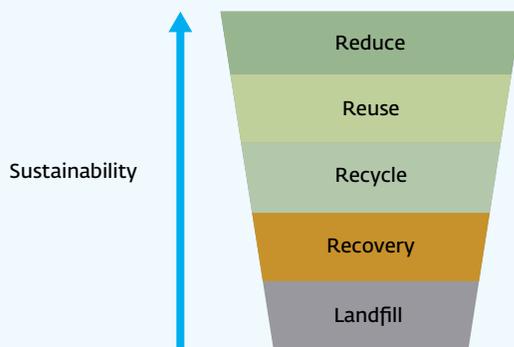
There are four methods for cooling the residual heat in the condensed steam from the turbine condenser. These cooling principles should be regarded as an alternative or supplement to recovering the residual heat for industrial use. The four methods are:

- Natural convection cooling towers
- Dry coolers
- Wet/dry coolers
- Wet coolers.

### NATURAL CONVECTION COOLING TOWERS

Natural convection cooling towers are a type of cooling tower that is well known from nuclear power stations, where cooling water flows over grates (or similar), and heat is

**Figure 5-25:** The Waste Hierarchy



Source: COWI.

**Table 5-4: Ash Analysis of Different Types of Biomass**

Fuel	Chlorine	Silicon Dioxide	Aluminum Oxide	Iron Oxide	Manganese	Magnesium Oxide	Calcium Oxide	Sodium Oxide	Potassium Oxide	Titanium Dioxide	Phosphorus Pentoxide	Sulfur Trioxide
Wood pellets	No data	4.30	1.30	1.50	5.90	8.50	55.90	0.60	16.80	0.10	3.90	1.03
Sunflower pellets	No data	2.90	0.60	0.80	0.10	21.60	21.60	0.24	22.80	0.10	15.20	14.00
Walnut shell	0.1	23.10	2.40	1.50	No data	13.40	16.60	1.00	31.80	0.10	6.30	2.20
Almond shell	0.2	23.50	2.70	2.80	No data	5.20	10.50	1.60	48.50	0.10	4.50	0.80
Olive husk	0.2	32.70	8.40	6.30	No data	4.20	14.50	26.20	4.30	0.30	2.50	0.60
Hazelnut shell	0.10	33.70	3.10	3.80	No data	7.90	15.40	1.30	30.40	0.10	3.20	1.10
Red oak wood	0.80	49.00	9.50	8.50	No data	1.10	17.50	0.50	9.50	No data	1.80	2.60
Wheat straw	3.60	48.00	3.50	0.50	No data	1.80	3.70	14.50	20.00	No data	3.50	1.90
Beech bark	No data	12.40	0.12	1.10	No data	11.50	68.20	0.90	2.60	0.10	2.30	0.80
Tamarak bark	No data	7.77	8.94	3.83	No data	9.04	53.50	3.40	5.64	0.11	5.00	2.77
Switch grass	No data	66.25	2.22	1.36	No data	4.71	10.21	0.58	9.64	0.28	3.92	0.83
Rice straw	No data	77.20	0.55	0.50	No data	2.71	2.46	1.79	12.59	0.04	0.98	1.18
Olive kernel	No data	67.70	20.30	0.05	No data	0.05	0.50	11.20	0.15	0.05	No data	No data

Source: Saidur et al., 2011.

transferred to an upward airstream through direct contact. Such a cooling tower would, for a 400 MW turbine, have a 100-meter diameter and a height of 150 meters. A specific problem for this type of cooling is the accumulation of unwanted elements such as *E. coli* bacteria in the cooling water. The natural convection cooling towers are not normally found in the range of power plants relevant for this guide.

#### DRY COOLERS

Dry coolers have no direct contact between the cooling air and the water to be cooled. The water transfers its heat to a conducting wall, where air is flowing on the opposite side. In theory, no evaporation happens from the condenser cooling water, and the accumulation of unwanted elements in the cooling water is therefore limited. Due to the absence of water, there is no plume from the cooling process.

#### WET COOLERS

Wet coolers, as opposed to dry coolers, have direct contact between the cooling air flow and the condenser cooling water; however, instead of natural convection, the air flows through the cooler driven by a fan. A certain amount of cooling water will evaporate, and steam can be seen above

the cooling tower. This steam can, depending on the cooling circuit solution, contain some bacteria and chemicals.

#### WET/DRY COOLERS

Wet/dry coolers are a combination of the wet and dry cooler concepts. Primary cooling is done in direct contact with the air flow, but afterward the air is heated by hot cooling water. This allows the air to leave the tower without visible evidence of steam and thus with less risk of spreading bacteria and chemicals.

Examples of forced (not natural) convection cooling towers are shown in Figures 5-26 and 5-27.

#### 5.3.8 ELECTRICAL SYSTEMS

For a 1–40 MWe biomass fuel unit, the main power distribution voltage level is typically given by the turbine generator terminal voltage, for example 10-kilovolt alternating current (AC).

Most consumers, however, are connected to 400-volt AC and 230-volt AC power distribution switchboards, and therefore several distribution transformers must be used to convert from 10-kilovolt AC to 400/230-volt AC. With very large

**Figure 5-26:** Cooling Tower from a Mexican Sugar Mill



Source: COWI.

**Figure 5-27:** Industrial Cooling Towers for a Power Plant



Source: Cenk Endustri, Wikipedia, 2016.

consumers, it may be beneficial to add an additional voltage level of 700-volt AC or even to connect them to the main power distribution.

In general, almost all motors in the plant will be supplied via variable frequency drives because of energy efficiency requirements.

In addition to the AC power systems, direct current (DC) power systems are required for critical and uninterruptable services. The DC power systems are, during normal operation, supplied by the AC systems via rectifiers. When a failure occurs in the AC systems, the DC systems are powered by batteries. Typical consumers are digital control systems, protection and shutdown systems, fire detection, emergency lights, etc. Critical pumps and fans also can be supplied by the DC systems during a power failure, but the power demand must be relatively small.

The electrical main distribution single-line diagram is a key element when describing and visualizing the concepts and the design of the electrical systems. Therefore, a preliminary single-line diagram should be constructed at the earliest possible stage of the project. The single-line diagram is then maintained and developed continuously throughout the

project until handover and commercial operation, where it is in an “as-built” version.

Figure 5–28 shows a simplified typical electrical single-line diagram for a 35 MWe unit. No consumers are shown on the diagram except two large motors supplied by variable speed drives. Almost all motors in the plant will be supplied via variable frequency drives because of energy efficiency requirements.

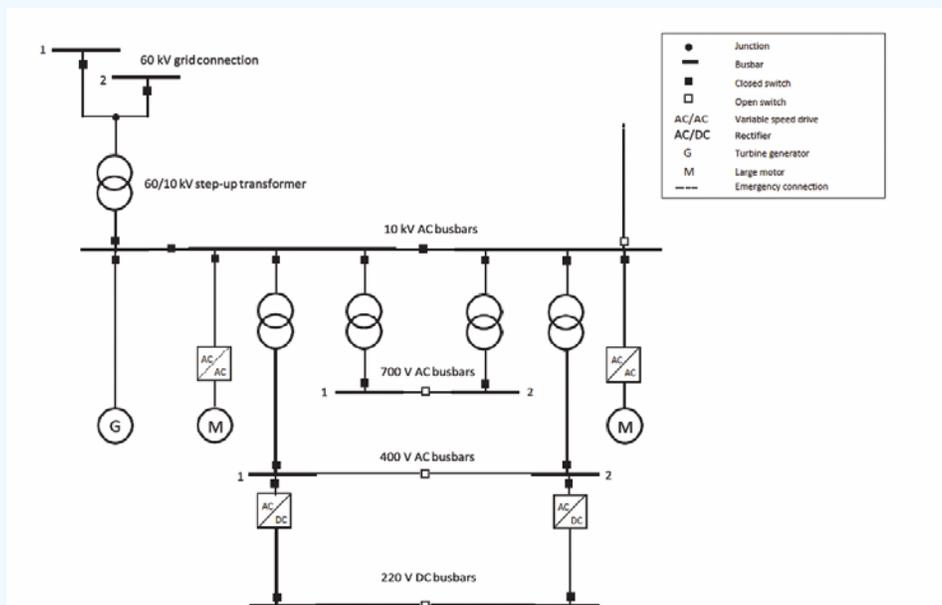
### 5.3.9 DCS

Distributed control system (DCS) automation for a 1–40 MWe biomass fuel unit typically consists of a control system for fuel handling, a control system for the steam turbine and generator, a control system for the boiler, and control systems for auxiliary systems such as cooling water, ash removal, etc. It is preferred that most, and if possible all, of the control systems mentioned are in a common DCS.

Supervision and operation is made from a common control room with human machine interface for all control systems, and preferable mainly from a common DCS.

Hardware (input-output modules, CPU units, interface modules, switches, relays, power supply, etc.) must be built

**Figure 5-28:** Simplified Typical Electrical Single-line Diagram for a 35 MWe Unit



Source: COWI.

into cubicles or cabinets with sufficient and suitable cooling and placed in rooms with sufficient cooling. Cooling of rooms for electrical and DCS equipment must protect against dust and moisture condensation by a small overpressure. Moisture condensation must be moved away safely to avoid contact with electronic and electric equipment.

Dependent on local regulation, a 1–40 MWe biomass fuel unit may require monitoring of the flue gas and its content of nitrogen oxides, dust, and maybe other contents.

In addition to a DCS system and other control systems, DCS automation for a 1–40 MWe biomass plant includes instrumentation, control valves, dampers, motors, and other electrical equipment. All are electrically connected to the DCS and the motor control center. Equipment and cables are exposed to different environments and must be able to resist negative impacts such as ultraviolet radiation, rodents that eat cables, heavy rainfall during monsoon periods, etc.

If the plant location is far from the airport or other traffic, a remote connection for the supplier to access the DCS and other major control systems is necessary. A remote connection enables the DCS supplier to access the DCS system, to assist during maintenance, and to prepare any major overhaul of the DCS. However, a remote connection makes the plant vulnerable to attack via the Internet and therefore must include firewalls and other measures to protect against Internet attack.

The fuel handling area might be categorized as an ATEX area. Therefore, cable trays and other electrical installations must be designed to avoid the collection of biomass dust and becoming a source for explosions and fire. Additionally, fire detection in the fuel handling area is necessary. Protection systems and interlocks must be made such that they cannot easily be overruled.

### 5.3.10 GRID CONNECTION

The turbine generators used for 1–40 MWe biomass fuel units are typically designed for a terminal voltage of around 10 kilovolts. In the lower power range, it may be possible to make a connection directly to the local power distribution networks. In the upper power range, there typically will be a need for a dedicated unit step-up transformer connecting the unit to the power distribution networks of 20 to 100

kilovolts. In some cases, in the upper power range, it may even be beneficial or required to connect the unit to the power transmission systems, which are voltage levels above 100 kilovolts.

At an early stage of the project, it is necessary to obtain close contact and dialogue with the local grid company. Knowing the maximum electrical power output, the grid company will be able to locate a point of connection in the existing networks or to advise if new networks are required to absorb the power production.

The grid company's grid connection requirements should be analyzed closely, as they often impose design requirements for the steam turbine, the boiler, and the protection and control systems. The design of auxiliary systems for the turbine generator, for example the excitation system and the relay protection systems, also often are influenced by the requirements given by the grid company.

Finally, the requirements from the grid company regarding grid code compliance documentation and testing should not be underestimated. Generally, a grid connection permit is obtained by proving compliance by both calculations and simulations supported by capability testing during commissioning.

## 5.4 BIOGAS PLANT

### 5.4.1 BIOMASS AS FEEDSTOCK FOR BIOGAS PLANTS

A biogas plant is based on biological processes, and it therefore is necessary that the organic feedstock be more or less ready for biological degradation by bacteria.

Several kinds of organic material may be used in a biogas plant:

- Manure from animals
- Leftover organic material from food-producing industries
- Sludge from flotation plants and other types of sludge
- Vegetables and fruit from agriculture
- Plant material from different types of production, such as the potato and seed handling industries, etc.

**Manure from animals:** Manure from cows, pigs, chickens, and other animals is suitable biomass for production of

biogas in a digester. However, because this biomass has already passed through the animals' digestive systems, the biogas potential is not very high. Normally, this biomass does not need any pretreatment before being pumped into the biogas plant.

**Leftover organic material from food producing industries:**

Biomass from food producing industries such as dairies, slaughterhouses, fishing industries, and the starch producing industry is considered very good for the production of biogas. It is rich in sugars, proteins, and fat, and the biogas potential is high. Normally, this biomass does not need any pretreatment before being pumped into the biogas plant.

**Sludge from flotation plants and other types of sludge:**

Sludge from flotation plants is considered a very good biomass for biogas production. Flotation plants are normally used at slaughterhouses, and the sludge is rich in fat and proteins, which gives it a very high biogas potential. This biomass does not need any pretreatment before being pumped into the biogas plant.

**Vegetables and fruit from agriculture:** Products from agriculture may be used for biogas production but should be limited to residues that cannot be used as food for humans and animals. The products normally are corn, sugar beets, grain, fruit, etc. This biomass needs pretreatment before being pumped into the biogas plant. It is necessary to cut these products into pieces and to grind them into a pulp, or, in the case of corn, to make compost that can be stored until it should be used. The pretreated products are pumped into the biogas plant.

**Plant material from different types of production:** Plant material may be grass, straw from grain, and fibers from sugar cane, palm, and other plants. This biomass needs pretreatment before it can be used in a biogas plant. It will be sufficient to grind the grass into a pulp. Because straw and fibers contain cellulose, which is difficult for the bacteria to use, this material must first be cut into small pieces and then heated or mechanically treated in a mill, extruder, or similar. This will open the cellulose to the bacteria in the digester. This type of biomass is difficult and demanding to handle before biogas production can begin.

Other types of biomass also may be used in a biogas plant, but these products most likely will fall into one of the five groups described above.

For efficient operation, different biomass types should be mixed before being pumped into the biogas plant.

*GAS POTENTIAL FROM DIFFERENT BIOMASS TYPES*

The biogas potential is not the same from all biomass types. In general, animal manure has the lowest gas potential, and agricultural crops have the highest biogas potential, since these products are very rich in starch (see Appendix B).

**5.4.2 PROCESS FLOW OF A BIOGAS PLANT**

Biogas is a product from an anaerobic (no oxygen) biological process in a biogas plant. Several groups of bacteria produce biogas from organic biomass. The biogas plant should provide the bacteria with optimal conditions, meaning an anaerobic atmosphere and a temperature of around 37°C or 55°C, depending on the process chosen. These conditions exist in the biogas reactor, which is the heart of the biogas plant.

Mesophilic operation requires a digester temperature of 37°C, while thermophilic operation takes place at a temperature of 55°C.

The biomass is usually delivered to the biogas plant in trucks. The biomass is collected in storage tanks, where

**Figure 5-29:** Biogas Plant with Integrated Gas Holding Tank Under a Soft Top



Source: Okologi, 2016.

**Figure 5-30:** Biogas Production Based on Pig Manure and Slaughterhouse Residues Using a Lagoon Digester



Source: COWI.

different biomass types are mixed into a homogeneous mass. A mixer is installed in the storage tank, which is normally constructed from concrete.

The unloading area should be indoors, since several biomass types will produce odors. Ventilation and cleaning of the air may be necessary.

From the storage tank, the biomass is pumped to the biogas reactor. The feeding of the reactor should be as stable and continuous as possible. It is common to feed the digester with 1/24th of the daily biomass charge each hour.

The biogas reactor can be a closed tank made from steel or concrete, or it could be a covered lagoon. However, lagoon digesters are less effective than biogas reactors built from steel or concrete.

Very small units may be made from fiberglass. The biogas reactor normally is insulated, since it is important to maintain a very stable temperature inside the reactor. A mixer is installed to ensure efficient mixing of bacteria and biomass, to ensure that produced gas is liberated from the

sludge, and to reduce the formation of floating substances on top of the sludge.

Biogas is collected from the top of the biogas reactor. It is accumulated in a gas tank from where the gas is burned in a CHP unit. The CHP unit produces electricity and heat. In case of failures or during maintenance of the CHP unit, the biogas is flared for safety reasons.

Safety valves are installed on top of the biogas tank to avoid damage to the tank if the gas pressure is too high or if a vacuum is created in the reactor. A heating system is installed to maintain a constant temperature in the reactor.

The size of the biogas reactor depends on the biomass. Most biomass types require a retention time of 20 to 22 days at mesophilic operation, but for biomass such as straw, agricultural crops, etc., a retention time of 40 to 50 days is needed for full gas production. At thermophilic operation, the retention time can be reduced by some 40 percent due to faster degradation at the higher temperature.

The degasified biomass (sludge) is taken out of the biogas reactor and stored until the sludge is transported to farmland or other places for use or disposal.

Figure 5–31 shows a simple flow chart for a biogas plant.

In some developing countries, a very simple biogas concept is used, where the biomass is stored in a big tank covered with a soft top. There is no mixing and no regulation of temperature. These digesters produce biogas but are not very efficient.

#### USE OF A BIOGAS-CHP UNIT WITH GAS ENGINE

Biogas normally contains 60 to 65 percent methane gas. The rest is mainly carbon dioxide.

Before the gas can be stored and used, it is cooled to remove water from condensation and is cleaned for, for example, sulfur. The biogas normally is used in a CHP unit equipped with a gas-fired internal combustion engine. Heat is recovered from the engine's cooling water system and from the exhaust gas.

A gas engine is connected to a generator that produces electricity. A general rule is that some 42 percent of the energy in the biogas is used to produce electricity. Heat from the cooling water system can be used at temperatures up to around 100° C. Heat from the exhaust gas can potentially be recovered at temperatures up to around 300° C via a thermal oil system. Some 47 percent of the energy in the biogas can be used as heat. The remaining part of the energy in the biogas cannot be recovered and is lost, mainly through the exhaust gas stack.

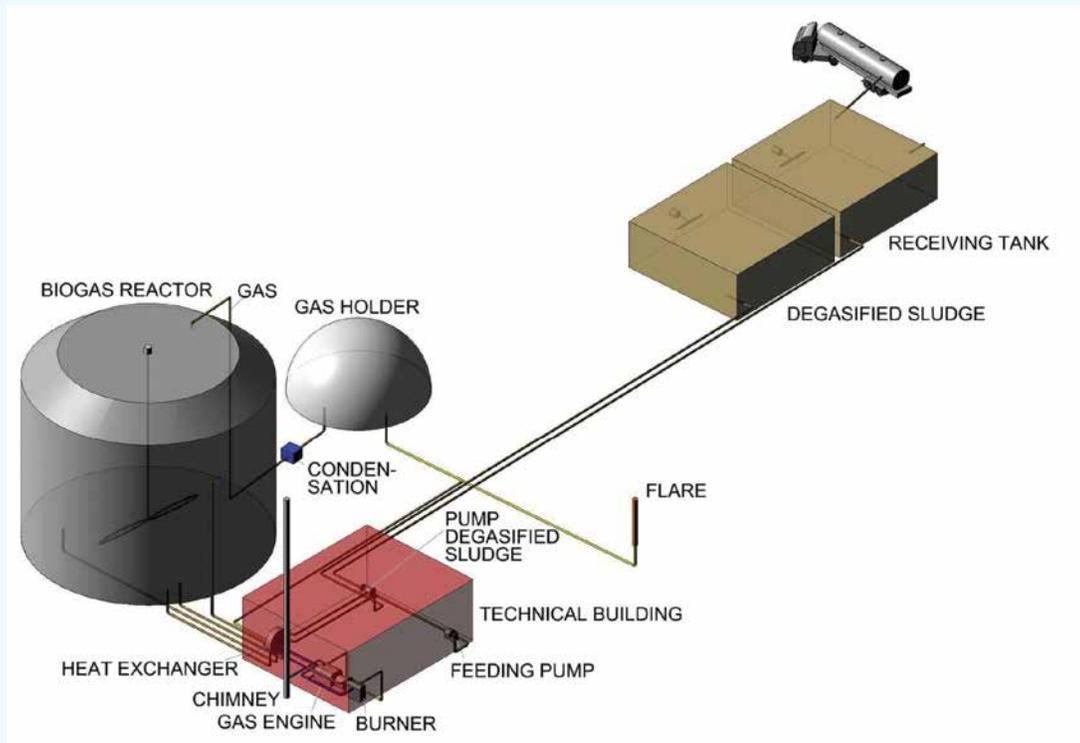
The CHP unit normally is connected to the public grid, and the electricity is sold to the electricity company.

#### 5.4.3 SAFETY AND ENVIRONMENTAL ISSUES

##### SAFETY

Since the biogas tank is a closed unit, and since biogas is produced continuously, gas pressure will always exist in the tank. Due to gas consumption, however, this pressure will normally be low. In case of blockage of the gas pipe, the pressure will increase. When the pressure gets too high,

**Figure 5-31:** Process Flow of a Simple Biogas Plant



Source: COWI.

**Figure 5-32:** Gas Engine and Generator Unit for Biogas Application



Source: Jenbacher, 2016.

a safety valve will open to reduce the pressure. In case of under-pressure, another safety valve will open to level the pressure and to prevent damage to the tank.

The biogas is explosive, and safety during working operations must be very high. Open fires, smoking, and mechanical sparks are not accepted near the biogas tank. As of July 2003, organizations in the European Union must follow ATEX directives to protect employees from explosion risk in areas with an explosive atmosphere.

The ATEX directive operates with three zones; zone 0 inside the digester; zone 1 on top of the digester; and zone 2, which is normally a three-meter zone around the digester.

There are two ATEX directives: one for the manufacturer and one for the user of the equipment. It is highly recommended to follow these directives, including for projects outside Europe. According to the ATEX directive, the mechanical equipment and electronic devices must be protected against sparks, and people working in an ATEX area must follow special safety rules.

### ENVIRONMENTAL CONSIDERATIONS

From an environmental point of view, there are benefits from using biogas plants. After treatment in a biogas plant, odor problems from, for example, manure will be reduced, and the nutrients in the sludge will be more ready for the plants to use. When sludge is stored for some time, methane gas will form and will pollute the atmosphere. When manure is treated in a

biogas plant, the methane gas is collected and burned in a CHP unit, and methane pollution of the atmosphere will be reduced.

### LOCATION OF BIOGAS PLANTS

Biomass is transported to the biogas plant in trucks, and residues are removed. This traffic should be considered when planning a new biogas plant.

There may be odor problems during unloading of the biomass, and it therefore is recommended to locate the biogas plant away from residential areas.

## 5.5 EMERGING TECHNOLOGIES

As mentioned at the beginning of this chapter, the focus of this guide is well-known and proven technologies. However, this section describes three emerging technologies that might be relevant in the near future, even though they currently are not proven and available on fully commercial terms. These technologies are:

- Thermal gasification
- Torrefaction
- Pyrolysis/hydrothermal upgrading.

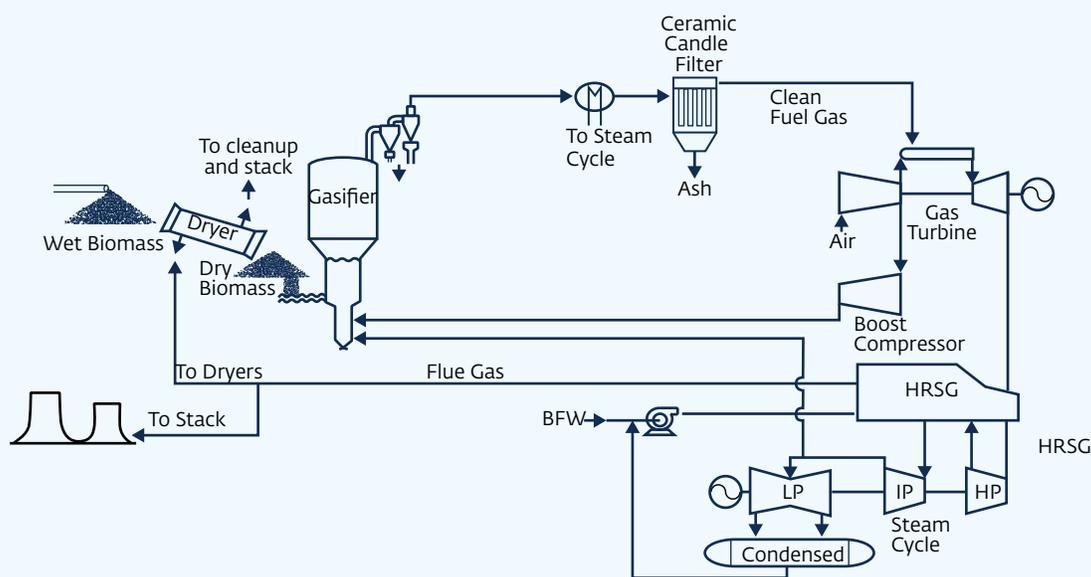
### 5.5.1 GASIFICATION

Gasification (see Figure 5–33) is a thermochemical process in which biomass is transformed into fuel gas, a mixture of several combustible gases. Gasification is a highly versatile process, because virtually any dry biomass feedstock can be converted to fuel gas. If wet biomass is supplied to the plant, it requires pretreatment and drying. The heat to drive the process comes from partial combustion of the biomass by supplying a limited amount of air.

The gas generated can, in principle, be used to produce electricity directly in engines or by using gas turbines at higher efficiency than via a steam cycle, particularly in small-scale plants (<5 MWe to 10 MWe).

At larger scales (>30 MWe), gasification-based systems can be coupled with a gas turbine with heat recovery and a steam turbine (combined cycle), thus offering improved efficiency.

**Figure 5-33:** Example of Biomass Gasification Power Plant



Source: Craig and Mann, 1996.

Combined-cycle technology based on natural gas is proven in many plants, but the efficiency and reliability of biomass-to-gasification still needs to be established. Several projects based on advanced concepts such as biomass-integrated gasification combined cycle (BIGCC) (see Section 5.5.3 and Figure 5-35) are in the pipeline in northern Europe, the United States, Japan, and India, but it is not yet clear what the future holds for large-scale biomass gasification for power generation.

Figure 5-33 provides an example of a biomass gasification power plant from the U.S. National Renewable Energy Laboratory.

### 5.5.2 TORREFACTION

In the torrefaction process (see Figure 5-34), biomass (currently mainly wood) is heated to between 200°C and 300°C in the absence of oxygen and is turned into char.

The torrefaction process is similar to conventional charcoal production, with the important difference that more volatiles remain in the biomass feedstock. The torrefied wood is typically pelletized and has a higher bulk density and 25 to

30 percent higher energy density than conventional wood pellets. The nickname for the pellets is “black pellets.”

In addition to the higher energy density, the torrefied biomass has properties closer to those of coal and can be handled, stored, and processed in existing coal plants without any modification. The first large-scale torrefaction plants, with capacities of 35 to 60 kilotons per year, have been demonstrated, but the economics of the process remain somewhat uncertain.

Potentially higher costs per unit of delivered energy for torrefied biomass compared to wood pellets could be offset through reductions in capital and operating costs in the combustion plant.

One of the critical research and development issues to address is the feedstock flexibility of the process, since this would greatly enhance the feedstock base and the role of torrefaction in mobilizing scattered biomass resources such as agricultural residues.

**Figure 5-34:** Wood Chips, at Different Steps Toward “Black Pellets”

STEP 1	STEP 2	STEP 3	STEP 4
Unprocessed wood	Dried wood chips	Torrefied wood chips	Final wood pellets
Wood chips are collected and stored, so they can be used as biomass	Wood chips are dried before they undergo torrefaction process	The wood chips are heated using micro wave technology within a rotating drum reactor, creating a charcoallike substance	The torrefied wood is milled and made into pellets that produce up to 10% to 20% more energy than untreated ones
			

Source: IZES, 2016; COWI.

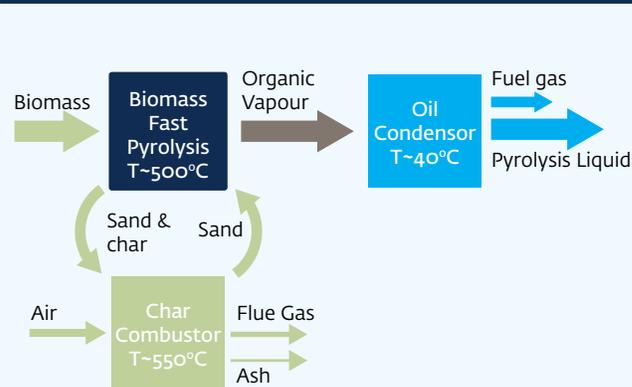
### 5.5.3 PYROLYSIS/HYDROTHERMAL UPGRADING

In this pyrolysis process (see Figure 5–35), biomass is heated to temperatures between 400°C and 600°C in the absence of oxygen. The process produces solid charcoal, liquid pyrolysis oil (also referred to as bio-oil), and a product gas. The exact fraction of each component depends on the temperature and the residence time.

Pyrolysis oil has about twice the energy density of wood pellets, which could make it particularly attractive for long-distance transport. So far, however, the technology is in demonstration phase for this application.

Challenging technical issues include the quality of the pyrolysis oil (such as relatively high oxygen content) and its long-term stability, as well as the economics of its production and use. Pyrolysis oil could be used in heat and/or power generation units, or upgraded to transport fuel. Research also is under way to explore the possibility of mixing pyrolysis oil with conventional crude oil for use in oil refineries.

**Figure 5-35:** Sketch of a Pyrolysis Process



Source: COWI.

## Case Story: Biomass Project for Sale to the Grid in Armenia



### PROJECT DESCRIPTION

Armenia has few natural resources but has inherited serious ecological problems from the Soviet era. The country is highly dependent on imports of energy supplies, mainly from Russia. Five Armenian plants produce electricity: two thermal power plants (using gas from Russia), a nuclear power plant (using nuclear fuel from Russia), and two hydropower plants (using local water sources).

Lusakert Pedigree Poultry Plant (LPPP) houses on average 2.5 million animals. The manure from the poultry is collected and spread into a system of five anaerobic throughflow stabilization lagoons where the manure settles. Greenhouse gases are produced from the manure.

LPPP is located in Nor Geghi village, 24 kilometers from Yerevan in the Kotayk Region.

The objective of the Lusakert Biogas Project is to reduce water pollution, secure an improved and reliable power supply, produce heat, produce fertilizer, and reduce climate-altering emissions, thereby facilitating future sustainable economic growth in Armenia.



### APPLIED TECHNOLOGY

The total investment cost for the Lusakert Biogas Project is around €3 million. Training of both management and staff was included in the project.

All equipment is installed in containers. The manure is diluted with some 150 cubic meters of water per day to obtain a dry solid content of 10 to 11 percent before it is pumped to the digester. The manure is heated in the heat exchanger before it reaches the digester. The digester is operated mesophilic at 38°C, and the hydraulic retention time is 20 days.

### PLANT PERFORMANCE

Some 24,000 kilograms of manure from digested sewage sludge are produced per day, and the digester is loaded with 250 cubic meters of manure per day. Daily production of 15,000 kilograms of dry solid digested manure is expected. The digested manure is used as fertilizer.

The gas is used to produce electricity and heat. The emission savings are some 26,370 tons of carbon dioxide-equivalent per year, based on the estimated yearly gas production. The biogas is burned in a CHP unit to produce electricity and heat. The biogas production is 5,500 normal cubic meters of methane per day. The plant produces some 6.3 MWh of electricity per year and some 4.8 MWh of heat per year.



### OUTCOME OF THE PROJECT

The project is a success, based on the following achievements:

- Significant reduction in the production of greenhouse gases
- Stable green electricity production
- Heat for the digester and to heat the production houses
- Fertilizer for a fruit plantation
- Significant reduction in pollution of the recipient water.

Other beneficiaries of the project include the plant workers and others who benefit from the improved environmental situation around the lagoons at the plant. Furthermore, the drinking water below the lagoons will not be affected by pollution from manure leaking to the groundwater.

### IMPORTANT LESSONS LEARNED

- It is important to secure a stable delivery of biomass to the digester.
- It is advised to prepare the project for alternative biomass types.
- Training should be sufficient to ensure optimized operation of the plant.

Source: COWI.



Source: COWI.

## 6.1 PLANT DESIGN

Designing a biomass plant that produces heat and power is a complex process that requires considerable technical experience and knowledge.

Any biomass project begins with a demand or a wish — whether a demand for electricity, for process steam or heat, or simply for the disposal of available biomass residues from an industrial process or from forestry or agriculture. Or, it could be a desire to save money or to increase fuel supply security by substituting an existing fossil fuel-based energy production facility with a new biomass-fired plant. The demand or wish will have to be transformed into a rough technical concept and a preliminary plant design, including:

- Fuel type and sourcing
- Site location and general layout
- Plant size and main design data
- Technology selection.

The following sections describe these main considerations in more detail.

### 6.1.1 FUEL TYPE AND SOURCING

The fuel type normally will be some kind of biomass residue or waste generated by a local agricultural or forest-based industry.

In case additional biomass sourced from off-site is needed, factors such as availability and similarity to the primary biomass residue should determine the type of supplementary biomass. This includes physical appearance (bales or not bales, etc.), heating value, moisture content, ash content, and ash composition. Ensuring similarity will reduce costs by enabling the use of the same storage, handling, and transport facilities for all types of biomass.

Any biomass residues that are considered for use should be analyzed for, at a minimum, net heating value, moisture content, ash content, and ash composition.

Depending on the type of biomass considered, certain combustion technologies can be excluded. Very wet fuel may require special machinery for feeding into the combustion chamber and also may require pretreatment to save costs on firing equipment.

Biomass sourcing is very important. If the biomass is a residue from production at the same site, this includes only storage and fuel preparation at the site, but if the main biomass or the supplementary biomass comes from outside the site, sourcing becomes an important issue that will influence the plant design.

Biomass has a relative low net heating value and low density; so large volumes will need to be handled. One issue is whether all storage and preparation of the fuel should take place at the plant site, or whether decentralized receiving stations for biomass collection, baling, and storage should be established.

### 6.1.2 SITE LOCATION AND GENERAL LAYOUT SOURCING

Usually, the biomass plant will be situated next to an industrial plant that can use the electricity, steam, or heat, or where the biomass residue is produced.

Even so, the specific location should be considered, taking into account consumers for electricity and steam/heat, access roads for the biomass, and storage conditions.

Figure 6–1 shows an example of a layout for a plant using biomass in the form of straw. Typically, the biomass storage and handling require most of the space, and, in this case, the storage on-site contains biomass for two weeks of normal

**Figure 6-1:** General Layout of Straw-fired Power Plant with Storage Facility Located in Pakistan



Source: COWI.

operation. On-site fuel storage is traditionally designed for 1 to 14 days of capacity.

### 6.1.3 PLANT SIZE AND MAIN DESIGN DATA

Several factors determine the optimal plant size:

- Demand for electricity, process steam, or heat
- Amount of biomass residue available
- Site conditions (available space)
- Grid connection possibilities
- Regulatory restrictions
- Economics including investment requirements, O&M costs, and price of energy sold.

#### DEMAND FOR ELECTRICITY, STEAM, OR HEAT

The project may be driven by a demand for electricity, steam, or heat. This could be a new demand or a wish to substitute existing gas-, oil-, or coal-fired units. The electricity generation could be used in an industrial production facility, with any surplus going to the grid. If the industry also needs process steam or perhaps heating, this may be the basis for cogeneration of electricity and steam. If only process steam or heat is needed, this can be produced without a turbine and thus without electricity production.

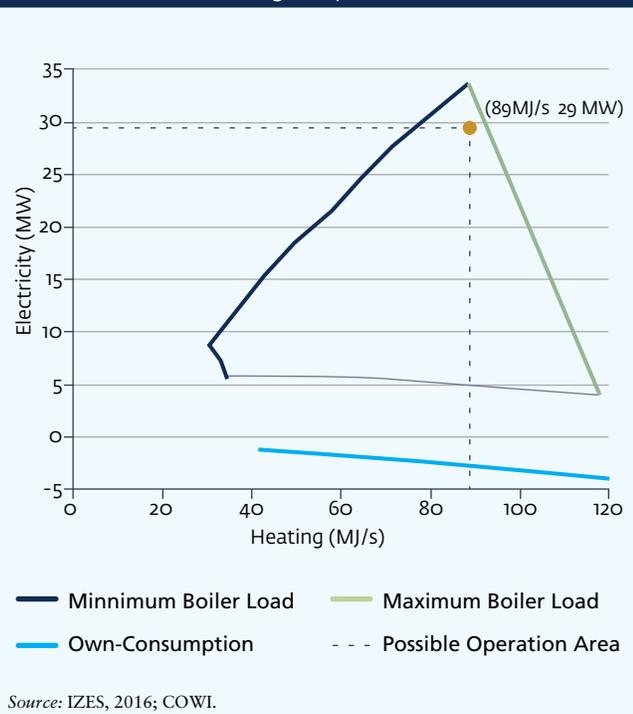
It is necessary to consider the cooling conditions on-site. A fully condensing turbine produces significant amounts of excess heat that must be removed either by water cooling (such as with river or ocean water) or by air cooling with natural convection towers or forced convection towers, which occupy significant amounts of space. Effective cooling also is important because it greatly improves the process efficiency, whereas limitations in access to cooling water may restrict the plant design.

Figure 6-2 is an example of a PQ-diagram for a power plant. It shows power output on the vertical axis and heating output on the horizontal axis. The area within the lines is the possible operation area. The thick line to the right corresponds to maximum boiler load, while the thick line on the left corresponds to minimum boiler load.

When planning a biomass plant, the PQ-diagram can be used to verify that the required operation modes (required power output and required heat output) are within the possible operation area.

The thick line below shows the operation line when there is only heat generated; the operation line is below zero because there is no power production, only power for own-consumption.

**Figure 6-2:** PQ-diagram Showing Power Output on the Vertical Axis and Heating Output on the Horizontal Axis



#### AMOUNT OF BIOMASS RESIDUE AVAILABLE

When the amount of biomass residue from a specific agricultural or forestry-based industry is the determining factor, the approximate plant size, expressed as electrical output for a steam-based power plant in full condensing mode, can be calculated from the equation:

$$P = \frac{0.278 \times M \times H_u \times e}{T_o}$$

Where

$P$  = Plant size (MWe)

$M$  = Mass flow (as received) (tons/year)

$H_u$  = Net heating valuer (as received ) (MJ/kg)

$T_o$  = Yearly operation time (hours)

$e$  = Efficiency of the plant

Example based on an optimised medium sized straw-fired plant:

$M$  = 50,000 ton/year

$H_u$  = 14 MJ/kg

$T_o$  = 6,000 h/year equivalent full load hours

$e$  = 38%

$$P = \frac{0.278 \times 50,000 \times 14 \times 0.38}{6,000} = 12.3 \text{ MWe}$$

The biomass residue may be supplemented with additional biomass if this is needed to meet the energy demand or if the biomass residue is only available seasonally. To reduce costs, it is important to identify a supplementary biomass type that is able to use the same storage, handling, and transport facilities.

Specific requirements for the size or efficiency of the plant may cause significant variations in the required technology. Flexibility requirements may rely on the possibility to bypass parts of the process equipment; high efficiency may require drier fuel and more-complex firing equipment (including drying facilities) or more advanced fuel preparation equipment (such as hammer mills), and large combustion requirements may require multiple boilers.

#### SITE CONDITIONS, AVAILABLE SPACE

The maximum plant size may be determined by the area available. If the plant is to be placed inside an existing building, this may restrict the size of the plant. If an outdoor site has been identified for the plant, the size of the available area or authority requirements also may present restrictions.

For biomass plants, the fuel storage and handling facilities will likely require the largest space, as illustrated in Figure 6-1.

Large amounts of biomass placed in the open may result in significant amounts of dust or smell, and covered storage therefore is often preferred.

A thorough fuel supply-chain management is advisable in order to secure just-in-time delivery to the site. Unless the fuel storage is very large, biomass stores often hold enough fuel for less than one week of operation.

#### GRID CONNECTION

The plant may be situated in a rural location with unstable or overloaded grid conditions. In this case, it is essential that the plant is able to operate in island mode, and it is important that the grid can handle the amount of electricity that is exported to the grid from the biomass plant.

#### REGULATORY RESTRICTIONS

The plant size may be restricted by local regulatory demands. Often, different rules apply for different plant sizes, or

different access to subsidies applies for different plant sizes, but this is very dependent on the local regulations.

Also, restrictions on access to cooling water, etc., can influence the decision regarding plant size.

### ECONOMICS

Economics—including investment requirements, operation and maintenance costs, and the price of energy sold—will also determine the design. The economics of biomass plants is described in more detail in Chapter 12.

#### 6.1.4 TECHNOLOGY SELECTION

The technology selection (see Table 5–2) can be used to determine the appropriate technology.

Based on the preliminary indications about fuel type, site, plant size, and technology, contact can be made with a potential supplier in order to get a first rough estimate of the CAPEX costs. For this supplier approach to be successful, a certain level of technical knowledge is required. If this is not available in-house, assistance from external experts will be helpful. If rigid decisions on technology are made at an early stage, prior to contact with a potential supplier or an adviser, this may cause significant financial losses later in the project.

Figure 6–3 shows a simplified biomass plant design.

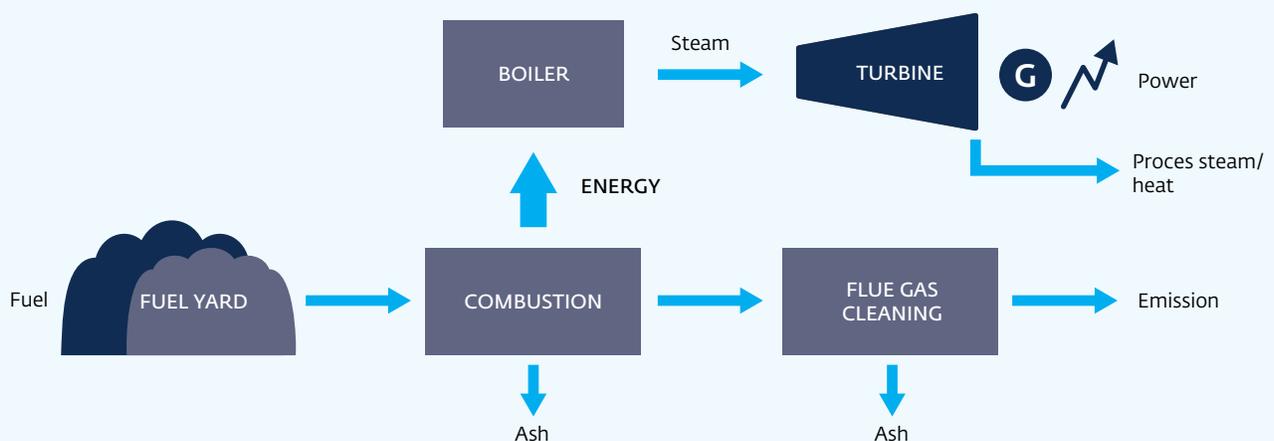
Although every biomass project is unique in terms of biomass residue, location, and surroundings, costs may be kept down if off-the-shelf and proven equipment is used wherever possible.

A potential supplier can assist with more precise estimates regarding costs, sizes, and the relationship between electrical output and steam output. On this basis, a firing diagram, as shown in Figure 6–4, can be made. The firing diagram shows the relationship between fuel mass flow and the firing rate in megajoules (MJ) per second. The mass flow design limit for the boiler and the moisture level of the fuel together determine the limits for maintaining full boiler load. The design limit for heat input determines the maximum fuel feeding rate at fuel moistures below the maximum moisture level. Using standard boiler plant sizes will usually be cheaper than tailormade plants.

If required for business case calculations, the process can be described and optimized in more detail, using a process simulation tool.

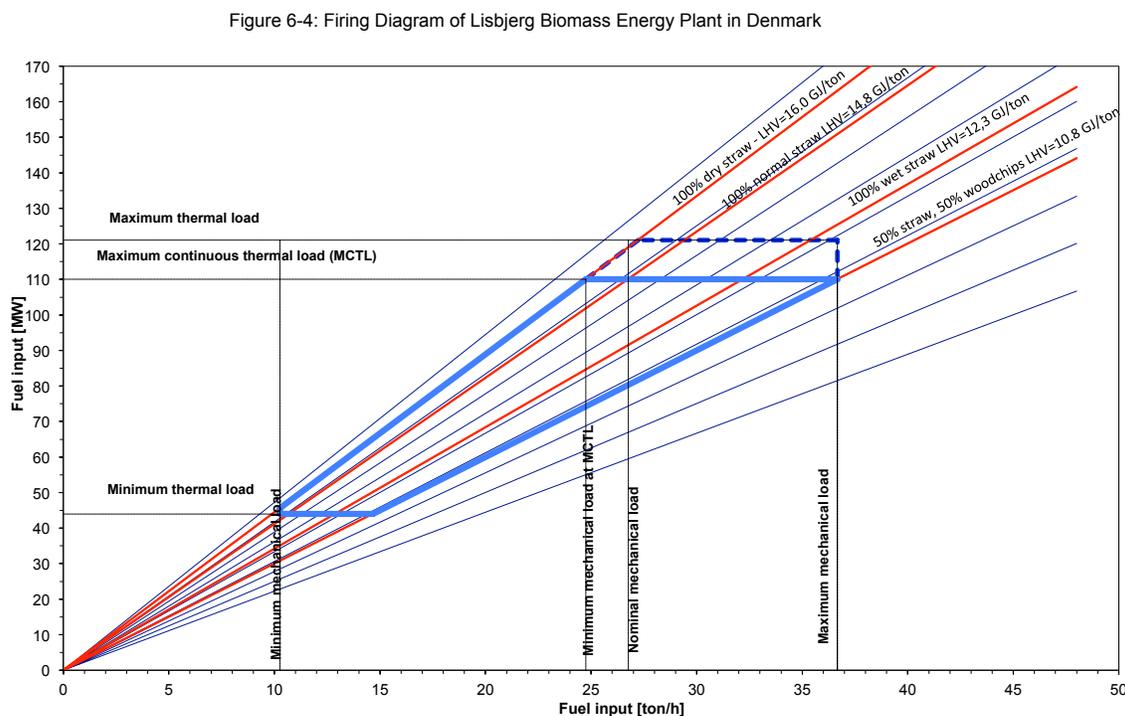
Process simulation calculations can determine the output in terms of electricity and steam/district heating from a given input. Figure 6–5 shows an example of a process simulation. This can be used in business case calculations in order to optimize a plant configuration. Often, several iterations between process simulations and business calculations will

**Figure 6-3:** Simplified Design of a Biomass Plant



Source: COWI.

**Figure 6-4:** Firing Diagram of Lisbjerg Biomass Energy Plant in Denmark



Source: COWI.

be required. Process simulation tools can determine optimal mechanical design of the plant hardware in terms of tube banks design, turbine stage design, heat exchanger design, etc.

For example, a requirements-to-turndown ratio larger than 1:3 (that is, operation at loads less than 30 percent load for the biomass plant due to large variations in consumption of industrial heat) must be identified at an early stage and prior to final design of the biomass plant.

## 6.2 PERMITTING

### 6.2.1 INTRODUCTION

This section describes the specific permits and authorizations necessary for establishing a new biomass plant, from the start of planning to the decommissioning of the plant. Chapter 15 provides a more general description of the environmental and social issues for biomass plants from a lifecycle perspective.

The owner of installations, such as biomass power plants, should obtain a number of authorizations, dispensations, permits, licenses, approvals, and other documentation

required by local and/or national authorities according to applicable laws and regulations. The majority of these must be obtained prior to the actual construction phase, while some are needed before start of operation. The majority of the documents issued by authorities will contain terms, clauses, and conditions regulating the construction and operation of the biomass plant.

Some of these official documents are business-related permits, while others are sector-specific. Sector-specific documents typically include: environmental and social impact assessment, wastewater discharge permit, building construction permit, planning permits (at the local, municipal, and/or provincial levels), licenses for electrical grid connection, and dispensations from natural and cultural conservation clauses, etc.

Environmental permits normally will apply if the installation exceeds a specified capacity threshold given in the permitting regulation of the country. The requirements and procedures related to the obtaining of the required documentation are highly country-specific. In some countries, several or even a



effectively managed in due time by changing the project and thus reducing or eliminating risks and negative impacts. With use of the right approach and tools, the authorization process ultimately may have a positive effect on the project.

The early preparation and implementation of a detailed plan for the statutory process will ensure that the necessary documents are in place in due time before the next phase of the project begins.

Assessments of the project impacts and the subsequent introduction of mitigation measures also may produce an economic advantage for the project because it will be implemented according to sustainable principles and in harmony with the existing natural environment and with the existing land-use plan, without any serious conflicts of interests.

An early and initial stage of consultations with the authorities, statutory bodies, and other relevant stakeholders is therefore advisable.

## 6.2.2 THE PLANNING PHASE

### CONCEPTUAL DESIGN STUDY

The first step is the preparation of a conceptual design study that will include the technical description of the proposed project and all boundaries and interfaces such as grid connection, residues, waste deliveries, etc.

The result of the conceptual study will be the most important input to the screening and scoping phases of the environmental and social impact assessment (ESIA). Based on this, the competent authority decides if a full ESIA is required for the project and defines the details and scope of the content of this report.

### ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

Environmental and social impact assessment is a requirement found in most countries for large industrial projects (including biomass combustion plants and biogas plants). The identification and assessment of environmental and



Source: COWI.

social risks and impacts (usually carried out through the preparation of an assessment) also is a general requirement under IFC Performance Standards, the Equator Principles, and standards applied by other international financial institutions.

Figure 6–6 provides an overview of the ESIA process. It defines the key guiding principles and processes that apply to all impact assessments, drawing on best practices.

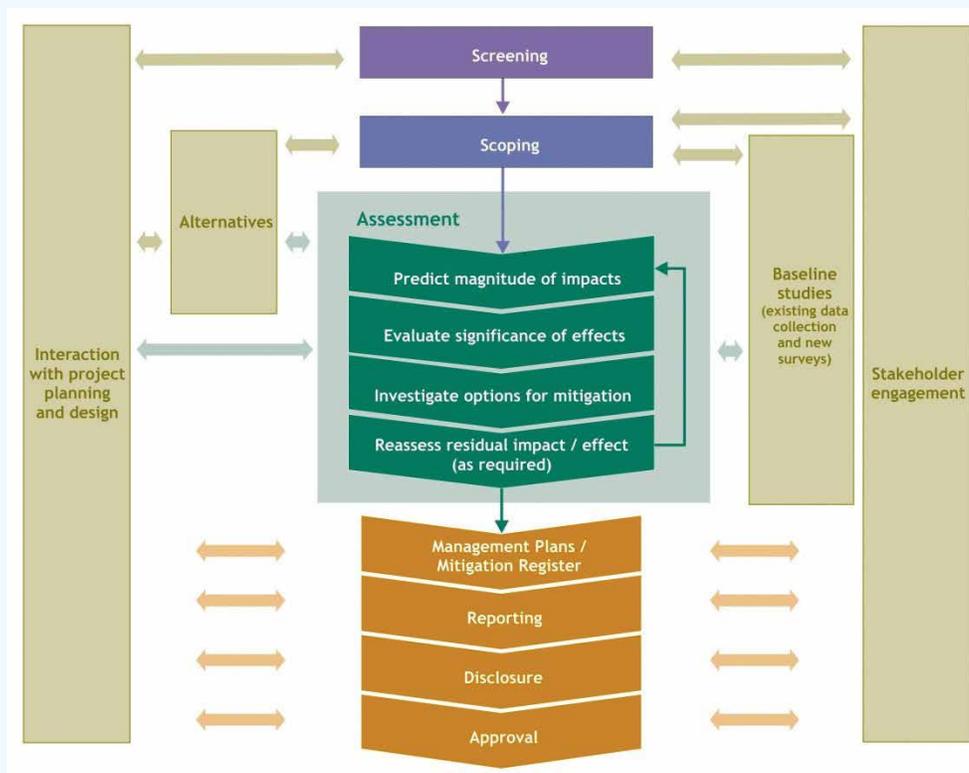
The ESIA process starts by registration of the project with the authorities. Registration may be on a standard template but will require a brief description of the planned project, in order to decide if a full ESIA is required. The authorities will do a **screening** of the project to decide the category of assessment.

In the **scoping** phase, the significant environmental and social aspects that should be included in the ESIA are selected. The scoping is generally based on current knowledge, but it also may require baseline studies of selected aspects.

Baseline studies may include:

- Review of the institutional and legal framework
- Biophysical and socioeconomic baseline surveys, including:
  - Terrestrial fauna
  - Terrestrial flora
  - Hydrology and aquatic ecology
  - Soil and seismic survey
  - Marine ecological surveys
  - Meteorology
  - Measuring of ambient dust levels
  - Measuring of ambient air quality
  - Air modeling
  - Measuring of ambient noise levels
  - Measuring of ambient vibration levels
  - Noise modeling

**Figure 6-6: The Environmental and Social Impact Assessment Process**



Source: COWI/ERM.

- Socioeconomic survey, including:
  - Demographic characteristics
  - Land use, cover/pattern
  - Land tenure
  - Housing and settlements
  - Social and physical infrastructure, for example education, health, transportation, health services, energy sources, water sources
  - Livelihoods/economic activities, including fisheries and maritime users
  - Employment and income
  - Livestock
  - Gender and HIV/AIDS issues
  - Public health and nutrition
  - Culture and traditions
  - Ethnic and community coherence
  - Planned development activities/development plans
  - Agriculture
  - Vulnerable and disadvantaged/marginalized groups
  - Social strengths (for example, community service organizations, savings and credit groups, public institutions, and agencies)
- Archaeological survey
- Land-use survey
- Fisheries survey and mapping
- Stakeholder identification and public consultation.

In the scoping phase, relevant technological alternatives and alternative locations will be selected, so they can be assessed in parallel with the project in the ESIA. As part of the scoping phase, it might be advantageous to hold a scoping workshop that includes the project owner and the main stakeholders.

The scoping report will define the Terms of Reference for the ESIA study.

The ESIA includes the following steps:

- Detailed baseline study

- Identifying and determining the significance of impacts
- Design of mitigation measures
- Analysis of project alternatives
- Preparation of environmental and social management and monitoring plans
- Public consultations.

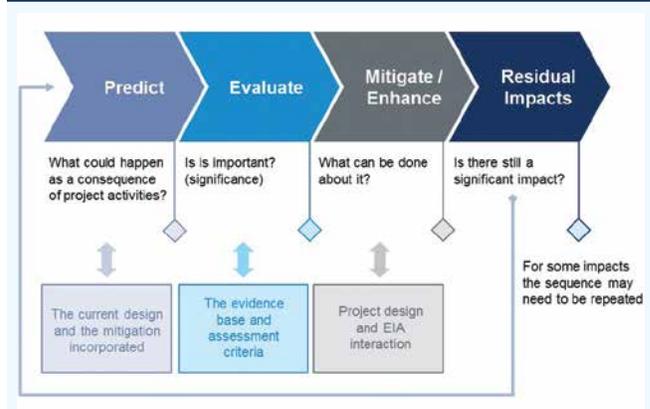
It is an iterative process, where certain elements of the project may be modified (for example, filters, treatment plants, noise attenuation, etc.) until the project complies with acceptable limits. This process is illustrated in Figure 6–7.

The ESIA should be subject to public consultations as required by IFC Performance Standards and local legislation, and comments and suggestions for improving the project should be assessed and included if relevant.

The **Environmental and Social Management Plan** will include procedures and organizations to ensure that the project is built and operated the way it is intended and described in the ESIA, and that the environmental and social effects are monitored and reported as required. The Environmental and Social Management Plan can provide details on operational instructions for contractors and operators.

Finally, the ESIA report (including the Environmental Management Plan) should receive final approval from the relevant authorities. The next page shows a sample table of contents for a biomass ESIA, based on COWI experience.

**Figure 6-7: The Mitigation Process in an Environmental and Social Impact Assessment**



Source: COWI/ERM.

**Figure 6-8:** Sample Table of Contents for an Environmental and Social Impact Assessment Report

<b>0.</b>	<b>NON-TECHNICAL SUMMARY</b>	<b>5.3</b>	Impacts of excavations
<b>1.</b>	<b>INTRODUCTION</b>	<b>5.4</b>	Impacts from leakage of oil/fuel contamination of soil and groundwater
1.1	Background	<b>5.5</b>	Impacts from construction waste
1.2	List of consultants	<b>5.6</b>	Impacts of excess rainfall ( <i>roads, surface runoff</i> )
1.3	Study area for the ESIA ( <i>including a map</i> )	<b>5.7</b>	Impacts on employment
<b>2.</b>	<b>LEGAL FRAMEWORK FOR ESIA STUDIES</b>	<b>5.8</b>	Conclusions
2.1	National legislation and procedures for ESIA studies in country	<b>6.</b>	<b>POTENTIAL NEGATIVE/POSITIVE IMPACTS ON THE ENVIRONMENTAL AND SOCIAL CONDITIONS IN THE OPERATION PHASE</b>
2.2	International legislation related to biomass-to-energy	6.1	Introduction ( <i>potential permanent impacts</i> )
<b>3.</b>	<b>DESCRIPTION OF THE PROJECT</b>	6.2	Impacts on terrestrial flora, animals, and birds
3.1	Introduction	6.3	Impacts on groundwater
3.2	Current energy source	6.4	Impacts on surface water
3.3	Conceptual study for the new biomass-to-energy plant	6.5	Impacts on air quality
3.4	Design and plant data	6.6	Impact on noise levels
3.5	Visualizations	6.7	Impact on consumption of raw materials and solid waste
3.6	Alternatives (including zero-alternative)	6.8	Impact on sociocultural and socioeconomic conditions, including health
<b>4.</b>	<b>DESCRIPTION OF BASELINE</b>	6.9	Summary of impacts and conclusions
4.1	Introduction	<b>7.</b>	<b>MITIGATION MEASURES</b>
4.2	Meteorology ( <i>available data on wind, temperature, rainfall</i> )	7.1	Control of noise and dust ( <i>during construction</i> )
4.3	Land use	7.2	Mitigation of ground water impacts
4.4	Topography, landscape, habitats, vegetation, and soil types	7.3	Mitigation of air impacts
4.5	Terrestrial fauna and birds	7.4	Mitigation of noise impacts
4.6	Groundwater	7.5	Mitigation of raw material consumption and solid waste
4.7	Hydrology	7.6	Mitigation of soil and groundwater impacts
4.8	Surface water	7.7	Mitigation of sociocultural, socioeconomic, and health conditions
4.9	Air quality	<b>8.</b>	<b>ENVIRONMENTAL MANAGEMENT PLAN</b>
4.10	Noise	8.1	Strategy for environmental management
4.11	Protected areas	8.2	Roles and responsibilities
4.12	Cultural and archaeological assets	8.3	Organization for implementation of the plan
4.13	Sociocultural and socioeconomic conditions, including health conditions	8.4	Monitoring during construction phase
4.14	Conclusions	8.5	Actions on exceedance and actions on emergencies
<b>5.</b>	<b>POTENTIAL IMPACTS ON THE ENVIRONMENTAL AND SOCIAL CONDITIONS IN THE CONSTRUCTION PHASE</b>	8.6	Monitoring in the operation period
5.1	Introduction ( <i>potential temporary impacts</i> )	<b>9.</b>	<b>REFERENCES</b>
5.2	Impacts of noise and dust from traffic		

Source: COWI.

### 6.2.3 THE CONSTRUCTION PHASE

Environmental impacts from actual construction of the facility are classified as “temporary” since these activities are limited in time. The environment normally recovers when the activities cease. One of the principal objectives of the ESIA is to contribute to the definition of the construction methods so that the impacts are kept to a minimum and do not develop into permanent impacts.

#### ENVIRONMENTAL IMPACTS DURING THE CONSTRUCTION PHASE

The important social and environmental impacts during construction are shown in Table 6–1.

Table 6-1: Environmental and Social Impacts: Construction Phase	
	Impact
Air	<ul style="list-style-type: none"> <li>Dust from soil handling and excavation</li> <li>Emissions from engines (trucks, excavators, generators, etc.)</li> </ul>
Noise	<ul style="list-style-type: none"> <li>Noise from machinery and materials transport</li> </ul>
Land/Soil	<ul style="list-style-type: none"> <li>Disposal of construction waste</li> </ul>
Surface water/ Groundwater	<ul style="list-style-type: none"> <li>Leakage of oil/fuel (contamination of soil and groundwater)</li> <li>Handling of excess rainfall (roads, surface runoff)</li> </ul>
Employment	<ul style="list-style-type: none"> <li>Employment effect of the project construction</li> </ul>
Land conversion	<ul style="list-style-type: none"> <li>Impact on habitats from clearing the area for plant construction</li> </ul>

Source: COWI.

#### PERMITS NECESSARY FOR THE CONSTRUCTION PHASE

These may include:

- Before excavations are started, it normally will be necessary to obtain a cultural heritage authority permit stating that the land parcel is free of archaeological/cultural heritage sites and objects.
- Permits for the environmental impacts and nuisances during construction are normally specified in an ESIA permit based on the ESIA report. Conditions may, for

example, include mitigation of noise and dust, use of specific fuels (natural gas or electricity) for engines, requirements for sorting and disposal of construction waste and handling of rainfall on the construction site, as well as handling of stormwater runoff.

- A construction or building permit normally will be required prior to the onset of the construction of the plant. The building permit will include an assessment of fire hazards and fire protection and mitigation. Implementation of the conditions in the building permit will ensure that the buildings adhere to all technical requirements for the buildings, as well as handling of stormwater runoff.
- A civil aviation security permit stating that any stacks or power transmission lines to be built by the project will not interfere with flight routes.
- A permit for land use (physical planning/zoning regulations) or approved local planning document.

### 6.2.4 THE OPERATIONAL PHASE

Impacts during the operational phase of the project are classified as “permanent.” They represent the permanent features of the project, such as new infrastructure locations and waste handling facilities. In this case, the objective of the ESIA is to interact with the designers to ensure that the impacts are at an acceptable low level, if necessary through the implementation of preventive and mitigating measures.

Impacts will be considered under both normal operational conditions and in the case of emergencies.

#### ENVIRONMENTAL IMPACTS IN THE OPERATIONAL PHASE

In the operational phase, particular attention will be paid both to the negative impacts and to the environmental enhancement by the project. Environmental enhancements include fewer environmental impacts from solid waste landfills, combined with energy production that is climate friendly and that substitutes fossil fuels. The project may ensure effective use of solid waste that otherwise would create environmental problems.

Examples of social and environmental impacts identified as important to biomass incineration and that should be the

focus of the ESIA report and the environmental permit for the operation are shown in Table 6–2. In specific cases, other impacts may be necessary to assess and include in the permit. See the section on ESIA.

Table 6-2: Environmental and Social Impacts: Operational Phase	
	Impact
Air	<ul style="list-style-type: none"> <li>• Gaseous emissions (combustion plant stack emissions)</li> <li>• Odor (biomass reception areas, stack from plant)</li> <li>• Noise (and vibration) (pretreatment, internal transport, plant)</li> </ul>
Land/Soil	<ul style="list-style-type: none"> <li>• Habitat changes (impact on vegetation and animals)</li> <li>• Disposal of residues (fly ash)</li> </ul>
Surface water/ Groundwater	<ul style="list-style-type: none"> <li>• Wastewater from discharge of wastewater from flue gas condenser and surface water from the installation</li> </ul>
Socioeconomic and health conditions	<ul style="list-style-type: none"> <li>• Traffic to and from the plant</li> <li>• Visual amenity</li> <li>• Employment effects of the plant</li> <li>• Health effects on neighboring areas</li> <li>• Taking of valuable farmland</li> </ul>

Source: COWI.

### ENVIRONMENTAL PERMITS AND OTHER PERMITS FOR OPERATION

The ESIA will, in some countries, constitute the sole and sufficient foundation on which the issuing of the environmental permit is based, while in other countries, a separate application for an environmental approval may be necessary according to standard forms. In many countries, BAT (Best Available Techniques) or BATNEEC (Best Available Techniques Not Entailing Excessive Cost) requirements will be essential for obtaining the environmental permits as well as complying with local emission limit values and standards (for example, the European Union’s BAT conclusions for Large Combustion Plants and Waste Incineration Plants, which sets binding limit values for EU countries but also is applied as guiding principles in many countries outside the EU). Further to this,

the World Bank Group (2007) Environmental, Health and Safety General Guidelines and the World Bank Group (2008) Environmental, Health, and Safety Guidelines for Thermal Power Plants are a key reference document.

The necessary environmental permits and other permits for the operational phase may include:

- ESIA approval, including approval of an environmental management plan regulating and monitoring all significant impacts as described in the assessment report
- Permits to operate each installation with conditions on noise and vibrations, air emissions, odor, stack heights, mitigation of risks (for example, from ammonia storage or heavy oil storage), disposal of solid waste, protection of soil and groundwater, and discharge of rain water from the project area
- Permit for discharge of wastewater to public sewer or to surface water bodies, with clauses and conditions on water quantities and concentrations of pollutants (for example, from flue gas condensate)
- Permit for water use or water extraction
- Energy permit or other authorization from the energy authority confirming that the project conforms with the national energy strategy/power development plan (in some countries)
- Permit for grid connection for electricity producers.

When pressurized equipment is erected for the first time, an inspector normally will carry out a control inspection on the equipment to ensure that proper documentation exists for the production of the pressurized equipment and its safety devices, before the permit for start of operation can be issued.

Different authorities may handle the individual permits, but sometimes the competent authority coordinates them.

### 6.2.5 THE DECOMMISSIONING PHASE

The decommissioning phase of the project is a temporary phase similar to the construction phase, but the environmental impacts from the decommissioning may be more permanent. The plant may have caused soil and groundwater pollution that needs to be cleaned

up over a long period, and the building waste from the decommissioning project may be hazardous waste that has to be disposed of safely in landfills or by incineration.

### ENVIRONMENTAL IMPACTS IN THE DECOMMISSIONING PHASE

During the decommissioning phase, particular attention is paid to the negative impacts that might follow. Thus, the project owner should pay specific attention to the environmental issues presented in Table 6–3.

In the decommissioning phase, the following permits may be necessary:

- A permit from national authorities to decommission the installation and remove it from the grid
- A permit for handling and disposal of building waste
- A building/construction permit for the decommissioning work.

Table 6-3: Environmental and Social Impacts: Decommissioning Phase	
	Impact
Air	<ul style="list-style-type: none"> <li>• Dust from soil handling and reclamation of land</li> <li>• Emission from engines (trucks, excavators, generators, etc.)</li> </ul>
Noise	<ul style="list-style-type: none"> <li>• Noise from machinery and materials transport</li> </ul>
Land/Soil	<ul style="list-style-type: none"> <li>• Disposal of building waste</li> </ul>
Surface water/ Groundwater	<ul style="list-style-type: none"> <li>• Leakage from oil/fuel (contamination of soil and groundwater)</li> <li>• Handling of excess rainfall (roads, surface runoff)</li> </ul>
Employment	<ul style="list-style-type: none"> <li>• Employment effect of project decommissioning</li> </ul>

Source: COWI.

## 6.2.6 IFC PERFORMANCE STANDARDS

IFC Performance Standards on Environmental and Social Sustainability<sup>2</sup> provide IFC clients<sup>3</sup> with guidance on how to identify environmental and social risks and impacts. They are designed to help avoid, mitigate, and manage risks and impacts as a way of doing business in a sustainable way, including stakeholder engagement and disclosure obligations of the client in relation to project-level activities.

In connection with its direct investments (including project and corporate finance provided through financial intermediaries), IFC requires its clients to apply the Performance Standards to manage environmental and social risks and impacts so that development opportunities are enhanced.

The IFC Performance Standards have become globally recognized good practice in dealing with environmental and social risk management, and many other financial institutions have aligned with them.

The eight Performance Standards establish standards that the client is to meet throughout the life of an investment by IFC:

**Performance Standard 1:** Assessment and Management of Environmental and Social Risks and Impacts

**Performance Standard 2:** Labor and Working Conditions

**Performance Standard 3:** Resource Efficiency and Pollution Prevention

**Performance Standard 4:** Community Health, Safety, and Security

**Performance Standard 5:** Land Acquisition and Involuntary Resettlement

**Performance Standard 6:** Biodiversity Conservation and Sustainable Management of Living Natural Resources

**Performance Standard 7:** Indigenous Peoples

**Performance Standard 8:** Cultural Heritage

2 Available at: [http://www.ifc.org/wps/wcm/connect/topics\\_ext\\_content/ifc\\_external\\_corporate\\_site/ifc+sustainability/our+approach/risk+management/performance+standards/environmental+and+social+performance+standards+and+guidance+notes](http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/our+approach/risk+management/performance+standards/environmental+and+social+performance+standards+and+guidance+notes).

3 The party responsible for implementing and operating the project that is being financed (or the recipient of the financing, depending on the project structure and type of financing).

Where environmental or social risks and impacts are identified, the client is required to manage them through its Environmental and Social Management System (ESMS) consistent with Performance Standard 1. Performance Standard 1 applies to all projects that have environmental and social risks and impacts. Depending on project circumstances, other Performance Standards may apply as well.

In addition to meeting the requirements under the Performance Standards, clients must comply with applicable national law, including those laws implementing host country obligations under international law. When host country regulations differ from the levels and measures presented in the Environmental, Health, and Safety Guidelines, projects are expected to achieve whichever is more stringent.

**Performance Standard 1—Assessment and Management of Environmental and Social Risks and Impacts**—underscores the importance of managing environmental and social performance throughout the life of a project. The objectives are:

- To identify and evaluate environmental and social risks and impacts of the project.
- To adopt a mitigation hierarchy to anticipate and avoid, or where avoidance is not possible, minimize, and, where residual impacts remain, compensate/offset for risks and impacts to workers, Affected Communities, and the environment.
- To promote improved environmental and social performance of clients through the effective use of management systems.
- To ensure that grievances from Affected Communities and external communications from other stakeholders are responded to and managed appropriately.
- To promote and provide means for adequate engagement with Affected Communities throughout the project cycle on issues that could potentially affect them and to ensure that relevant environmental and social information is disclosed and disseminated.

**Performance Standard 2—Labor and Working Conditions**—recognizes that the pursuit of economic growth through

employment creation and income generation should be accompanied by protection of the fundamental rights of workers. The objectives are:

- To promote the fair treatment, non-discrimination, and equal opportunity of workers.
- To establish, maintain, and improve the worker-management relationship.
- To promote compliance with national employment and labor laws.
- To protect workers, including vulnerable categories of workers such as children, migrant workers, workers engaged by third parties, and workers in the client's supply chain.
- To promote safe and healthy working conditions, and the health of workers.
- To avoid the use of forced labor.

**Performance Standard 3—Resource Efficiency and Pollution Prevention**—recognizes that increased economic activity and urbanization often generate increased levels of pollution to air, water, and land, and consume finite resources in a manner that may threaten people and the environment at the local, regional, and global levels. The objectives are:

- To avoid or minimize adverse impacts on human health and the environment by avoiding or minimizing pollution from project activities.
- To promote more sustainable use of resources, including energy and water.
- To reduce project-related greenhouse-gas emissions.

**Performance Standard 4—Community Health, Safety, and Security**—recognizes that project activities, equipment, and infrastructure can increase community exposure to risks and impacts. The objectives are:

- To anticipate and avoid adverse impacts on the health and safety of the Affected Community during the project life from both routine and non-routine circumstances.
- To ensure that the safeguarding of personnel and property is carried out in accordance with relevant

human rights principles and in a manner that avoids or minimizes risks to the Affected Communities.

**Performance Standard 5—Land Acquisition and Involuntary Resettlement**—recognizes that project-related land acquisition and restrictions on land use can have adverse impacts on communities and persons that use this land. The objectives are:

- To avoid, and when avoidance is not possible, minimize displacement by exploring alternative project designs.
- To avoid forced eviction.
- To anticipate and avoid, or where avoidance is not possible, minimize adverse social and economic impacts from land acquisition or restrictions on land use by: 1) providing compensation for loss of assets at replacement cost; and 2) ensuring that resettlement activities are implemented with appropriate disclosure of information, consultation, and the informed participation of those who are affected.
- To improve, or restore, the livelihoods and standards of living of displaced persons.
- To improve living conditions among physically displaced persons through the provision of adequate housing with security of tenure at resettlement sites.

**Performance Standard 6—Biodiversity Conservation and Sustainable Management of Living Natural Resources**—recognizes that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development. The objectives are:

- To protect and conserve biodiversity.
- To maintain the benefits from ecosystem services.
- To promote the sustainable management of living natural resources through the adoption of practices that integrate conservation needs and development priorities.

**Performance Standard 7—Indigenous Peoples**—recognizes that Indigenous Peoples, as social groups with identities that are distinct from mainstream groups in national societies, are often among the most marginalized and vulnerable segments of the population. The objectives are:

- To ensure that the development process fosters full respect for the human rights, dignity, aspirations, culture, and natural resource-based livelihoods of Indigenous Peoples.
- To anticipate and avoid adverse impacts of projects on communities of Indigenous Peoples, or when avoidance is not possible, to minimize and/or compensate for such impacts.
- To promote sustainable development benefits and opportunities for Indigenous Peoples in a culturally appropriate manner.
- To establish and maintain an ongoing relationship based on Informed Consultation and Participation (ICP) with the Indigenous Peoples affected by a project throughout the project's lifecycle.
- To ensure the Free, Prior, and Informed Consent (FPIC) of the Affected Communities of Indigenous Peoples when the circumstances described in this Performance Standard are present.
- To respect and preserve the culture, knowledge, and practices of Indigenous Peoples.

**Performance Standard 8—Cultural Heritage**—recognizes the importance of cultural heritage for current and future generations. The objectives are:

- To protect cultural heritage from the adverse impacts of project activities and support its preservation.
- To promote the equitable sharing of benefits from the use of cultural heritage.



Source: COWI.

The procurement process can be structured in many ways, and it is of utmost importance to discuss and decide the procurement strategy at an early stage in the project, as this can influence many other choices to be taken. The procurement strategy also is crucial to investors, as it outlines who takes the design risks, the interface risks, and the risks associated with final price and time.

## 7.1 THE PROCUREMENT STRATEGY

Procurement and contracting of biomass plants may come in the form of a variety of models that reflect the increasing transfer of responsibility from the owner to the contractor(s):

- Traditional contracts, with division of the plant into a number of partial contracts with separate detailed designs
- DB (Design–Build) / EPC (Engineering, Procurement, Construction) / Turnkey contract, with one contractor being responsible for the design and construction for the entire plant
- DBO (Design–Build–Operate) / BOT (Build–Operate–Transfer) type contracts, where the contractor also operates and maintains the plant
- DBFO (Design–Build–Finance–Operate), where the contractor takes full responsibility for the provision of a biomass-based power plant and is remunerated through the provision of heat and power.

The decision on the type of contract will depend on the degree to which the biomass plant is integrated with the owner’s existing facilities and on the owner’s ability and willingness to transfer design decisions, operational control, and project risks to the contractor.

The procurement and contracting approaches are, to some extent, linked to the available financing sources that typically reflect one of the following:

- Self-finance (the cash flow and reserves of the owner)
- On-balance sheet debt (from banks or a mother company)
- Supplier credits and leasing solutions under traditional contracts, DB and DBO
- Off-balance sheet financing through an SPV (Special Purpose Vehicle) under a DBFO (mainly for larger facilities).

For small and medium companies, supplier finance may offer better terms than the financing obtainable in the local financial market. To keep competitive pressure on suppliers, the possibility of supplier finance may be included as an evaluation parameter when requesting supplier costings or tendering technology/equipment packages. This will enable all suppliers to compete on equal terms and will ensure the owner a good overview of the available supplier finance options and terms. For further information on financing, see Chapter 15.

## 7.2 TYPE OF CONTRACTS

The most common approaches worldwide are traditional contracts that divide the plant into a number of partial contracts with separate detailed designs and a DB / EPC<sup>4</sup> / turnkey contract with one contractor being responsible for the design and construction of the entire plant.

In Table 7–1 below, we compare the two different approaches, also including an approach based on EPC principles, but having a few EPC-like contracts.

<sup>4</sup> EPC stands for Engineering, Procurement, and Construction and is a prominent form of contracting agreement in the construction industry. The engineering and construction contractor will carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct to deliver a functioning facility or asset to its clients. Companies that deliver EPC projects are commonly referred to as EPC contractors.

**Table 7-1: Types of Contracts**

	EPC/Turnkey (one contract)	Multiple EPC Contractors (for example, 2–4 contracts)	Many Contractors
The owner does not wish to be involved in the day-to-day progress monitoring of the work, provided that the end result meets the performance criteria that have been specified.	Yes	No	No
The owner wishes a high degree of certainty that the agreed contract price and time will not be exceeded.	Yes	Yes	No
The owner is willing to pay more for the construction of the project in return for the contractor bearing the extra risks associated with enhanced certainty of final price and time.	Yes	Yes	No
The owner wants a high degree of involvement, for example in the choice of subcontractors and in the detailed design.	No	No	Yes

Source: COWI.

- The first approach is an EPC/turnkey contract with one contractor responsible for the entire plant construction, including mechanical, electrical, and civil works.
- The second approach is also based on EPC principles but divides the plant into two to four EPC contracts, for example an electro/mechanical EPC and a civil construction EPC. The electro/mechanical contract may be further split into, for example, fuel handling equipment and energy plant, dependent on the specific project and the owner's wishes.
- The third approach is to divide the plant into a number of partial contracts and to prepare separate detailed design for some of these, such as civil construction.

The use of multiple contractors places the responsibility of interface management, coordination, and risk allocation between the contractors with the owner or the owner's engineer. This critical coordination task requires a very experienced engineer, because coordination and supervision responsibility begins with the study and planning phase and continues until and beyond plant commissioning. An alternative solution is to assign an EPCM (Engineering, Procurement, and Construction Management) contractor<sup>5</sup> that has overall responsibility, including for plant engineering. In such a case, the developer would have less direct coordination, but the EPCM contractor would have to

<sup>5</sup> A general contractor (main contractor) is responsible for the day-to-day oversight of a construction site, the management of vendors and trades, and the communication of information to all parties throughout the course of a project.

be supervised, applying principles similar to those used for individual contractors.

DBO and especially DBFO contracts may be more complex and require careful considerations involving financial experts. A contract involving operation and maintenance requires a certain length, typically five to seven years or more. If the owner is uncertain about operation and maintenance, an alternative to DBO or DBFO may be a traditional setup with partial contracts or EPC/turnkey, but engaging the contractor as operation supervisor for a certain period of time after handover/takeover, for example for six months to two years. In this period, the contractor's supervisor will assist and train the owner's own operation and maintenance staff. This solution is especially useful in situations where it is difficult to engage sufficient well-skilled/trained personnel.

Alternatively, the owner can enter a DBO or DBFO contract but negotiate an optional right to take over the operation and maintenance of the biomass plant after two and four years. If, after two years' operation, the owner has mobilized sufficient and skilled staff, the owner can exercise the right to take over the operation and maintenance obligations. This alternative, however, may introduce discussions about the maintenance standard at the time of takeover of the operation and maintenance obligation.

All in all, the coordination of many contracts for one biomass plant has a cost, and it seems reasonable to take a

premium for taking risks. Owners or developers of biomass plants must carefully evaluate the add-on to the contract price for moving from a setup with the plant divided into many contracts to an EPC type of contract. If the add-on to the contract price is evaluated as too large, the owner or developer may, to minimize the CAPEX, choose the setup with the plant divided into multiple contracts.

### 7.3 FORM OF CONTRACT

A wide range of standard contract forms are available worldwide, but most of them are national or regional standards. These may be used, but the disadvantage might be that international contractors do not know these specific standard contracts and might be reluctant to use them. Typically, international contractors will require internationally accepted standard contracts.

Standard contract templates are available from sources such as the FIDIC (International Federation of Consulting Engineers), the ICE (Institution of Civil Engineers), and the JCT (Joint Contracts Tribunal).

The standard forms from the FIDIC are widely used for international procurement in the energy sector. The FIDIC contracts are written in formal legal English and are drafted based on common law background. They have been developed over decades and are well respected among owners, contractors, and investors.

FIDIC publishes standard conditions of contract, such as for:

- Conditions of contract for EPC/Turnkey projects (also called “The Silver Book”).
- Conditions of contract for construction for building and engineering works designed by the employer (also called “The Red Book”).
- Conditions of contract for plant and DB for electrical and mechanical plants for building and engineering works designed by the contractor (also called “The Yellow Book”).
- All FIDIC standard conditions of contract form a contract between a client/employer and a contractor. The consulting engineer is not a party to these contracts but

plays a role as the employer’s representative to ensure that the contract is carried out properly.<sup>6</sup>

Figure 7–1 provides a guide to the choice of contract.

The FIDIC Silver Book pertains to EPC and turnkey projects and is generally applicable to biomass-to-energy projects. The Silver Book is a template for a lump-sum contract and assigns most risks to the contractor, offering greater certainty to the owner concerning project cost and completion date. Using this type of contract, the owner is typically not involved in the day-to-day progress of the work, provided that the end result meets the performance criteria that have been specified.

The advantage of the EPC/turnkey contract is the higher degree of certainty that the agreed contract price and time will not be exceeded. The parties concerned (for example, sponsors, lenders, and the owner) are willing to see that the contractor is paid more for the project construction in return for the contractor bearing the extra risks for meeting the agreed price and time.

If the procurement is split into two or more contracts typically the Yellow or the Red Book is used. The Gold Book pertains to DBO projects.

The individual clauses of the FIDIC standard contracts are of general nature. Amendments and supplements (as mentioned below) are needed and should turn the standard contract into a bespoke and project-specific contract form:

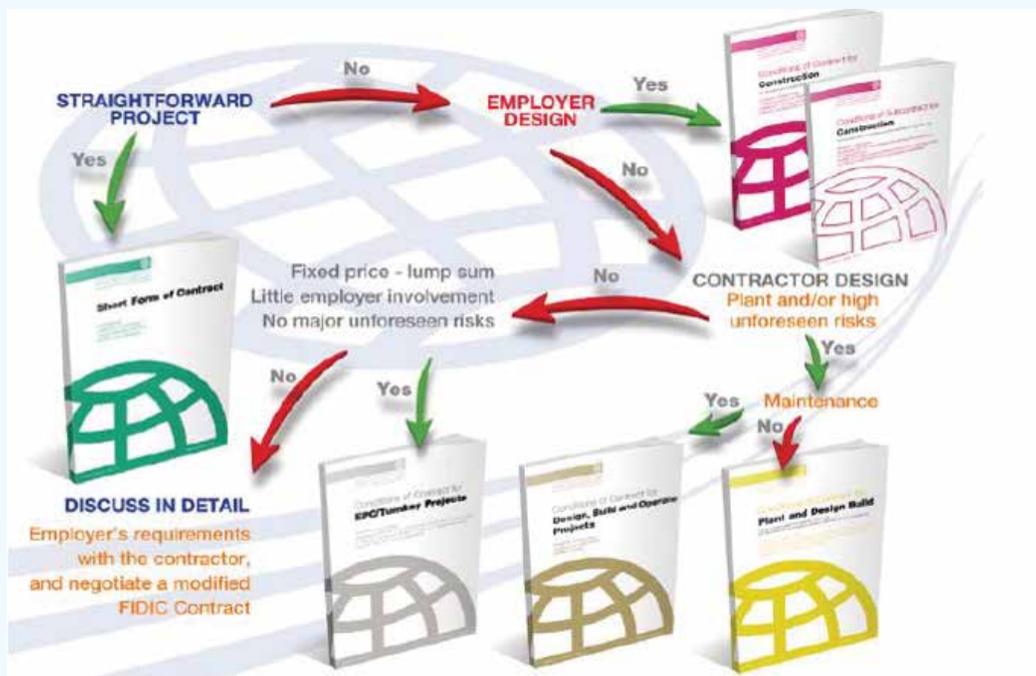
- Working language
- Applicable law and ruling language
- Place of arbitration
- Liability
- Liquidated damages
- Delay damages.

More information on the FIDIC standard contracts can be found at [www.fidic.org](http://www.fidic.org).

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6 FIDIC offers a special contract for the employment of the engineer—Client/Consultant Model Services Agreement (2006 White Book).

**Figure 7-1:** Selecting Which FIDIC Contract to Use



Source: FIDIC.

## 7.4 TENDERING PROCEDURE

The tendering procedure may use a national or regional public procurement system. Alternatively, direct contact with selected contractors may be used if allowed under national law. The public procurement system offers the advantage of coming in contact with all potential bidders. It is recommended to conduct a market sounding prior to the tendering procedure to gain an overview of potential bidders, their applied technologies, and their attitude to the various contract forms. The market sounding may include the following questions:

- Does the supplier offer technology that is suitable and proven for the specific project?
- Does the supplier have experience with the biomass fuel to be used?
- Does the supplier have reference plants of the same size?
- Does the supplier offer sufficient financial strength?
- Does the supplier possess the necessary capability—that is, know-how and technical capacity (technicians, workers, workshop facility, etc.)
- Does the supplier have a local service setup?

During the project development phase, potential contractors also may use budgetary proposals.

### 7.4.1 PUBLIC PROCUREMENT

If a public procurement system is used, it is recommended to use prequalification of potential suppliers. In this approach, only experienced, financially sound, and capable contractors should be selected for the bidding process.

The prequalification should specify relevant selection criteria, such as financial strength and technical capacity, with references from similar projects.

It is recommended that the tender specification be ready at the time of prequalification and that the evaluation criteria are presented.

Having selected typically three to five bidders, the tender specification is issued. The bidders typically will need around three months to prepare an EPC/turnkey proposal. The contract will be awarded to the successful bidder according to the award criteria described and applying the evaluation model and methods adopted and announced.

## 7.4.2 NON-PUBLIC PROCUREMENT

Investors for mid-size projects are likely to be private companies operating, for example, plantations and/or processing facilities. Typically, one or more bidders are invited to submit a bid, usually based on a simple tender specification stating the overall requirements of the supply. Following an evaluation of the budgetary bids received, all details must be discussed with the preferred bidder and incorporated in the draft contract.

When applying a private (non-public) procurement system, it is still possible to use a similar approach with prequalification and tendering based on a detailed tender specification. It is important that the tendering procedure be competitive and transparent, also if not procured under public procurement.

The owner also may choose to enter an agreement with one selected contractor on an exclusive basis, which shall come into force if the contractor meets the requirements and a target price that is favorable to the financial model of the owner. The upside for the owner is that the selected contractor is willing to take on some of the costs for development of the biomass project, and the time schedule is minimized as much as possible. However, the owner reduces the influence on the quality of materials and components of the biomass plant, as the contractor requires more freedom during the subcontracting phase. This alternative also lacks the competition among two or more bidders, giving the lowest possible price.

## 7.4.3 REQUEST FOR PROPOSAL

The Request for Proposal (RfP) is closely linked to the pre-feasibility and feasibility analyses in order to use the appropriate information collected and agreed upon during these initial project stages.

The RfP can be structured in many ways that are highly dependent on the procurement strategy. Public procurement usually requires more comprehensive and detailed specifications, whereas non-public procurement among a few invited bidders may use less-detailed specifications.

The RfP requirements can eventually be developed in detail during the period from tendering until final contract. This replaces a comprehensive RfP with a “light” version (maybe

10 to 20 pages) defining the most important issues such as scope of supply, limits of supply, performance requirements, guarantees, time schedule, and commercial issues. The first proposal from the invited bidders can be a budget proposal. Based on this budget proposal and a first round of meetings, the owner or project developer calls for a final budget proposal. Based on this, the preferred bidder can be selected, and, during the final negotiations, detailed requirements are developed in the contract. This approach, however, is only possible in non-public procurement.

## 7.5 CONTRACTS

### 7.5.1 WARRANTIES AND GUARANTEES

It is of utmost importance to specify and agree upon the performance of the biomass plant. Sufficient time must be spent and the necessary technical expertise must be involved to define a solid contractual base, including general warranty, performance guarantees, availability guarantee, etc.

Table 7–2 presents important figures to agree upon for an EPC/turnkey contract.

Non-compliance with the guarantees is normally subject to payment of penalties or liquidated damages, which must be stated in the contract.

If contracts involve, for example, a boiler or a turbine contract, more detailed guarantees must be agreed, such as steam flow, steam temperature, steam pressure, etc. Furthermore, it is important to include an interface list, specifying all important technical data within the supply limits between contracts on, for example, the boiler or turbine, such as location, media, design, and operational data.

### 7.5.2 ENVIRONMENTAL PERFORMANCE

Environmental performance data typically include:

- Emissions to air (for example, nitrogen oxides or carbon dioxide)
- Emissions to soil (for example, leakages or landfilling of residues)
- Emissions to water (for example, wastewater)
- Noise (for example, from machinery).

**Table 7-2: Warranties and Guarantees**

	Unit	Remarks
General warranty	years	Typically, two years from takeover.
Availability	%	<ul style="list-style-type: none"> <li>Typically measured in the first two years of operation. A lower figure might be agreed in the first year, since this is where operational problems are solved.</li> <li>Experienced contractors should comply with at least 92 percent availability, allowing for both planned and unplanned outages.</li> </ul>
Continuous operating time	hours	<ul style="list-style-type: none"> <li>Without stop for mechanical cleaning.</li> <li>Experienced contractors should comply with around 8,000 hours.</li> </ul>
Gross electrical output	MW	
Net electrical output	MW	
Steam or heat export	kg/s	If applicable, steam parameters must be stated as well (temperature, pressure).
Consumption of various consumables	kg/s	Lime, makeup water, lye, ammonia water/urea, etc.
Production of bottom ash	kg/h	May be difficult to specify, as it depends on the fuel and should only be implemented if deemed necessary for the owner.
Production of fly ash	kg/h	May be difficult to specify, as it depends on the fuel and should only be implemented if deemed necessary for the owner.
TOC (total organic carbon)	%	Unburned in the bottom ash. This figure shows whether the combustion process is operating well.

Source: COWI.

These requirements are mandatory and are normally specified in the environmental permit, and they consequently are not subject to discussion. Therefore, they are absolute and usually are not subject to liquidated damages, but if the environmental requirements are not met, handover to the owner should not be accepted.

Local/regional standards and guidelines on environmental performance may apply, but a few international guidelines should be mentioned. Key guidance documents include the World Bank Group (2007) Environmental, Health, and Safety General Guidelines (3–50 MWth) and the World Bank Group (2008) Environmental, Health, and Safety Guidelines for Thermal Power Plants (>50 MWth). Further to this, the EU has formulated various directives (e. g., the Large Combustion Directive) as well as BAT Reference Documents (BREFs) and BAT Conclusions (e. g., for Large Combustion Plants) that also may be relevant outside Europe (IPCC, 2015).

It also should be carefully considered if the plant should be designed/prepared for stricter environmental requirements expected in the future. A later upgrade may be more expensive and may require outage for a long period of time.

### 7.5.3 TIME SCHEDULE AND MILESTONES

Although an EPC/turnkey contract places the entire responsibility on the contractor, it is highly recommended to include a time schedule showing the important milestones of the project, such as start of erection, pressure test, start of hot commissioning (first fire), first synchronization to electrical grid, start of trial run, performance test, and handover.

To keep pressure on the contractor, these milestones might either be penalized or payments are subject to postponement if the milestones are not met. This will (partly) compensate the owner from the delayed startup.

### 7.5.4 COMMISSIONING

It is important to describe the intended commissioning program, including the owner's right to approve the project moving to the next stage—for example, is the contractor ready to commence trial run (trial operation)?

Details about commissioning can be found in Chapter 8.

## Case Story: Biomass Project for the Textile Industry in Honduras



### PROJECT DESCRIPTION

Gildan is a leading Canadian multinational company that manufactures high-quality basic clothing, with production facilities in the Dominican Republic and Honduras. Its industrial activity requires a high saturated steam flow. This used to be produced by heavy oil boilers, which drove the company to face high energy costs and resulted in a larger carbon footprint.

In the Rio Nance plant in Honduras, Gildan produces 150 tons per hour of vapor using six boilers of 25 tons per hour each.

### APPLIED TECHNOLOGY

From 2009 to 2013, the company installed six steam boilers with 16 bar(g) design pressure and a two-pass vertical economizer. Each boiler line is equipped with primary and secondary combustion air systems for both combustion zones, respectively. The system has a water-cooled moving step grate with a total area of 21.2 square meters, which is divided into three sections.

For flue gas cleaning, each boiler system has a double multicyclone, with 72 cyclones each made in a special execution with hatches for cleaning. A modulating control system ensures that all parameters are automatically adjusted according to the current load of the boiler and that the system therefore operates continuously in the range of 40 to 100 percent.

### PLANT PERFORMANCE

- Average biomass cost: \$55 per ton Average LCV: 2.2 MWh per ton
- Price for biomass energy: \$25 per MWh
- Average heavy oil cost (at the time of construction of the plant): \$2.2 per gallon
- LCV for 1 gallon of heavy oil: 44 kWh per gallon
- Price for fossil energy: \$50 per MWh
- Boiler efficiency: 87 percent.

### FUEL TYPE AND HANDLING

A mixture of different types of biomass are used as fuel, including waste from the plant's own processes, African palm byproducts, king grass from energy crops, and wood sawdust. The biomass composition for the project is: 40 percent empty fruit bunches from African palm, 40 percent wood, and 20 percent king grass bagasse (an energy crop).

A silo with a capacity of 3,000 cubic meters was built. Two semiautomatic cranes collect biomass from the silo and deliver the biofuel to the boiler hoppers.

### DEVELOPMENT / INVESTMENT COST

The total contract amount was €15 million, not including the civil works.

### LESSONS LEARNED

Gildan saved considerable money from switching to biomass. In the period 2010–2013, all of the steam produced by heavy oil combustion was replaced with “green” steam produced by biomass combustion, allowing Gildan to greatly reduce its energy invoices and to massively reduce its carbon footprint.



Source: LSolé s.a., 2016, [www.lsole.com](http://www.lsole.com); Justsen Energiteknik A/S, 2016, [www.justsen.dk](http://www.justsen.dk).



Source: COWI.

## 8.1 CONSTRUCTION

The split of responsibilities between the owner and the contractor for the construction and commissioning phase is dependent on the type of contract adopted for the biomass plant (that is, multiple contracts, DB/EPC, DBO, or DBFO; see Section 6.1). However, the tasks to be performed during the construction and commissioning phase are the same regardless if they are done by the contractor or by the owner.

The construction of a biomass plant is a complex process that requires both extensive technical experience and knowledge and considerable experience and knowledge in planning and management. Successful construction of a biomass plant requires project management in accordance with general construction project management best practice.

A biomass plant is a complex construction, and for a typical steam-based power plant, the following part systems should be considered:

- Fuel reception station
- Fuel yard
- Fuel shredding
- Fuel storage
- Fuel transport
- Boiler feeding
- Combustion
- Boiler
- Flue gas cleaning
- Emission monitoring
- Chimney
- Bottom ash transport and storage

- Fly ash transport and storage
- Turbine/generator
- Condensate
- Makeup water
- Chemical dosing
- Compressed air
- Soot-blower system
- Control and instrumentation
- Electricity and power distribution
- Grid connection
- Connection to steam or district heating
- Workshop
- Cooling

The most visible activity in the construction phase is the actual construction of the biomass plant where all the mechanical, electrical, and control and instrumentation (C&I) components are being erected and installed. This is normally the job of a turnkey EPC contractor, alternatively with a multiple contract approach employing two to four main contractors depending on the chosen contract strategy.

However, to make sure that this happens in the most optimal way, the owner should be actively involved in the construction phase regardless of the contract strategy, whether it is a full turnkey EPC contract or a multiple-contract approach.

Even smaller 1 to 5 MWe projects and biogas plants require a construction site organization to plan and coordinate the activities on-site on a daily basis.

For an EPC contract, the contractor will coordinate and carry out many of the following disciplines. For a multiple-contract project, the owner or the owner's representative has to coordinate the activities on site. For EPC projects, the owner (or the owner's representative) also should get involved in all disciplines to closely monitor the progress of the work.

The layout of the construction site should be planned at an early date before construction actually begins on-site. Often, the area available for staff facilities, a temporary storage yard for materials, a pre-fabrication area, etc., will be limited, and thus the layout of the construction site must be planned well in advance. In addition, access to bathroom, bathing, and catering facilities, and connection to utilities (water, electricity, etc.) may be limited during the construction phase, and this must be taken into consideration in the planning.

Planning and coordination during the construction phase include the following disciplines:

- Scheduling
- Roles and responsibilities
- Risk, stakeholder, and quality management
- Environment, health, and safety management
- Cost management.

### 8.1.1 SCHEDULING

An overall time schedule with tasks, duration, milestones, and interdependence among tasks is developed during the design phase.

During the construction phase, this time schedule must be much more detailed, down to a level where ongoing activities must be identified each day. A comprehensive time schedule is crucial, and it is highly recommended that professional software (Primavera, MS Project, or similar) is used for this task.

At a minimum, the schedule should include the following components:

- Tasks and duration with specified start and end dates
- Milestones and key dates

- Interdependencies among tasks
- Person responsible for the task
- Project critical path
- Actual progress against planned progress.

A planner should be dedicated to this task and should follow up on progress on a daily basis.

The time schedule should be divided into groups of activities. For a biomass plant, these include:

- Civil construction
- Mechanical installations
- Fuel handling
- Boiler
- Turbine
- Environmental plants
- Balance of plant
- Electrical installations
- C&I installations.

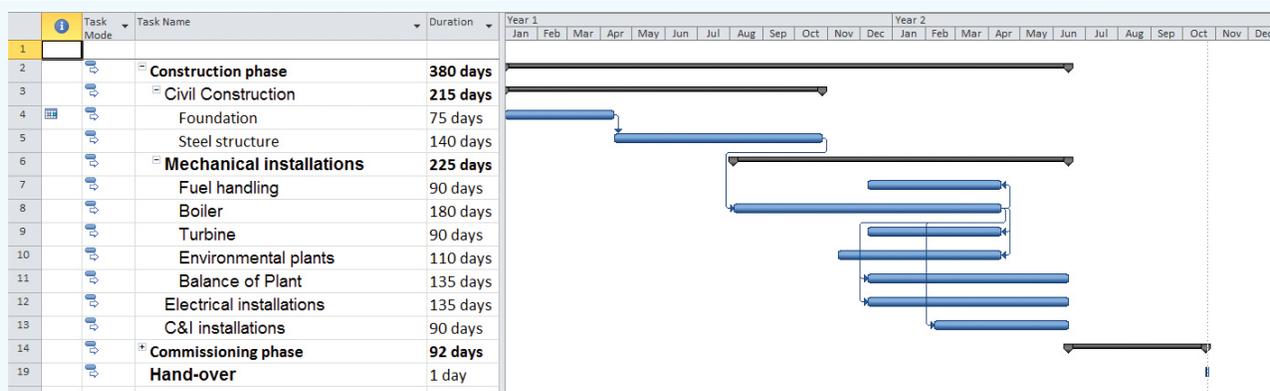
Each task should be divided into detailed activities, making it possible to carefully plan and to follow up. Planning is crucial in order to identify the influence that each activity has on another and to identify which activities of the construction phase are critical. These activities should be given special attention, but if other activities are delayed, the critical path could change and thus require a shift in focus.

During the construction phase, changes and amendments to the time schedule are made, and new revisions of the time schedule must be issued. It is crucial for a successful construction phase that all involved parties receive any new revision of the time schedule.

A simplified example of a construction phase time schedule is shown in Figure 8–1. In reality, a time schedule for a biomass construction project can contain maybe 2,000 or 3,000 lines with different activities.

Compared to scheduling for conventional construction projects, transportation, storage, and handling of biomass

**Figure 8-1:** Simplified Time Schedule for the Construction Phase of a Biomass Project



Source: COWI.

require special attention in the schedule. The facilities for transportation, storage, and handling of biomass are more complex than facilities for conventional fuels, and this must be reflected in the schedule.

The construction of the other parts of a biomass plant is similar to the construction activities in conventional power plant projects.

In the time schedule, each task should be broken down into activities with short duration (a few days or a week). This allows careful monitoring of the progress of the activity and permits prompt corrective actions to be taken.

Milestones are incorporated in the contract, and they are connected to contractual obligations, advanced payments, or penalties. Milestones should be monitored very carefully to assure on-time completion.

### 8.1.2 ROLES AND RESPONSIBILITIES

A construction site organization should be in place to plan and coordinate the activities on-site on a daily basis during construction.

For smaller projects or for projects with only one EPC contractor, several of the roles listed below may be carried by the same person, but all roles must be covered.

The owner's construction site organization should, at a minimum, include:

- Construction site manager
- Environment, health, and safety manager
- Civil construction supervisor
- Mechanical supervisor
- Electrical supervisor
- C&I supervisor
- Planner
- Quality manager
- Secretary and archiving.

The owner's construction site organization refers to the owner and should be independent of the contractors on site. In addition, the contractor will have his or her own construction site organization in place, and the two parties should work together.

The owner's company is usually engaged in other types of business, different from biomass plant construction and operation, and the owner probably will not have qualified personnel for this type of task in his or her organization. Therefore, the owner should hire external experts independent of the contractor to represent his or her interests.

The responsibility of the construction site organization includes:

- Coordination of activities on-site
- Ensuring that all activities are carried out in a safe way
- Daily follow-up on the contractor’s installation regarding the technical disciplines: civil, mechanical, electrical, and C&I
- Follow-up on the construction time schedule.

### 8.1.3 RISK, STAKEHOLDER, AND QUALITY MANAGEMENT

A project risk register should list all risks associated with the project, such as approvals from authorities, time schedule, costs, and quality.

Each risk should be evaluated in terms of probability and consequence. The probability and the consequence should each be evaluated separately, for example with a score from one to five. The two scores are multiplied, and the risks are ranked according to this score, directing focus on the most severe risks.

The register should note the mitigation strategy to reduce each risk, the deadline for mitigation, and who is responsible for acting on the risk, as shown in Figure 8–2. The risk register should be updated frequently, perhaps on a monthly basis.

Stakeholder communication and management should be performed right from the project start, but when the project enters the construction phase, it becomes more visible and may attract new stakeholders. It therefore is important to identify all potential stakeholders before construction begins and to develop a plan for interacting with each stakeholder and updating them about project progress.

Special attention to the risks of fire, explosion, boiler quality (welding, etc.), delays, and claim management are important items in the risk register during the construction phase.

The risks of fire and explosion are more serious for biomass plants than for conventional energy plants. Biomass dust is easier to ignite than coal dust, and the explosion coefficient for biomass is much higher than for coal. The risks can be mitigated with careful design of the fuel handling and transportation system and by specifying cleaning instructions in the operation instructions.

As with conventional energy projects, is it important that quality management ensures that the boiler welding meets the relevant standards, and it is essential to carefully follow up on quality reviews. In the contract with the contractors, the owner’s requirements for quality and quality management should be specified.

The requirements regarding quality should include:

- Contractor’s quality management system
- Sub-suppliers’ quality management systems
- Quality assurance
- Quality control
- Document requirements.

The construction phase is always the most hectic phase of project execution, with many activities taking place simultaneously and with many workers on-site. It therefore is important to handle the risks for delays and additional claims from the contractors in a professional way. One way to do so is to acknowledge the risks and to describe how to mitigate them in the risk register.

**Figure 8-2:** Simplified Risk Register

Identification of Risk				Risk Evaluation			Risk Handling			
ID No	Risk Description	Potential Effect	ID Date	Frequency	Consequence	Risk Level	Mitigation Method	Mitigation Status	Responsible Party	Last Updated

Source: COWI.

Risks associated with safety are described in Section 8.1.4.

### 8.1.4 ENVIRONMENT, HEALTH, AND SAFETY MANAGEMENT

During the construction phase, environment, health, and safety (EHS) management should have the highest priority. Construction sites in general are dangerous working places, and this also is the case for biomass plant construction sites (independent of size). Safety must come first in all decisions at the construction site.

The owner should specify in a document his or her requirements for EHS together with the general site conditions. This document should be known and followed by everybody engaged at the construction site.

A risk register with a focus on EHS issues should be created, similar to the project risk register described in Section 8.1.3. The EHS risk register should be updated regularly, at least on a weekly basis.

All personnel with access to the construction site (including the owner, the contractor, and any subcontractor) should be instructed in safety issues specific for the actual site. This information should, at a minimum, include:

- Alarms
- Meeting points
- Requirements for personnel protection.

The requirements for personnel protection should include demands for using safety helmets, safety shoes, etc., as well as the standards for fall prevention, scaffolding, hoists, etc.

As part of the EHS activities, a 15 to 30 minute toolbox meeting should be held every morning during the construction phase. At the toolbox meeting, all parties involved at the site should go through the day's activities on the site, with a focus on dangerous activities and on areas where multiple parties work at the same time.

Local EHS directives should always be followed. In addition, the recommendations in the IFC Environmental, Health, and Safety General Guidelines should be observed, and, for biomass plants, the majority of the good practice in the IFC

Environmental, Health, and Safety Guidelines for Thermal Power Plants also will be relevant.

### 8.1.5 COST MANAGEMENT

The biomass plant generates no revenue until it is up and running. During the construction phase, there are only payments to be made to the contractors and to the owners' own personnel.

In the contracts with the contractors, a payment schedule is an important element. Normally, the payments are divided into a number of installments, often linked to measurable milestones. It therefore is essential to closely follow up on the progress of the construction site activities.

It also is important to manage carefully any extra work that will appear during the construction phase. No matter how carefully the planning has been done, it is normal that not all activities have been foreseen. Therefore, a contingency sum of 10 to 20 percent is often added to the budget. It is important, however, to manage carefully this amount. The pressure on the time schedule will be highest during the construction phase, and therefore the tendency to accept extra costs will be open in order to keep up with the time schedule.

In brief, "extra work" is any activity not defined in the contract, or any activity that is defined in the contract but whose volume or size exceeds the originally planned activity. One way to manage extras is that all extra work should be agreed in writing before it is executed.

## 8.2 COMMISSIONING

When all equipment has been erected, the project goes from construction phase to commissioning phase. During the commissioning phase, it is important to test all equipment in a systematic way.

Before the commissioning can begin, certain documentation requirements should be met in order to plan and conduct the commissioning in a systematic and safe way. This requires a well-prepared commissioning plan.

The commissioning phase should demonstrate that the installations erected during the construction phase are complete and comply with the requirements as specified in the contracts.



Source: COWI.

As for any other energy project, the commissioning phase for a biomass plant project includes a cold test, a hot test, a functional test, a trial run, a performance test, and handing over to the owner.

During the cold test, all signals—from the individual components to the control system—are tested to ensure that they are connected correctly. During the hot test, the plant actually starts to operate on the main fuel, and all controls and regulations are trimmed and optimized.

When the cold and hot tests are finalized, the contractor must demonstrate that the plant can operate and perform as it was supposed to do. This is called the functional test.

When the functional test is approved by the owner, the trial run can start. The purpose of the trial run is to demonstrate that the plant can operate safely and reliably for an extended period, for example 720 hours.

After or during the trial run, the performance or demonstration test can take place, and the performance and availability of

the plant should be measured over a defined period, typically during the subsequent guarantee period.

In addition, it is also during the commissioning phase that the operating staff should be trained, and the operators should become confident with the equipment so that they are able to run and maintain the plant during operation in the future.

The commissioning phase includes, at a minimum, the following:

- Planning
- Roles and responsibilities
- Training
- Cold testing
- Hot testing
- Functional test and trial operation
- Performance test and availability
- Handover documentation.

## 8.2.1 PLANNING

As in the construction phase, a well-planned, detailed time schedule is important in the commissioning phase to identify the activities for each day. A comprehensive time schedule is crucial, and it is highly recommended that professional software be used for this task.

A planner should be dedicated to this task and should follow up on progress on a daily basis.

The time schedule should be divided into phases of cold testing, hot testing, and performance testing and trial operation.

Each task should be divided into detailed activities that makes it possible to carefully plan and follow up on progress.

In the time schedule, each task should be broken down into activities with short duration (one to two days). This allows for careful monitoring of the progress of each activity and permits prompt corrective actions to be taken.

A simplified example of a commissioning phase schedule is shown in Figure 8–3.

## 8.2.2 ROLES AND RESPONSIBILITIES

During the commissioning phase, a commissioning site organization should plan and coordinate the activities on-site on a daily basis.

For smaller projects, one person may carry out several of the roles listed below, but the commissioning organization should include, at a minimum:

- Commissioning manager

- EHS manager
- Mechanical supervisor
- Electrical supervisor
- C&I supervisor
- Planner
- Quality manager
- Secretary and archiving.

This commissioning organization should refer to the owner and be independent from the contractors on-site.

If qualified people are not available within the owner’s organization, consultants independent of the contractor should be hired to protect the interest of the owner. It is, however, important that the owner’s personnel get involved and participate in the operation of the biomass plant during the commissioning phase, as they shall operate the plant after takeover.

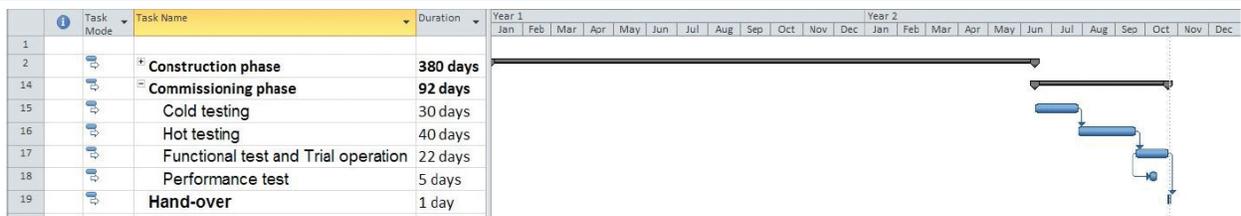
The responsibility of the commissioning organization includes:

- Coordination of activities on-site
- Ensuring that all testing is carried out in a safe way
- Daily follow-up on the contractor’s testing
- Follow-up on the commissioning time schedule.

## 8.2.3 TRAINING

During the commissioning phase, the owner’s operation and maintenance personnel should become more and more familiar with the plant and get increasingly involved in the operation of the plant.

**Figure 8-3:** Time Schedule for the Commissioning Phase



Source: COWI.

This should be done in two ways:

- Within the contractor’s scope of supply, the contractor should arrange dedicated training sessions for all systems, both for the operational personnel and for the maintenance personnel.
- During commissioning testing, the owner’s operational personnel should work closely together with the contractor’s testing personnel.

For a biomass plant, this could include training prior to cold testing, during cold and hot testing, and during test operation.

The contractor should present a training plan to the owner for approval, for example three months prior to the start of cold testing and covering all parts of the training program.

Training sessions should be based on drawings and on operating and maintenance instructions delivered by the contractor, and the training should be arranged in such a way that during the training sessions each trainee will have to execute all actions related to the upcoming tasks.

Training should cover the function of the actual machinery and the function of the control and instrumentation devices related to the machinery. After the training program is complete, the operating personnel must possess all the necessary skills for the complete and safe operation of the plant under all conditions.

### TRAINING PRIOR TO COLD TESTING

If the future operation and maintenance personnel are unfamiliar with the new biomass plant, training may be arranged at an existing reference plant elsewhere.

In addition, before the DCS factory acceptance test, the supplier should provide training in the use of and programming of the DCS system, enabling the owners’ programmers to make changes in the DCS program by themselves.

In addition, training should be arranged during cold and hot testing and during test operation, as shown in Tables 8–1 and 8–2.

**Table 8-1:** Training Schedule: Phase One

#### Training during cold test and hot test

At a minimum, the theoretical part of the training should contain:

- A study of the process flow diagram (PFD)
- A study of all pipe and instrumentation diagrams (PID)
- A study of the general layout of the plant
- A study of the functional descriptions of all systems, including auxiliary systems
- A study of all main equipment such as boiler, flue gas treatment, fuel handling, air preheater, pumps, fans, valves, etc.
- A study of operations and maintenance manuals, including startup and shutdown
- A study of safety procedures and plans
- Questions and discussions

At a minimum, the practical part of the training should contain:

- Identification of all main equipment
- A practical study of all main equipment
- Participation in the commissioning if requested by the owner
- Special training on all main equipment from the equipment manufacturer
- A study of the maintenance plan/schedule
- A study of the lubrication plan/schedule
- A study of preventive maintenance procedures
- Questions and discussions

Source: COWI.

For a biogas plant, the staff that will operate the wastewater treatment plant should receive special training for this. As a minimum, the training should include maintenance and repair of equipment, service check for oil etc., safety during handling of biogas, firefighting, basic knowledge of the biological processes in the anaerobic digester and in the aerobic process tank, optimization of the operation of the plant, and analyses of the quality of the wastewater discharged.

### 8.2.4 COLD TESTING

Cold testing is the phase where the contractor tests that all signals—from the individual components to the control system—are connected correctly.

Cold testing includes testing of all individual components (valves, pumps, fans, motors, etc.) and of the individual systems.

**Table 8-2: Training Schedule: Phase Two**

**Training during test operation**

At a minimum, the theoretical part of the training should contain:

- A study of all control-loop diagrams, control logic, control sequences, etc.
- A study of Interlock diagrams
- A study of alarm lists
- A study of safety procedures
- A study of normal operation procedures
- A study of startup and shutdown procedures
- A study of normal operating parameters, set points limitations, etc.

At a minimum, the practical part of the training should contain:

- A study and operation of the distributed control system (DCS) program covering all systems
- Training in DCS operation (for example, making trend curves, adjusting controller settings, printing, saving, etc.)
- Participation in the commissioning if requested by the owner
- Startup, normal operation, and shutdown of all parts of the plant
- Training in safety procedures
- Troubleshooting

*Source: COWI.*

The cold commissioning should include complete:

- Cable check and test
- Signal test
- Instrument test
- Motor test
- Equipment test
- DCS test
- Test and adjustment of frequency converters, soft starters, circuit breakers, motor protection units, relays, etc.

It is the responsibility of the contractor to carry out the cold testing, but it is useful for the owner's staff to be involved in the testing and to carefully follow up on the testing in order to get to know the biomass plant as much as possible.

### 8.2.5 HOT TESTING

When the cold testing has been finished successfully, the hot testing can begin.

In the hot testing, the plant actually starts to operate on the main fuel, and all controls and regulations are trimmed.

The hot commissioning should include complete:

- Startup of all motors
- Startup of all systems
- Tuning of all parameters of control systems
- Operation of the plant until the test run
- Participation in the performance test.

The hot testing should be carried out by the owner's personnel, but under the supervision and at the responsibility of the contractor.

### 8.2.6 FUNCTIONAL TEST AND TRIAL RUN

When the cold and hot tests are finalized, the contractor must demonstrate that the plant can operate and perform as defined in the contract. This is called the functional testing.

During the functional (acceptance) test, the function of the whole plant is tested in all operation modes: startup, stop, load variations, etc. The test should prove that all design specifications are met.

When the owner has approved the functional test, the trial run can begin. The purpose of the trial run is to demonstrate that the plant can operate safely and reliably for an extended period. This period is normally 30 days, equivalent to 720 hours.

During the trial run, the plant should be able to operate at any load specified by the owner. The test run should demonstrate proper functionality and readiness for commercial operation of the entire plant.

Minor adjustments and fine-tuning of components may be accepted during the trial run if they do not interfere with the operation of the plant.

If the plant is not able to run at the specified load, the trial run must be cancelled. The contractor must make the necessary repairs and adjustments, and the trial run must be restarted and completely repeated.



Source: COWI.

### 8.2.7 PERFORMANCE TEST AND AVAILABILITY

During the trial run or within the guarantee period, the performance of the plant should be tested in a performance test, which could be according to international standards.

The performance test should prove that the performance guarantees in the contract are met.

This typically will include:

- Electrical output / boiler efficiency
- Steam or district heating flow quality
- Electricity in-house consumption
- Startup times
- Load variation times
- Emissions
- Noise.

The contract should specify the conditions under which the performance test should take place. In reality, it usually is not possible to achieve exactly the specified conditions. It therefore is important that the contract includes correction curves for the variable conditions.

The guarantees for electrical output, steam/district heating flow quality, and electricity consumption are usually associated with penalties, while the guarantees for emissions and noise are guarantees that should meet authority regulations. If these guarantees are not met, the contractor has to modify the installation until the required guaranteed values are met.

In addition to the guarantees listed above, availability should be guaranteed in the contract. Availability is normally determined over the guarantee period (typically two years or 15,000 hours of operation).

The availability  $A$  is defined as:

$$A = \frac{T_{actual}}{(T_t - T_p) \times 100\%}$$

Where

$T_{actual}$  = Actual number of hours per year in which the equipment has been in operation or has been ready for operation

$T_t$  = 8,760 hours

$T_p$  = Number of hours of planned outage per year (normally one to three weeks)

For a biogas plant, performance tests should be made after a month with stable operation. The specified guarantees should be verified and documented. The tests should be repeated after one year of operation and before the guarantee expires.

### 8.2.8 HANDOVER DOCUMENTATION

The handover documentation consists of updated as-built documentation including:

- Drawings
- Descriptions
- Operation and maintenance manual
- Certificates and declaration of conformity
- Shortage list.

All this documentation must be delivered before final payments are made. It is important that the as-built documentation is updated with any changes to the original design that may have been implemented during the design, construction, and commissioning phases.



Source: COWI.

The profitable operating life of a biomass plant could be 20 to 40 years depending on the fuel, operational profile (number of starts, stops, and operating hours), and maintenance history. Major overhauls or rehabilitation of key systems and components may take place during the operating period.

Operation and maintenance of a biomass plant is, in some respects, more complex and requires a larger staff than a conventional oil- or gas-fired plant, which may be the alternative to a biomass plant.

The low heating value and low bulk density of biomass compared to fossil fuels require equipment for handling of large tonnages and storage space for volumes of fuel feedstock. The fuel handling systems will be exposed to wear and tear during normal operation, which requires regular maintenance. Some fuels, especially with high contents of alkaline and chloride, also may cause corrosion problems in the fuel handling systems and in the boiler and the ash handling systems. The use of high-pressure steam boiler, turbine/generator, and flue gas cleaning equipment calls for easy access to specialized technical competence, either within the operational staff or available at short notice.

The development and construction of a biomass plant is a large investment. Therefore, maintaining a high efficiency is key to securing the optimum benefits of the investment. Likewise, a high availability and reliable production of electricity and heat (for CHP plants) is crucial for the economic outcome of the plant. Finally, compliance with environmental and other authority requirements is necessary to match the license to operate. All of these concerns call for a strong focus on operation and maintenance in all planning and operational phases.

This chapter focuses on plants with steam boilers and steam turbines. However, most of the general considerations and systematics for planning operation and maintenance also can be applied to ORC and biogas plants. Section 9.4 describes the special issues related to ORC and biogas.

## 9.1 PLANT ORGANIZATION AND STAFFING

### 9.1.1 OPERATION

Plant operation includes a number of tasks and responsibilities, such as:

- Scheduling of power and heat production and fuel supply
- Operating and monitoring all functions of the energy-producing plant and equipment
- Operation of fuel reception and handling, including weight measuring and quality control (moisture content and presence of stones, metal pieces, and oversize particles or elements)
- Operation and handling of systems for bottom ash, fly ash, and other byproducts
- Supervising plant operation, including scheduled “walk through” on each shift
- Planning and ordering of necessary maintenance work and securing plant before start of work.

The project development phase will show whether cooperating with a host or nearby industrial complex is feasible. A biomass plant can, to some extent, be designed for monitoring and control of operation from a remote control facility, for example during nights and weekends. The plant can be designed to go into a safe mode/condition if a critical alarm occurs, but it will normally require presence of operating staff during startup. Critical delivery of process



Source: <http://jfe-project.blogspot.dk/>.

steam or heat to an industry should be taken into account when contemplating unmanned operation.

An option may be to contract all or part of the operation and maintenance work to a specialized O&M service company or to the EPC contractor. O&M contracts are typically made for a five-to-seven-year period.

Section 12.3.1 presents generic cost estimates for operation of a biomass plant.

### 9.1.2 STAFF

The typical operation and maintenance staff at a plant may vary in size from 3 to 5 people for a 1 to 5 MWe plant to up to 20 to 40 people for a 20 to 40 MWe plant. The size of the on-site operation and maintenance staff and organization will depend largely on:

- Plant size
- Fuel type

- Plant design
- Degree of plant automation
- The need for a 24/7 presence of a dedicated shift staff versus the possible cooperation or integration with other industrial operations
- The operation and maintenance strategy; on the one extreme, the owner does everything; on the other extreme, substantial work (both for scheduled and unscheduled outages) is outsourced.

The staff should have the necessary skills and education. It will be beneficial if the future plant staff can participate in plant construction, commissioning, and testing. This will generate a good knowledge and understanding of the plant before the start of commercial operation.

## 9.2 MAINTENANCE PLANNING

Various methodologies can be applied for maintenance planning. The following outlines the most commonly used approaches.

### 9.2.1 SCHEDULED (PREVENTIVE) MAINTENANCE

Preventive maintenance aims to achieve fewer and shorter outages by following routine procedures on a regular schedule based on elapsed time or metering.

The major advantage of scheduled maintenance is that it facilitates budgeting, prevents major problems, and reduces forced outages. The downside is that strict reliance on scheduled maintenance can be time consuming and expensive if maintenance is performed without regard to the actual equipment condition.

Suppliers' maintenance manuals and recommendations should be the starting point for planning preventive maintenance schedules and procedures.

### 9.2.2 RELIABILITY CENTERED MAINTENANCE (RCM)

RCM aims at providing appropriate and just-in-time maintenance to prevent forced outages and avoid unnecessary maintenance.

The analysis and planning of a RCM system can be time consuming and may require additional monitoring. An analysis will identify the systems and equipment that are most critical for plant availability and reliability, and these should deserve priority attention/focus.

Table 9–1 below provides examples of operation and maintenance activities.

Main Plant Item	Systems/Types	Activity	Typical Planning Method
Fuel storage and handling	Front loaders, trucks	Fueling Change of lubrication oil Change of tires	When needed Scheduled Condition based
	Cranes, conveyors	Change of lubricating wires, belts Change of rollers, bearings	Scheduled Condition based, scheduled testing
Boiler	Firing system/burners, ash systems	Change of wear parts for grate, burners, air nozzles, refractory, ash handling	Condition based, scheduled testing
Flue gas cleaning	Bag house, scrubbers, removal of nitrogen oxides	Change of / supplying of chemicals	When needed/scheduled
		Change of filters Servicing of pumps, valves	Condition based, scheduled testing Condition based, scheduled testing
Turbine	Lubrication and hydraulic system components	Annual maintenance	Scheduled
		Minor overhaul	Condition based on recommendation
		Major overhaul	Condition based on recommendation
Electrical systems	Basic electrical components	Change of cables, fuses	When needed
		Overhaul of generator	Condition based on recommendation
		Overhaul of transformers	Condition based on recommendation
		Change of motors	Condition based
Controls and instrumentation	Standard instrumentation	Calibration of thermocouples, pressure gauges	Scheduled
		Change of instruments	Condition based
Balance of plant (BOP)	Piping and auxiliary system components	Supplying of chemicals	When needed or scheduled
		Change of filters	Condition based, scheduled testing
		Servicing of pumps, valves	Condition based, scheduled testing
Buildings	Standard building materials	Painting, repair of roofs and walls	Condition based

Source: COWI.

### 9.2.3 CONDITION-BASED MAINTENANCE

Condition-based maintenance also aims to provide appropriate and just-in-time maintenance to prevent forced outages and avoid unnecessary maintenance. Various methods are available for assessment of equipment conditions, including the following:

- Monitoring and recording process and equipment parameters such as temperatures, pressures, flows, electrical currents, online analysis of flue gas, vibrations, etc.
- Scheduled chemical analysis of, for example, fuel, ash, water and steam, lubrication oils, and transformer oils
- Scheduled tests supplemented by sporadic tests when problems are suspected of, for example, control valves, safety valves, other control and protection equipment
- Scheduled specialized tests supplemented by sporadic tests when problems are suspected, using, for example, ultrasound (pipe wall thickness), infrared scanning, vibrations analysis, noise analysis, etc.

The authority permit or license may require the periodic performance of some of these tests. Table 9–2 below provides examples of consumables and wear parts for a steam technology plant.

### 9.2.4 COMBINATION OF MAINTENANCE PLANNING METHODS

In most cases, the practical approach preferred is a combination of condition-based, reliability-centered, and preventive maintenance. The maintenance history and as-found equipment condition should be documented and readily available.

The combination of this information with regular condition measurements will form the basis for failure analyses and a decision to shorten or lengthen the equipment suppliers' recommendations.

### 9.2.5 PERFORMANCE MONITORING, EVALUATION, AND OPTIMIZATION

The value of fuels and the sales price for electric power and heat produced (for CHP plants) represent the major economic elements during the operational life of a plant. It therefore is very important to maintain the expected efficiency and capacity of the plant. Performance monitoring covers various activities and procedures to achieve this goal.

A record of operation and availability during the first two years of operation will typically be the basis for approval of supplier guaranties.

Table 9-2: Examples of Consumables and Wear Parts for a Steam Technology Plant		
Main Plant Item	Systems/Types	Examples
Fuel storage and handling	Front loaders, trucks	Fuel, lubrication oil, tires
	Cranes, conveyors	Lubricants, wires, chains, belts, rollers, bearings
Boiler	Firing system/burners, ash systems	Wear parts for grate, burners, air nozzles, refractory, ash handling
Flue gas cleaning	Bag house, scrubbers, removal of nitrogen oxides	Chemicals, filters, gaskets, valves
Turbine	Lubrication and hydraulic system components	Lubrication oil, hydraulic liquid, filters, gaskets, valves
Electrical systems	Basic electrical components	Cables, switches, fuses Generator brushes, gaskets
Controls and instrumentation	Standard instrumentation	Temperature transmitters, pressure transmitters, cables, connectors
Balance of plant (BOP)	Piping and auxiliary system components	Chemicals, filters, gaskets, valves
Buildings	Standard building materials	Roof and wall elements, paint

Source: COWI.

It is recommended that an annual efficiency test of the plant be performed. The plant should operate as close as possible to one or more predefined operating points during the test, which will normally last one day. These tests often are also the basis for process guarantees from suppliers.

The test results compare the actual plant performance to design specifications and guarantees. Process calculation tools can be used to adapt the test results to actual test conditions such as ambient temperature.

For larger plants, online systems are often installed for continuous performance monitoring.

### 9.2.6 DOCUMENTATION AND OPERATIONS AND MAINTENANCE MANUALS

Comprehensive and well-structured documentation and O&M manuals are essential for reliable and efficient operation and maintenance. The tender specification should define the structure, quality, timing, and extent of the equipment suppliers' documentation.

Documentation should include:

- General description of plant and functional description of individual systems
- Drawings of layout and diagrams with a clear tag number system for systems and components
- Operation manuals for each system
- Detailed description of all major equipment and components with precise and understandable maintenance manuals
- Performance data and technical guarantees with correction curves for variations in preconditions, such as ambient temperature.

Clear procedure instructions from plant management to operators and maintenance staff are essential for a safe working environment.

### 9.2.7 SPARE PARTS

Efficient operation and maintenance also must include an efficient system for managing spare parts. It should be in line with the overall maintenance strategy and system selected. An

optimal spare parts inventory will minimize costs and maximize availability, and will reduce unplanned forced outages.

A start supply of spare parts typically will be provided by the DB/EPC contractor or by the individual suppliers as part of the investment contracts.

As a rule, consumables and frequently replaced parts should either be in stock or available on short notice from local suppliers. Using standard and locally available components can reduce the capital bound in spares stock. A selected number of critical strategic parts with long delivery time (such as the impeller for a pump) should be ordered together with the plant. The extent of this depends on the technology applied and on the local market conditions.

Installation of excess capacity for critical equipment or functions should be considered during the design of a plant. As an example, the installation of 3 x 50 percent pump capacity may be considered as an alternative to 1 x 100 percent or 2 x 50 percent. A further option could be to have a complete spare unit (for example, a complete pump unit) in stock, enabling a quick change to recover full operational capacity (see Table 9–3).

Costs for spare parts will be very dependent on the plant type and geographical location. Costs of consumables and wear parts are included in the estimates for operation and maintenance (OPEX) costs shown in Section 12.3.1. Costs of initial supply of strategic spare parts should be considered part of CAPEX, whereas replacement of used spare parts is considered part of OPEX. For some parts, it can be an option to refurbish used parts and to keep these in stock for future maintenance work.

**Table 9-3: Examples of Strategic Spare Parts for a Steam Technology Plant**

Main Plant Item	Strategic Spare Parts, Examples
Fuel storage and handling	Crane grab, cable wires, bearings Conveyor belts, rollers, chains
Boiler	Special components for grate, burners, air nozzles, refractory, fans, compensators and valves Small stock of pipes for evaporator and superheaters
Flue gas cleaning	Special components for reactors, pumps, piping, filter elements
Turbine	Valve seats, spindles, bushings, gaskets Bearing components or complete Coupling components or complete
Electrical systems	Special components for transformers, switchgear, generator
Controls and instrumentation	Input/output and interface modules, CPUs, server hard discs, special instrumentation
Balance of plant (BOP)	Special components for heat exchangers, pumps, valves
Buildings	Special building components

Source: COWI.

### 9.3 TYPICAL MAINTENANCE FOR THE MAIN SYSTEMS AND COMPONENTS

Table 9-4 describes some typical maintenance issues for a steam-producing power plant.

#### 9.3.1 HANDLING AND STORAGE OF FUEL, FLY ASH, AND BOTTOM ASH

The handling systems for fuels, fly ash, bottom ash, and other residues and byproducts include cranes, conveyors, bulldozers, silos, etc. These systems and equipment will be exposed to wear and tear during normal operation, and require regular maintenance such as lubrication and replacement of wear parts. Corrosion also can give rise to problems, especially if

**Table 9-4: Typical Maintenance Issues for a Steam Technology Plant**

Main Plant Item	Typical Maintenance Issues
Fuel storage and handling	Wear parts to be serviced and exchanged Corrosion issues possible
Boiler	Cleaning of heat transfer surfaces High and low temperature corrosion
Flue gas cleaning	Maintenance of exchange of filter elements Monitoring and service of systems for removal of nitrogen oxides
Turbine	Maintenance of stop and control valves Cleaning of condenser Minor and major overhauls
Electrical systems	Testing and service of generator Scheduled testing of transformers and switchgear
Controls and instrumentation	Calibration of instrumentation Testing of DCS system and special instrumentation
Balance of plant (BOP)	Service of critical auxiliary systems

Source: COWI.

the choice of materials and/or corrosion protection has not been considered from the start.

### 9.3.2 BOILER

Cleaning of heat transfer surfaces for deposits of ash and slag is a normal part of the daily operation and maintenance. Boilers are often equipped with soot blowers that can be operated online. However, depending on the fuel composition and the boiler design, it may be necessary to perform additional cleaning when the boiler is out of operation.

Fuels with a high alkaline content in the ash (such as straw) are prone to creating slag deposits in the boiler furnace. Alkaline and chlorine may cause high-temperature corrosion in the furnace and in superheaters and low-temperature corrosion in the cold end of the boiler.

Planning of eventual renewal of, for example, superheaters should be included in the design and layout of the boiler.

Inspection and servicing of the main mechanical equipment and auxiliary equipment such as grates, fans, and pumps are normally included in scheduled maintenance programs.

Over the years, corrosion and erosion may reduce the wall thickness of boiler tubes to a point where boiler leaks occur frequently. If this happens, an analysis may indicate if *ad hoc* repairs are sufficient or if parts of the boiler should be replaced.

High-temperature parts of the boiler operating above approximately 400°C will undergo material changes due to creep. Boilers are normally designed for 200,000 hours of operation. When approximately half of the design lifetime is used, a systematic inspection of material condition should be initiated. This is particularly the case for thick wall components, steam drums, and live steam pipelines.

### 9.3.3 FLUE GAS CLEANING

Depending on emission requirements, flue gas cleaning may comprise filters, scrubbers, and possibly systems for the removal of nitrogen oxides.

Filters such as electrostatic precipitators and bag houses must be cleaned regularly using online systems as part of normal operation. Filter bags must be renewed a number

of times during the normal lifetime of a plant. Pressure drop and particle concentration in the flue gas should be monitored and recorded in order to optimize operation and planning of maintenance. The time between changes of filter bags will depend strongly on the design, the ash composition, and operational factors.

For plants with either selective or non-selective catalytic reduction systems for the removal of nitrogen oxides, it is very important to monitor emissions and the consumption of ammonia, urea, or similar substances. A change in temperature or injection profile can lead to increased emissions and in the slippage to the ambient environment of media for nitrogen oxide removal. For selective catalytic reduction units, the catalyst must be partly or completely replaced after some years, depending on the ash composition and operating conditions.

### 9.3.4 TURBINE INCLUDING CONDENSER/COOLING SYSTEM

The two most common causes for reduced turbine efficiency and capacity are fouling of heat transfer surfaces in condensers and air ingress through leaks in components operating below atmospheric pressure. Monitoring the performance of condenser systems therefore is very important in order to take necessary action in time. Actual maintenance and repairs will differ with the type of condensers: water cooled, cooling tower, or direct/indirect air cooled.

Scheduled (for example, annual) maintenance of the turbine includes inspection and possible repair of the turbine auxiliary systems, including lubrication oil and hydraulic control system. Special attention should focus on the key components of the turbine control and safety system, stop and control valves, overspeed protection, etc. Endoscopic inspection for cracks, fouling, and erosion also can be included, supplemented by visual inspection where possible.

Most original equipment manufacturers (OEMs) recommend “minor overhauls” to be performed every 25,000 operating hours or three to four years (whatever comes first). Some suppliers calculate equivalent operating hours taking into account the number of start/stops and trips. A “minor overhaul” normally includes opening and inspection of

bearings and turbine valves in addition to the service prescribed under the annual maintenance.

A “major overhaul” is often recommended every 50,000 hours or six to eight years (whatever comes first). A major overhaul includes opening of the turbine housing and removal of all inner components for cleaning, inspection, and repair of possible damages. The scope also includes the services under the minor overhaul. Seals and wear parts are inspected and refurbished or renewed if necessary. Finally, clutches and alignment will be checked before commissioning.

### 9.3.5 ELECTRICAL SYSTEMS

#### GENERATOR

In the range of 2 MW to 40 MW of electrical power, the turbine generators for a typical biomass plant are dominated by air-cooled three-phase synchronous generators with brushless excitation systems. The cooling can be either direct air cooling (DAC) or totally enclosed water to air cooling (TEWAC). Between the steam turbine (high-speed side) and the generator (low-speed side), a reduction gearbox matches the speeds.

Scheduled overhauls recommended by OEMs generally require an annual visual inspection of the generator interior and exterior. Endoscopes are useful for visual inspections inside the generator, requiring only covers to be removed.

Minor overhauls and major overhauls typically are performed every 25,000 and 50,000 operating hours, respectively, for the turbine. A minor overhaul typically includes opening and inspection of, for example, bearings, excitation systems, coolers, and gearbox.

A major overhaul includes removal of the generator rotor. When the generator rotor is removed, access is given for a thorough inspection and testing of the stator and rotor. The focus areas are windings and iron cores.

Even though the generators are maintained according to the OEM recommendations, experience shows that in order to reduce unplanned outages, it is important to carry out systematic condition-based maintenance. Modern online monitoring systems are recommended for this.

#### TRANSFORMERS

Scheduled tests and maintenance of dry and oil transformers include cleaning of transformers and their surroundings, test of instrumentation, and protection relay. The maintenance plan should follow the supplier’s instructions, including auxiliary equipment for the transformer (for example, the cooling system).

It is recommended that scheduled oil and gas analyses be performed during the lifetime of the transformers. Records of the analysis should be kept. Changes in analyses will provide an indication of upcoming failure.

As a supplement, further measurements may be carried out, such as frequency response analysis (FRA). FRA is an effective method of evaluating the mechanical integrity of the core, winding, and fixings in the transformers. FRA may be carried out on both oil and dry transformers.

Generally, the supplier’s assessment of the transformers should be invited when progressed aging causes increased failure rates during the operation and maintenance period.

#### SWITCHGEAR

Operation and maintenance of the switchgear should follow the supplier’s recommendations. The supplier will normally have a test-and-service program for both the mechanical and electrical components of the supplier’s equipment.

### 9.4.6 CONTROL AND INSTRUMENTATION (PLANT CONTROL SYSTEM)

The control and instrumentation (C&I) system consists of all of the plant’s instrumentation plus the distributed control system (DCS). The instrumentation includes the measurements of temperatures, pressures, flows, positions, etc. More specialized measurements such as flue gas analyzers also may be included.

The DCS includes input and output modules and communication modules. These provide the necessary interface between the DCS and field instrumentation and devices, central processing unit (CPU) modules, communication network, servers and workstations, and human machine interface (HMI) with

monitors and keyboards in the central control room, and possibly at other locations.

Instrumentation should be checked and calibrated as part of a scheduled routine, describing time intervals and procedures for each measurement. The basic routines normally will be performed by on-site personnel or contractors available on short notice. Special instrumentation may require the call-in of specialists.

The DCS system may include continuous monitoring of system components and provide diagnostic views that help preventive maintenance. However, the DCS should be subject to a scheduled (for example, annual) inspection to check CPU and bus-load, capacity of data storage media, and components with limited lifetime, etc.

Functional safety systems, which are part of the plant protection, should be maintained and tested in accordance with relevant standards and authority requirements.

The basic instrumentation often will have a technical life similar to the main process and mechanical equipment. However, parts of the DCS system may have a shorter practical life due to changes in technology and availability of spare parts. Exchange of HMI systems may be expected after 10 to 15 years, and renewal of the automation level of DCS (input and output modules, communication modules, CPU modules, etc.) after 15 to 20 years.

### 9.3.7 BALANCE OF PLANT (BOP)

Balance of plant consists of a number of supporting auxiliary systems, for example cooling water, water supply and makeup, water conditioning, compressed air, firefighting systems, etc. These systems may be considered as secondary, but some are highly critical for operation, safety, and plant availability. Therefore, an analysis of each system should be made in order to decide an appropriate maintenance strategy.

Depending on potential integration and cooperation with a nearby industrial installation, the plant also may include facilities for administration offices and staff facilities.

## 9.4 ORGANIC RANKINE CYCLE (ORC) AND BIOGAS PLANTS

This chapter focuses on plants with steam boilers and steam turbines. However, most of the general considerations and systematics for planning operation and maintenance also can be applied to ORC and biogas plants. This section describes the special issues related to ORC and biogas.

### 9.4.1 ORC PLANT

A biomass-based ORC plant will consist of a biomass-fired boiler delivering heat to the ORC unit via a thermal oil circuit. It thus includes the same main systems as a steam-based plant, for example biomass fuel handling and storage, a boiler with furnace, a flue gas system with cleaning and stack, ash handling, etc.

Operation and maintenance of a biomass ORC plant therefore will include the same basic operations and activities as described above for a steam plant. However, the types of boilers are smaller and more simple than a typical steam boiler, and ORC plants also are designed for much lower pressures and temperatures than steam plants and are usually built with a high degree of automation.

ORC plants often are designed and built in prefabricated modules, which require less assembly work on site compared to steam plants.

This generally reduces the necessary human power for operation and maintenance. Often, the maintenance of the fuel and boiler-related systems can be performed by staff or contractors available locally.

However, maintenance of the core ORC unit, its components, and the handling of the working fluid will require expert skills and special spare parts that are often available only from the OEM. It therefore can be advantageous to have a contractual agreement with the OEM supplier for some years.

### 9.4.2 BIOGAS PLANT

The investment in a biogas plant is rather high, so yearly depreciation is high. In addition, there are many types of operation costs such as biomass transport and pretreatment,

process heat, cost of chemicals, and costs of cleaning the gas for, for example, sulfur.

The only revenue is from the sale of biogas (or produced electricity and heat). The sales price depends on the market price for natural gas, and it therefore is essential to operate the plant optimally to obtain the maximum biogas output from the biomass.

A biogas plant depends on a stable and sufficient supply of biomass of a quality that will enable optimal production of biogas.

The feedstock for a biogas plant consists mainly of manure, plant material, and industrial residues mixed with water into a slurry that can be transported by heavy-duty pumps and metered into the digester. This slurry is very different from the solid fuels normally used in boilers.

It often will be necessary to supplement the biomass with some slaughterhouse offal in order to keep the gasification process going, when the quality of the biomass feedstock is poor.

### OPERATION

The operation of a biogas plant comprises the following tasks needed for safe and optimal production of biogas:

- Receiving biomass and storing it in storage tanks
- Mixing the different kinds of biomass to extract the maximum energy from the biomass
- Pretreating the biomass to optimize the gas production
- Testing the suppliers' biomass samples for gas potential and dry solid content in order to control contractual issues
- Cleaning the areas where spills may occur
- Routinely checking and calibrating the sensors
- Inspecting the top of the digester daily
- Investigating potential access to new types or suppliers of biomass.

The plant management should update or prepare new contracts with biomass suppliers.

Most biogas plants operate fully automatically, and several safety devices are installed to avoid explosions and accidents. However, there is still a need for people to observe the processes and to ensure that all process units are operating.

The digester does not require any manual labor for its operation. Biomass is mixed in the storage tanks and is automatically pumped into the digester. Following gasification, the biomass residues are automatically emptied from the digester, and the gas is collected in the top of the digesters.

### MAINTENANCE

The biomass used may contain sand and other solid particles, which will influence the operation of pumps, pipes, mixers, valves, tanks, heat exchangers, etc. Pumps and mixers require frequent maintenance since the equipment is subject to wear.

It is normal to have a strategic stock of the most used spare parts for pumps, etc., at the plant.

Normally, it is possible for the staff on-site to replace damaged parts in pumps and to perform daily maintenance. In case of major repairs, experts will be required, or the equipment must be shipped to specialized workshops.

On-site staff will be able to perform routine cleaning, maintenance, and calibration of standard measuring sensors and equipment. However, some flow meters can be critical and so-specialized that expert companies are needed for their calibration and maintenance.

The gas engine generator converting the biogas to electricity and heat normally will be a more or less standard unit, not very different from other stationary internal combustion engines. Based on some basic training and OEM-supplied manuals and schedules, the on-site staff will be able to perform routine monitoring and maintenance work, such as control and change of lubrication oil, control, and simple maintenance of cooling water circuit, etc. Larger overhauls and complicated repairs normally should be contracted to specialized companies.

## *STAFF*

The staff at a biogas plant is limited to three to six persons, depending on the plant size. Since operation is fully automatic, the plant is only manned between 6 a.m. and 6 p.m. On weekends, there is normally no staff, but the alarm system will call for support if there is a breakdown or other irregularities at the biogas plant.

The staff consist of a plant manager and operators. At large biogas plants, a process specialist may be employed to supervise the mixing of biomass types, optimization of the operation, etc.

## *OPERATION AND MAINTENANCE MANUALS*

Each plant should have a set of operation and maintenance manuals. These are the basis for maintenance of the plant since they include information on each component at the plant, such as the pumping capacity, power demand, when oil shall be changed, which type of oil is needed, etc.



Source: COWI.

Energy generation from on-site available biomass residues can be cost competitive with fossil fuels today. However, if the biomass resource needs to be purchased and transported to the production site, the cost difference between biomass and fossil fuels may be too big to allow for cost-competitive bioenergy generation. Many countries therefore are adopting a favorable policy framework to promote the sustainable use of bioenergy for heat and power generation.

This chapter outlines and exemplifies how sector-specific regulatory frameworks may affect biomass-to-energy projects.

## 10.1 PROMOTION OF RENEWABLE ENERGY

The most-used policies to promote renewable energy include:<sup>7</sup>

### *ABOLITION OF FOSSIL FUEL SUBSIDIES*

Fossil fuel subsidies, which in many cases encourage a wasteful use of energy, are being scaled back in many countries. Many countries (such as Ghana, Indonesia, Mexico and Egypt) have abolished or reduced fossil fuel subsidies over the last decade, whereas a number of mainly energy-producing countries retain national fossil fuel subsidies. The abolition of subsidized fossil fuel-based energy for industry contributes positively to biomass project viability.

### *INTRODUCTION OF CARBON PRICING*

One way to level the playing field for biomass-based energy is to price the environmental impacts of fossil fuel through the introduction of a price for carbon dioxide emissions. This may be through a carbon tax (such as those introduced in Australia, China, Denmark, Finland, India, Mexico, South Africa, and Sweden) or through an emission trading scheme (such as those in California, China, the European Union, India, New Zealand, and the Republic of Korea).

<sup>7</sup> For further information, see: IEA, 2011a; IEA, 2012; IEA, 2011b.

### *RENEWABLE ENERGY TARGETS*

Most countries have established an official commitment or goal to achieve a certain amount of renewable energy by a future date. These targets often define a certain share of renewable energy in total energy supply (for example, 20 percent renewable energy by 2020 in Australia and the European Union), rather than referring to specific technologies.

### *RENEWABLE ENERGY MANDATES/OBLIGATIONS*

Some countries have requirements for consumers, suppliers, or generators to meet a minimum target for renewable energy in their energy mix (such as a percentage of total energy consumption). Mandates can, for example, be in the form of obligations that require the installation of renewable energy production capacity, renewable energy purchase requirements, or requirements for blending specified shares of biofuels (biodiesel or bioethanol) into transport fuel.

### *FEED-IN POLICIES*

Feed-in policies typically guarantee renewable generators a specified price per kilowatt-hour of electricity/heat that is fed into the grid over a fixed period. The price level may depend on the specific technology and size of the conversion plants. The feed-in policies may structure the payment as a guaranteed minimum price (a feed-in tariff) or as a payment on top of the market-based wholesale electricity price (a feed-in premium). The feed-in policies are often combined with regulations by which renewable energy generators are ensured priority rights to interconnect and sell power to the grid.

### *RENEWABLE ENERGY CERTIFICATES*

A renewable energy certificate is awarded to certify the generation of one unit of renewable energy (typically 1 MWh of electricity but also, less commonly, of heat). The certificates then can be traded on a separate market and sold to industries or large consumers or retailers that need

to meet their own renewable energy obligations. They also may be sold to consumers who desire to purchase renewable energy voluntarily.

### *RENEWABLE ENERGY TENDERS*

Some countries conduct competitive tenders or auctions for renewable energy capacity, in which project developers propose establishing a certain energy capacity based on a specified renewable energy source at a certain price. Bids may be evaluated on both lowest price and non-price factors, and the tenders typically are combined with long-term power purchase agreements.

### *TAX INCENTIVES OR CREDITS*

Tax incentives for renewable energy are fiscal incentives that improve the viability of a renewable energy generation project through reduction on the tax obligation of the project developer, investor, or owner. This may be in the form of a production tax credit (where the investor or owner of a qualifying renewable energy production facility receives a tax credit based on the amount of renewable energy generated by the facility) or an investment tax credit (which allows investments in renewable energy to be fully or partially credited in the tax accounts).

### *INVESTMENT GRANTS*

Investment grants are financial support mechanisms whereby governments provide direct assistance to reduce the investment costs associated with a specific project. The support can be in the form of grants or loans to aid the development or deployment of renewable energy technologies. These mechanisms are particularly valuable for projects that are perceived to have considerable investment risks (for example, because they are the first of their kind in the country).

### *NET METERING / NET BILLING*

Companies with on-site electricity generation may have periods of excess generation that is sold to the grid and periods where they are dependent on purchasing energy from the grid. In such cases, a regulated arrangement will be useful in which they can receive credits for excess generation to be offset against their consumption at other times. Depending on the individual country, this may be in the form

of net metering (where on-site generators typically receive credit at the level of the retail electricity price) or net billing (where they typically receive credit for excess power at a rate that is lower than the retail electricity price).

### *FLEXIBILITY PREMIUM*

Bioenergy can play a role in balancing a rising share of variable renewable electricity within a grid system such as wind and solar energy. Some large-scale biomass plants are able to react to predictable demand changes and thus provide very important flexibility to the power system. This is the case for biogas and bio-methane that are converted in open-cycle gas plants. They can respond quickly to short-term demand peaks in the power system. However, for solid biomass plants, corrosion and fouling caused by ramping production up and down will imply additional investments or higher operation and maintenance costs. For such biomass plants to be available as a dispatchable, flexible electricity source, these additional costs will need to be compensated through a flexibility premium (such as that applied under the German Renewable Energy Sources Act).

### *SUPPORT FOR BIOMASS SUPPLY CHAIN DEVELOPMENT*

In addition to policy measures addressing the generation part of the supply chain, some countries are addressing upstream investments in feedstock cultivation and biomass refining through the integration of bioenergy and biofuel projects in their agricultural and rural development strategies. This can increase the potential for symbioses between investments in bioenergy and those in agricultural production and can enhance the overall benefits for rural economies.

## **10.2 SALE OF ENERGY TO THE GRID**

To enhance the use of bioenergy, the available supporting policy measures may need to offset the cost difference between conventional coal and biomass and to encourage investments in refurbishing of existing assets and dedicated biomass plants. This is often done through some combination of feed-in tariffs, renewable energy certificates, and renewable energy tenders (Box 10-1).

The specific regulatory framework (for renewable energy in general and for biomass-to-energy in particular) that is in place in the country and sometimes region where a project is located

## Box 10-1: Calculating Biomass-to-Energy Versus Existing Use of Coal

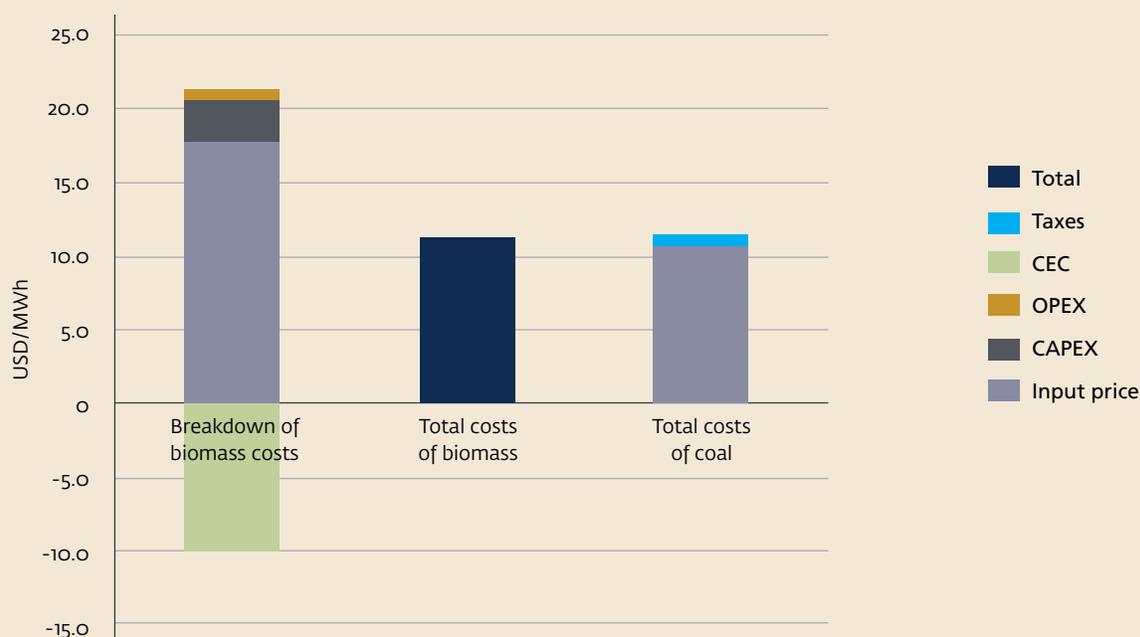
Before investing in the retrofitting of a coal power plant to accommodate co-firing with biomass, it is essential to clarify the financial viability of such an investment. The following calculations provide an indicative estimate of the costs per MWh related to co-firing compared to business as usual. It becomes clear that the investment is financially viable only if there are financial incentives such as a carbon dioxide tax and clean energy certificates (CEC).

The business-as-usual scenario is electricity generation based on coal firing. This scenario applies no additional CAPEX or OPEX, and thus the price per MWh consists only of the costs of coal and the related tax on carbon dioxide emissions for comparison purposes.

The scenario of co-firing with biomass adds a few elements to the equation. First, there is the price of the biomass, including collection and transport. Then, there is the additional CAPEX and OPEX due to the retrofitting of the power plant. Finally, there is the CEC incentive, which is intended to outweigh the additional costs of using biomass for energy generation.

Assumptions	\$/MWh
Average biomass price (assuming 50% coconut husk and 50% sugarcane trash)	18
Coal price	11
CAPEX (including depreciation)	3
OPEX	0.5
CEC	10
Carbon dioxide emission tax	0.2

Assumptions	
Depreciation	10 years
Electrical efficiency	40%
Carbon dioxide emissions	94.6 kg/GJ
OPEX (percentage of investment)	2%



Without the CEC, the co-firing solution is significantly more expensive than the business-as-usual scenario. However, including the CEC, the total cost of the co-firing solution becomes lower than the business-as-usual scenario, indicating that, subject to the assumptions, a co-firing solution is financially viable and a sound investment.

Therefore, project developers should, at an early stage of the project development process, seek to identify and understand the specific regulatory framework in place for biomass-to-energy in their country and region.

Source: COWI.

will often become an important determinant of a project’s financial viability. Box 10–1 shows the impact of a combination of a carbon dioxide tax and renewable energy certificates on the viability of a coal-to-biomass conversion project.

As shown in Box 10–1, a biomass-to-energy retrofit project selling excess electricity to the grid cannot always compete based on a direct comparison with the cost of fossil fuel. But when the supportive measures of the regulatory framework are taken adequately into account, it may be quite attractive.

Table 10–1 provides an overview of the renewable energy support policies in selected developing countries and emerging economies (2015 data). Note that many developing

countries and emerging economies have comprehensive regulatory support regimes in place.

In this context, firm economic support measures, such as a price for carbon dioxide, feed-in tariffs, renewable energy certificates, and renewable energy tenders will have a more direct impact on project financial viability than softer policies such as renewable energy targets.

### 10.3 REGULATORY RISKS AND THEIR MITIGATION

Table 10–2 presents the key regulatory risks (and opportunities) faced by biomass-to-energy projects and suggests strategies for their mitigation.

**Table 10-1: Overview of the Renewable Energy Support Policies in Selected Countries, 2015**

Country	Renewable Energy Targets	Price for Carbon Dioxide	Feed-in Tariffs	Renewable Energy Mandates/Obligations	Net Metering/Net Billing	Renewable Energy Certificates	Renewable Energy Tenders	Investment Grants	Tax Incentives or Credits
Argentina	✓		✓		✓		✓	✓	✓
Brazil	✓			✓	✓		✓	✓	✓
China	✓	✓	✓	✓			✓	✓	✓
Colombia	✓			✓	✓			✓	✓
Ghana	✓		✓	✓		✓		✓	✓
India	✓	✓	✓	✓	✓	✓	✓	✓	✓
Indonesia	✓		✓	✓			✓	✓	✓
Mexico	✓	✓	✓		✓	✓	✓	✓	✓
Nepal	✓		✓			✓	✓	✓	✓
Nigeria	✓		✓	✓				✓	✓
Pakistan	✓		✓	✓	✓	✓		✓	✓
Peru	✓		✓	✓			✓	✓	✓
South Africa	✓	✓		✓			✓	✓	✓
Sri Lanka	✓		✓	✓	✓			✓	✓
Turkey	✓		✓	✓				✓	
Uganda	✓		✓				✓	✓	✓
Vietnam	✓		✓	✓		✓		✓	✓

Source: REN21, 2015.

Table 10-2: Regulatory Risks	
Regulatory Risk	Strategy for Mitigation
Availability of policy support measures necessary for project viability	<p>Seek early engagement with relevant authorities in relation to eligibility, process, and terms for policy support measures.</p> <p>Key points to consider are:</p> <ul style="list-style-type: none"> <li>• Is the country/region generally supportive of renewable energy?</li> <li>• Are there support mechanisms in place (most importantly feed-in tariffs, but also renewable energy certificates, taxes on carbon dioxide, renewable energy tenders, renewable energy mandates/obligations, investment grants, or tax incentives)?</li> <li>• Are policies limited in time, and what are the procedures for benefiting?</li> </ul>
Changes in political priorities that may reduce attractiveness of regulatory regime	The best insurance against adverse changes in the regulatory regime (such as a reduction in or abolition of feed-in tariffs) is to seek contractual security on regulatory regime aspects that are essential to project viability at the time of the investment decision.
Planning permits are not obtained in a timely and transparent manner	<p>Seek early engagement with relevant authorities on process and documentation need.</p> <p>National support for projects and engagement with international donors also may help ensure transparency of permitting procedures.</p>
Environmental impact assessment process is smooth and predictable	Seek early engagement with relevant authorities and key stakeholders (including nongovernmental organizations and local communities) on the project's environmental and social aspects and on how to mitigate any adverse effects.

Source: COWI.



Source: COWI.

This chapter focuses on the contractual framework for biomass and the sale of excess power or steam/heat. This is important for biomass-to-energy projects that are dependent on an external biomass supply to supplement on-site waste from the production process or where the project is dependent on the external sale of produced energy (beyond the direct substitution of energy used in the on-site production process).

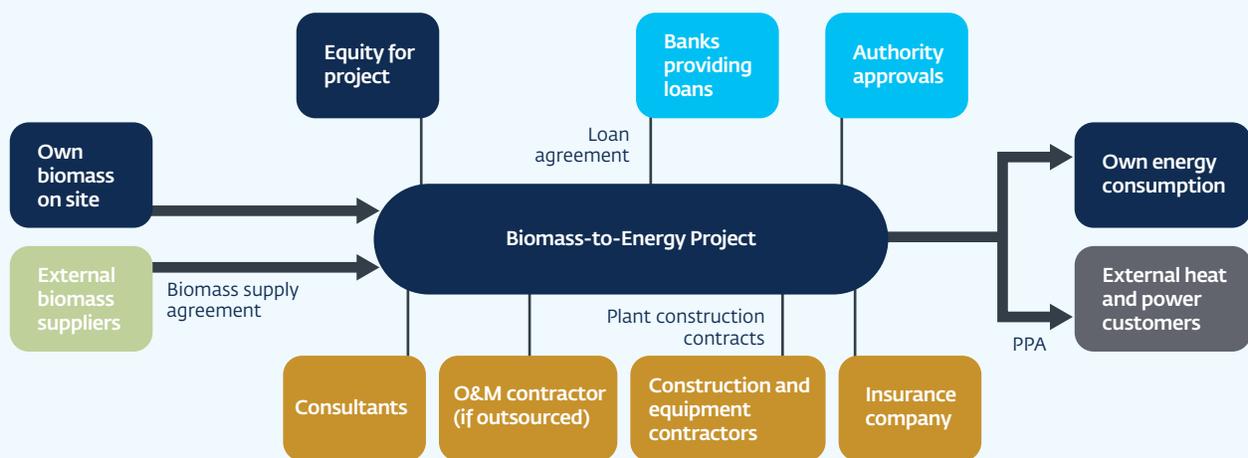
Formalizing the agreements with suppliers and offtakers is essential for ensuring a robust financially viable project. Once the key terms have been established, the project developer will have concrete knowledge of the input and output of the plant. This will enable the developer to conduct a realistic financial analysis, which is the basis for a bankable feasibility study to be used for ensuring financing. Chapter 14 goes in-depth on the requirements for obtaining financing, but a robust business case is definitely the key.

Figure 11–1 illustrates the structure of a biomass-to-energy project and the commercial contracts/agreements that are necessary to ensure a stable supply of biomass and access to a market for energy produced, but not used, by the project owner. These commercial contracts/agreements are the biomass supply agreements, the power purchase agreement, potential steam/heat agreements, and the bio-residue disposal agreement.

## 11.1 BIOMASS SUPPLY AGREEMENTS

A biomass supply agreement is essential for ensuring a viable biomass-to-energy project, if the necessary biomass is not owned by the project owner. If the supply of biomass fails, the whole operation of the plant stalls, with severe financial consequences to follow. The agreement is entered between the biomass-to-energy project and one or more

**Figure 11-1:** Commercial Agreements



Source: COWI.

external biomass suppliers. The most important factors to incorporate in a biomass supply agreement are the following:

- Quantity of biomass (tons per day, delivered on-site) and what happens if the supplier does not supply biomass in accordance with the agreement
- Quality of biomass (typically weight and moisture content), how quality is determined, and what happens if the specifications are not met
- Price of biomass (dollars per ton) and how the price varies with quality parameters
- Place of delivery (ideally on site)
- Rejection criteria and consequences of late delivery.

Besides being self-sufficient in biomass supply, the preferable situation would be to have one stable biomass supplier, so the owner has only one agreement to manage. The chosen biomass supplier will then be responsible for subcontracting with other suppliers, collecting and transporting the biomass, and delivering the agreed amounts of biomass at the agreed quality and price.

The example in Box 11–1 outlines the structure and the most common aspects of a biomass supply agreement.<sup>8</sup>

## 11.2 POWER PURCHASE AGREEMENTS

When a biomass-to-energy project generates power beyond the owner's energy needs, a power purchase agreement (PPA) can be entered into between the biomass-to-energy project acting as an independent power producer and a purchaser of power (often a state-owned electricity utility).

The PPA is a long-term agreement that lays down key commercial provisions for energy prices and sales quantities during a given period. Such agreement provides both the project owner and the energy purchaser with a level of security and stability, by eliminating otherwise unknown market factors. This allows the biomass project to secure a revenue stream that can provide comfort to lenders.

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<sup>8</sup> Examples of bulk fuels supply agreements are available at: <http://ppp.worldbank.org/public-private-partnership/sector/energy/energy-power-agreements/bulk-fuel-supply-agreements> and <http://www.carbontrust.com/resources/guides/renewable-energy-technologies/bio-mass-heating-tools-and-guidance>.

Key elements of a PPA include the following:

- Required quality of the power (frequency, voltage, planned outage)
- Quantities of capacity and energy sold (MWh per year)
- Price of electricity output (dollars per MWh) and available capacity (if the project is perceived as baseload), the price may reflect special feed-in tariffs for renewable energy and renewable energy credits (see Section 10.2)
- Flexibility for producer to make third-party sales (if allowed by the purchaser)
- Compensation to producer in case of production limitations (by purchaser or transmission system operator) due to constraints in transmission system
- Compensation to purchaser in case of delays in completion of project or underperformance of delivery (may include sanctions or liquidated damages for projects being perceived as baseload)
- Timeframe of the agreement (typically five years or more)
- Dispatching rules, including potential restrictions.

Further to this, the infrastructure cost of transmission and connection to the nearest suitable grid-access point should be estimated and agreed. For projects where the prime purpose is energy production for own use and only residual energy is sold to the grid, the cost of the transmission line and connection costs typically will have to be funded by the project.

For biomass projects that are dependent on the sale of electricity to third parties, negotiating an acceptable PPA is a key step in the project development, and the PPA therefore should not be entered into without the advice of experienced legal counsel. The PPA is a mandatory part of the documentation to reach a financing agreement.

The example in Box 11–2 outlines a typical structure of a PPA. PPAs for grid tie-in of renewable energy sources are often regional or national standard documents developed by (or on behalf of) the transmission system operator.<sup>9</sup>

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<sup>9</sup> Examples of PPAs are available at <https://ppp.worldbank.org/public-private-partnership/sector/energy/energy-power-agreements/power-purchase-agreements>

## Box 11-1: Example of the Structure of a Biomass Supply Agreement

### Contract between [SUPPLIER] and [END USER] for the supply of solid biomass to [SITE]

#### 1. Purpose

The supplier agrees to supply to the end user, and the end user agrees to purchase from the supplier, biomass to the specifications, in the quantities, for the period, at the price, and on the terms and conditions set out below.

#### 2. Duration of contract

This contract is for a period of [XX MONTHS/YEARS] and will commence on [DATE] and end on [DATE].

#### 3. Quantity

The minimum monthly quantity of biomass supplied during the defined contract will be [XX] cubic meters [OR XX TONS]. In case of a shortfall in the biomass available to the supplier, the supplier shall be responsible for [SOURCING FROM THIRD PARTIES/PAYING COMPENSATION].

#### 4. Source and delivery

The biomass will be derived from the following sources: [insert as appropriate].

Biomass will be supplied in [BAGGED/BALED/LOOSE] form and delivered to the end user by a suitable vehicle for delivery into the end user's fuel store.

#### 5. Quality and specifications

Regulating key quality parameters such as, for example, moisture content.

The target moisture content on a wet basis shall be [XX%] by weight based on the [relevant standards] but in any event shall not exceed [YY%]. In case of delivered biomass not meeting the minimum specifications as determined through sampling, the supplier shall be responsible for [COMPENSATION].

#### 6. Weights, sampling, analysis

The end user may at any time send representative samples of biomass for evaluation, analysis, testing, and approval. All samples must meet the specification.

#### 7. Price

The price for biomass delivered into the fuel store of the end user will be based upon the following tariff up until [DATE] \$ [XX] per cubic meter of biomass; [OR: \$ XX PER TON OF BIOMASS]. For biomass complying with minimum specifications but with a moisture content above [ZZ%] the price shall be [ADJUSTED PRICE].

#### 8. Invoices, billing, payment

The supplier will invoice the end user on a monthly basis. This will be based upon the number of loads recorded (by weight or volume) and will be assessed on the XX day of each month.

#### 9. Insurance

The supplier will have adequate public liability insurance for handling and transport of the specified quantities of biomass. The responsibility for insuring the end user against the economic consequences of a possible inability of the supplier to meet the contractual obligations shall be with [END-USER/SUPPLIER]. Irrespective of this, the supplier shall in case of default of the obligations under this contract pay the end user a penalty defined as [definition of penalty upon default].

#### 10. Event of dispute

#### 11. Termination

#### 12. Force majeure

#### 13. Representation

#### 14. Governing law and jurisdiction

Source: COWI.

## Box 11-2: Example of the Structure of a Power Purchase Agreement

### PPA between [PRODUCER] and [PURCHASER] for the supply of power from [FACILITY]

- Purpose
- Facility description
- Interconnection facilities and metering
- Obligation to sell and purchase energy output
- Payment for energy output
- Supporting regulatory framework (feed-in tariff, purchase obligations, etc.)
- Billing and payment
- Operation and maintenance
- Default and termination
- Contract administration and notices
- Dispute resolution
- Force majeure
- Representations and warranties
- Insurance and indemnity
- Regulatory jurisdiction and compliance
- Assignment and other transfer restrictions
- Confidential information
- Miscellaneous

Source: COWI.

## 11.3 STEAM/HEAT SUPPLY AGREEMENT

For biomass projects with excess production of steam/heat (hot water), sales to a nearby industry may supplement the project revenues. A steam/heat supply agreement defines the key commercial terms concerning steam/heat prices and sale quantities during a given period and provides both the project owner and energy purchaser with a level of security and stability.

The heat supply agreement should include and define the following elements:

- Steam/heat parameters (temperature/pressure) and maximum variations
- Quantities of heat sold (MWh per year)
- Price of heat (dollars per MWh)
- Responsibility for investment costs for the heat transfer infrastructure between the heat supplier and the heat user
- Timeframe of the agreement (years).

Box 11-3 outlines the structure and the most common aspects of a heat supply agreement.<sup>10</sup>

## 11.4 BIO-RESIDUE DISPOSAL AGREEMENT

The ash residues from the combustion process, or the de-gassed bio-slurry from biogas production, must somehow be disposed of.

<sup>10</sup> A template heat supply agreement can be found at: [https://www.carbontrust.com/media/74612/revised\\_contract\\_for\\_supply\\_of\\_heat\\_energy.doc](https://www.carbontrust.com/media/74612/revised_contract_for_supply_of_heat_energy.doc).

If treated properly, bio-residues from the energy production may have the same qualities as a fertilizer.<sup>11</sup> In some situations, the bio-residues might be of such high quality that the project owner will be able to obtain a price for them. However, in most cases, the local farmers will be willing to collect the bio-residues free of charge. Thus, the project owner will gain by saving both transport and disposal of the residues from the energy generation.

This disposal of the bio-residues shall be formalized to ensure that the project owner will not face an unexpected capacity/storage issue or any extra disposal costs if the regular users find another supplier. The project owner may be forced to commit to many user agreements, to meet production demand.

The bio-residue disposal agreement should specify the following:

- Quantities of the bio-residue (tons per day)
- Quality of the bio-residue (nutrient value)
- Price (or cost of disposal) of the bio-residue (dollars per ton).

<sup>11</sup> For ash residues, this is the case for bottom ash, whereas fly ash will contain substances that may require it to be managed as waste. For further discussion of ash utilization, see: [http://www.ieabcc.nl/publications/ash\\_utilization\\_kema.pdf](http://www.ieabcc.nl/publications/ash_utilization_kema.pdf) and [http://www.biomassenergycentre.org.uk/pls/portal/docs/page/practical/using%20biomass%20fuels/emissions/ash/ash%20laymans%20report\\_english.pdf](http://www.biomassenergycentre.org.uk/pls/portal/docs/page/practical/using%20biomass%20fuels/emissions/ash/ash%20laymans%20report_english.pdf).

### Box 11-3: Example of the Structure of a Heat Supply Agreement

#### **Agreement between [SUPPLIER] and [HEAT USER] for the supply of heat energy derived from biomass**

##### **1. Purpose**

The supplier agrees to supply to the end user, and the end user agrees to purchase from the supplier, heat energy generated from biomass to the specifications, for the period, at the price, and on the terms and conditions set out below.

##### **2. Duration of contract**

This agreement is for a period of [XX YEARS] and will commence on [DATE] and end on [DATE].

##### **3. Facility description**

The heat supply facilities of the supplier, the heat using facilities of the [HEAT USER], and the interconnecting facilities between them are described in [SCHEDULE].

##### **4. Interconnection facilities and metering**

Investment in and subsequent operation and maintenance of the interconnection between the boiler and the heat user is the responsibility of [SUPPLIER/HEAT USER].

The installation and effective operation of an appropriate heat meter to record heat output from the boiler is the responsibility of [SUPPLIER/HEAT USER].

##### **5. Quantity of heat**

The minimum heat purchase during the defined contract period will be [AMOUNT] megawatt hours (MWh) per [UNIT OF TIME] (the minimum total offtake).

##### **6. Obligation to sell and purchase heat**

The supplier is required to sell heat energy based on the predicted annual demand and at the tariff specified in the contract, unless [SPECIFIC CONDITIONS].

The heat user is required to purchase heat energy based on the predicted annual demand and at the tariff specified in the contract, unless [SPECIFIC CONDITIONS].

##### **7. Price for heat delivered**

The price for heat delivered to the end user will be based upon the following tariff(s): \$ [XX] per MWh per unit of heat used within the minimum total purchase and \$ [YY] per MWh per unit of heat used above the minimum total purchase.

##### **8. Billing and payment**

The supplier will invoice the heat user on a monthly basis on the [XX] day of each month based upon the tariff structure and the measured heat consumption.

##### **9. Insurance and indemnity**

The supplier will indemnify the heat user against any damage to the heat user's facilities caused by the supplier or his agents within a total maximum of [MAX. INDEMNITY]. The supplier will have public liability insurance of [INSURANCE AMOUNT].

##### **10. Event of dispute**

##### **11. Default and termination**

##### **12. Force majeure**

##### **13. Representations and warranties**

##### **14. Governing law and jurisdiction**

Source: COWI.



Source: COWI.

The aim of this chapter is to provide an indication of capital costs (CAPEX) and operation and maintenance costs (OPEX) for a biomass-to-energy plant and to compare alternatives. These cost indications are intended to assist project developers and investors with the initial assessment of a candidate project in order to decide at an early stage whether to proceed with the project. Actual costs will depend strongly on several factors, and a more detailed and precise analysis of cost structure and cost level should be made at a project-specific level. Such cost analysis should be performed during the pre-feasibility and feasibility phases, as detailed in Chapter 2.

This chapter presents the factors influencing the investment costs for a project, along with generalized CAPEX and OPEX estimates for the main technology groups described in Chapter 5:

- Steam cycle
- ORC
- Biogas plant.

The estimates presented use cost estimates published by the International Renewable Energy Agency (IRENA, 2015) and cost estimates made by COWI based on other available open-data sources and a number of specific projects.

## 12.1 FACTORS INFLUENCING INVESTMENT COSTS

A large number of factors determine the level of investment cost (CAPEX) for a biomass plant. These factors can be roughly categorized as: site specific, plant specific, and local conditions.

### 12.1.1 SITE-SPECIFIC ISSUES

There will always be site-specific issues that must be considered during the project development. For a biomass plant, these include:

### *INTEGRATION/SYNERGIES WITH OTHER INDUSTRIES*

One of the most important issues to consider is the possible integration or joint operation with a host or nearby industry, which may supply the fuel and/or be the primary customer for the produced electricity or heat. The integration also may include operational and maintenance staff and facilities, such as the control room, workshops, management, administration, staff rooms, etc.

### *FUEL HANDLING AND STORAGE FACILITIES ON-SITE*

If residual products or waste from an industrial operation are the partial or main source of fuel for the biomass plant, some facilities for handling, storage, and pretreatment will probably already be available.

### *GREENFIELD OR EXISTING SITE*

If the plant is to be built on an existing site, some infrastructure may already be in place, such as roads, harbor, water supply, sewage water system, grid connection, etc.

### *CAPTIVE POWER CONSIDERATIONS*

In this context, the access to energy produced from biomass residues may reduce the need for reliance on potentially unstable local electricity grids or the need for heat and power production based on expensive imported fossil fuels.

### 12.1.2 PLANT-SPECIFIC ISSUES

A number of issues related to the specific plant must be analyzed during the pre-feasibility and feasibility phases of the project in order to establish a good investment estimate. The main issues to consider during the project development phase are:

#### *PLANT SIZE*

For plants of similar type and location, the specific costs will generally decrease with increasing plant capacity due to economies of scale.

## FUEL TYPE

Homogeneous fuel with high density and small needs for pretreatment requires a lower investment. The need for covered storage, pretreatment, and mixing will increase investment.

## TECHNOLOGY

Boiler type and the choice of steam cycle or ORC must be made based primarily on the type and amount of fuels available. Fuel type also will influence the choice of flue gas cleaning equipment.

## COOLING OF CONDENSER

Access to cooling water may reduce investment and operation and maintenance costs compared to the use of cooling towers or air-cooled condensers.

## COMBINED HEAT AND POWER PRODUCTION (CHP)

Back-pressure turbines delivering all exhaust steam as a heat source for industrial process will reduce the need for cooling towers or air coolers compared to condensing plants designed for electric power production only. Adding steam extraction for supply of industrial process heat or district heat may add investment costs compared to a condensing plant for power production only.

## DEGREE OF AUTOMATION

The degree of automation should be balanced with the salary and skills of local operators.

## REQUIREMENTS FOR EFFICIENCY

Requirements for maximizing the net electrical output of the biomass plant for a fixed amount of fuel will result in a higher CAPEX.

### 12.1.3 ISSUES REGARDING LOCAL CONDITIONS

Investment costs are very dependent on conditions, which vary among countries and regions, including:

#### LOCAL MARKET FOR CONTRACTORS AND EQUIPMENT SUPPLIERS

The price of equipment and availability of qualified contractors and equipment suppliers and skilled workers differ across countries and regions.

## AUTHORITY REQUIREMENTS

Authority requirements with regard to planning procedures and environmental issues (for example, emissions and water supply) are important cost factors. They also can be of great importance for the project time schedule.

Figure 12–1 shows investment costs for plants of different sizes and for different regions. For some of the data points, the applied technology is indicated. Note that the Asian projects are mainly Chinese. Furthermore, authority requirements for, for example, the environment may vary among countries and regions.

There is a substantial difference in the specific investment costs among regions, with Asia having the lowest costs and Europe having the highest costs. Differences in the costs of local labor and materials are among the main determining factors. However, there also is a general difference in complexity, efficiency, and quality of the plants.

## INVESTORS HAVE A CHOICE OF DIFFERENT APPROACHES:

- Use local contractors for design and manufacture and installation of equipment
- Use local contractors for manufacture and installation, but use design based on license and/or consultancy from OECD countries; investors from OECD countries often choose this option when investing in other regions.
- Use design and EPC or main contractors from OECD countries with, for example, Asian contractors as subcontractors for specific equipment (mostly used for projects within OECD countries).

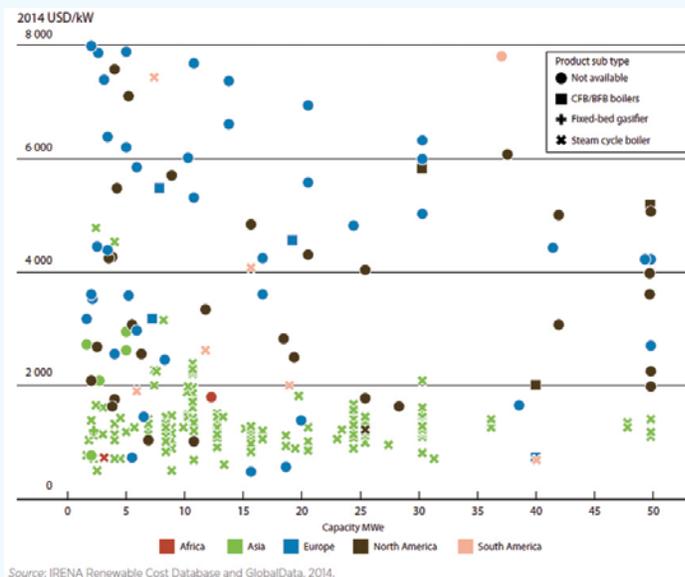
## 12.2 INVESTMENT COST (CAPEX) ELEMENTS

This section presents the CAPEX elements and sizes across the three main technology types: steam-cycle, ORC, and biogas plants.

The project development phases will clarify the project definition and enable the preparation of a more detailed investment budget with a breakdown of costs into the actual components.

Publicly available investment data from IRENA and similar sources are most often presented on a highly aggregated level.

**Figure 12-1: Investment Costs for Plants of Different Sizes and for Different Regions**



Source: IRENA, 2015.

Investment data also may be unclear regarding the technology, actual cost elements included, and country or geographical situation of the projects presented.

### 12.2.1 CAPEX COST ESTIMATES

Table 12-1 presents the main CAPEX groups and sub-items for a typical biomass plant. The table only shows investment elements “inside the fence” of the plant site.

Other project-specific elements that are not included in the following cost estimates are:

- Site purchase
- Fuel collection and logistics for delivery to plant site
- Transmission lines and other grid connection outside plant site
- Pipelines for heat delivery outside the plant site (steam or district heating)
- Costs of financing.

These additional costs should always be included in the financial analysis, as explained in Chapter 13, but they are excluded here to enable comparability between cost estimates.

### CAPEX ESTIMATES ACROSS TECHNOLOGIES

Table 12-2 presents typical CAPEX estimates for plants differing across technologies and size. These data are collected by COWI based on experience from a number of

**Table 12-1: Main CAPEX Groups and Sub-items for a Steam-cycle Plant**

Main Item	Sub-item
Project development	Design and engineering
	Supervision
	Environmental assessment
	Administration
Storage and handling of fuel and residual products	Fuel handling equipment
	Pretreatment of fuel
	Storage for fuel and ash
Main process equipment	Boiler
	Flue gas cleaning
	Turbine
	Electrical systems
	Controls and instrumentation
	Balance of plant (BOP)
Civil works	Buildings
	Roads on-site

Source: COWI.

**Table 12-2: Typical Investment Costs (CAPEX) on a European Basis**

Plant Size (MWe)	Steam Cycle CAPEX (\$/kW)	ORC CAPEX (\$/kW)	Biogas CAPEX (\$/kW)
1–5	5,000–10,000	3,000–8,000	3,500–6,500
5–10	4,000–8,000	2,000–5,000	n.a.
10–40	3,000–6,000	n.a.	n.a.

Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.

mainly European projects and on information from dialogue with various contractors and suppliers.

### COST DISTRIBUTION OF CAPEX

Table 12-3 shows an estimate of how the main investment costs are distributed on the main CAPEX items. The estimates are based on experience from a number of European projects.

Figures 12-2, 12-3, and 12-4 show a model calculation illustrating how typical investment costs vary with the size of

the plant and the geography. The highest CAPEX costs are found in the European Union, the United States, and South Africa. China and India have a typical CAPEX of one-third of the EU prices, whereas the remaining countries (rest of the world) lies in between.

### 12.3 OPERATION AND MAINTENANCE COSTS (OPEX)

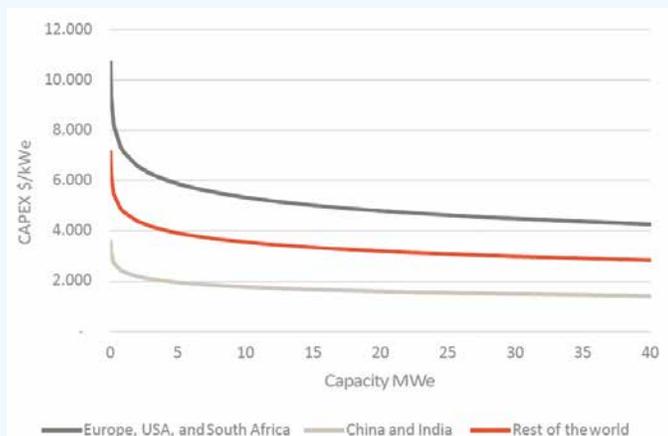
The operational and maintenance expenditures for a biomass plant across the three technology types may be divided into four subcategories:

**Table 12-3: Example of Cost Distribution of the Main CAPEX Items for Biomass Plants**

Main Item	Sub-item	Steam Cycle (% of CAPEX)	ORC (% of CAPEX)	Biogas (% of CAPEX)
Project development	Design and engineering	10	10	10
	Supervision			
	Environmental assessment			
	Administration			
Storage and handling of fuel and residual products	Fuel handling equipment	7	10	20
	Pretreatment of fuel			
	Storage for fuel and ash	3		
Main process equipment	Boiler	15	20	
	Biogas process plant			30
	Flue gas cleaning	5		
	Turbine/generator	15		
	ORC module		20	
	Engine/generator			15
	Electrical systems	7		
	Controls and instrumentation	3		
	Balance of plant (BOP)	15	20	10
Civil works	Buildings	20	20	15
	Roads on site			

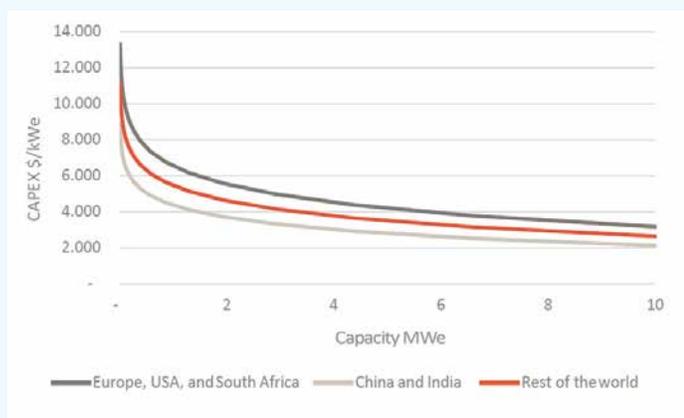
Source: COWI.

**Figure 12-2:** Range of Typical Investment Costs (CAPEX), Depending on Plant Size, for Steam Cycle



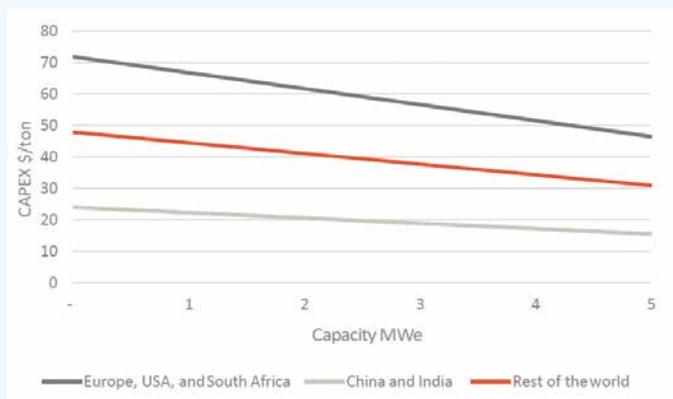
Sources: Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.

**Figure 12-3:** Range of Typical Investment Costs (CAPEX), Depending on Plant Size, for ORC



Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2014; COWI.

**Figure 12-4:** Range of Typical Investment Costs (CAPEX), Depending on Plant Size, for Biogas



Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.

### VARIABLE OPERATIONAL COSTS

These are costs related to consumables, electricity consumption, disposal of residues, etc. that are directly linked to the amount of fuel used and the amount of energy produced.

### VARIABLE MAINTENANCE COSTS

These are costs related to the maintenance of process equipment, such as fuel handling, boiler, turbine/generator, flue gas treatment, etc. They depend, to a certain extent, on the amount of fuel used and the amount of energy produced.

The costs may be averaged over the plant lifetime, but, in practice, costs will vary from one year to the other. The annual maintenance cost has substantial variations over the plant life. During the first few years, some of the equipment will still have to be repaired, or even exchanged under the contractor's guarantee. During the plant life, some years will show considerable maintenance costs for major repairs or equipment refurbishment, but compensated by less-than-average costs in other years.

These costs do not include the salary, etc., for the plant's in-house maintenance personnel, which is usually accounted for together with the plant's other staff. A large plant will normally have in-house staff with the skills to deal with all or most day-to-day maintenance requirements. A smaller plant typically will have less in-house capabilities and therefore will depend more on outside contractors and service companies.

### FIXED OPERATIONAL COSTS

These costs are related to operational costs independent of the amount of fuel used and the amount of energy produced, for example, salaries, insurance costs, electricity consumption for lighting, ventilation and other consumption linked to non-process equipment.

### FIXED MAINTENANCE COSTS

These costs are related to maintenance of non-process equipment, which needs to be maintained independently of the amount of fuel used and the amount of energy produced, such as buildings and roads.

The costs described above do not include:

- Financing costs
- Costs of fuel purchase.

Typical insurance costs may amount to approximately 1 percent of CAPEX per year. However, they can vary considerably with local conditions and requirements from financing institutions.

### 12.3.1 OPERATION AND MAINTENANCE COST ESTIMATES

Unfortunately, the available data often merge fixed and variable operation and maintenance costs into one number, thus rendering a breakdown between fixed and variable costs impossible.

Table 12–4 shows data collected by IRENA for plants based on various types of plants with steam boilers and turbines, as well as for biogas plants.

Fixed operation and maintenance costs of larger plants can be expected to be lower per kilowatt due to economies of scale, especially for labor.

Table 12–5 presents typical OPEX estimates for different biomass-to-energy technologies and sizes. These data were collected by COWI based on experience from a number of mainly European projects and on information from dialogue with various contractors and suppliers.

**Table 12-4:** Operation and Maintenance Costs (OPEX)

	Fixed O&M per Year (% of CAPEX)	Variable O&M (2014 \$/MWh)
Stoker/BFB/CFB boilers	3.2	4–5
Biogas	2.1–3.2 2.3–7	4.4

Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.



Source: <http://jfe-project.blogspot.dk/>.

**Table 12-5: Typical Operation and Maintenance Costs (OPEX) on a European Basis**

Plant Technology	Plant Size (MWe)	OPEX Fixed Costs per Year (% of CAPEX)	OPEX Variable Costs (\$/MWh)
Steam boiler and turbine	1–5	3–6%	3–7
	5–10	3–6%	3–7
	10–40	3–6%	3–7
ORC	1–5	2–3%	5–10
	5–10	1.5–2%	5–10
Biogas	1–5	Included in variable costs	20–40
	5–10		

Sources: Turboden, 2016; Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.



Source: DP Clean Tech Group, [www.dpcleantech.com](http://www.dpcleantech.com).

- Name and location:** Mahachi Green Power Plant, Thailand
- Project:** Power plant using coconut residues in the Samut Sakhon province in Thailand
- Description:** Grate-fired boiler with high efficiency (90 percent) producing electricity for the grid.
- Boiler data:** 92 bar / 537 °C / 40 tons of steam per hour
- Turbine output:** 9.9 MW gross power output
- Fuel:** Coconut residues (husk, shell, bunch, frond, leaves, trunk)



Source: COWI.

The decision to implement a biomass project follows an assessment of the viability of the project in terms of technological, organizational, environmental, economic, and financial aspects. Once a project has been analyzed in the areas mentioned above, the project developer can commence the construction phase.

Financial analyses and economic analyses are both essential approaches when assessing a biomass project. Both analyses provide the ability to compare different technical and financing solutions from both an investor perspective and a regulator (society) perspective. A financial and economic analysis should always include a comparison to a “business-as-usual” scenario.

#### Business as usual

A business-as-usual scenario could contain the following elements:

- Current costs of energy, either market price for electricity and heat or cost of own-production based on coal, oil, or gas
- Stability of current energy supply
- Current costs and other issues related to biomass residue storage and disposal
- Planned reinvestment costs in existing plant.

A financial analysis assesses the financial viability of a project by evaluating the costs and benefits of the project from the investor’s perspective.

One main indicator for a biomass project to be a financially sound investment is a return on the investments equal to or higher than the investor’s weighted average cost of capital (WACC). Other financial indicators are the net present value (NPV), the internal rate of return (IRR), the economic levelized cost of electricity (LCOE), the debt service coverage ratio (DSCR), and the payback period, all of which are explained and processed in this chapter.

An economic analysis evaluates a project’s impact on society by valuating its costs and benefits to the overall economy. An economic analysis compares a baseline scenario, without the project, to a scenario where the project is implemented, assessing the effects, including quantifying externalities (such as social or environmental effects) in monetary terms. If the net benefit of a project is positive, then the project will have an overall positive effect on society, despite the results of the financial analysis.

The shaded box below summarizes the difference between a financial and an economic analysis. Projects with large benefits to society (for example, reduction in greenhouse-gas emissions through the use of secondary or tertiary biomass instead of coal or oil) will most likely have a better economic result compared to the financial result. Projects using primary biomass for energy production may cause an increase in greenhouse-gas emissions or cause a rise in food prices. They may result in a positive financial business case, but might have a negative economic business case.

Additional information on financial and economic analyses can be found in the World Bank publication *Economic Analysis of Investment Operations: Analytical Tools and*

#### Financial analysis:

- Investor’s perspective
- Based on market prices
- Including taxes, tariffs, subsidies, etc.
- Does not include externalities
- Important for both small- and large-scale biomass projects

#### Economic analysis:

- Society’s economic perspective
- Applies economic prices excluding taxes, tariffs, subsidies, etc. to reflect the value of the project to society
- Externalities (positive and negative) are included and quantified in monetary terms (such as reduction in greenhouse-gas emissions, if applying secondary biomass)

*Practical Applications* and in the Asian Development Bank publication *Guidelines for the Economic Analysis of Projects*.

When assessing financial and economic analyses, there are specific basic aspects that are essential for ensuring a viable project. If these aspects are in place when initiating the project, the probability of a successful project will increase significantly.

The key elements to ensure that the biomass project is financially sustainable are:

- A secure and stable supply of quality biomass feedstock is available.
- There is easy access to a stable market for the produced electricity and/or heat.
- Available biomass volumes are sufficient to justify the technology and scale of operation.
- Biomass is available as process residues (at zero or low costs) or the cost of collecting, transporting, and storing biomass can be financed by the project.
- Cost of pretreatment can be financed by the project.
- Access to financing is at affordable rates and acceptable terms.

The economic analysis adds a few important aspects for a sustainable project, in addition to those mentioned in the financial analysis. The key elements to ensure an economically viable biomass project are:

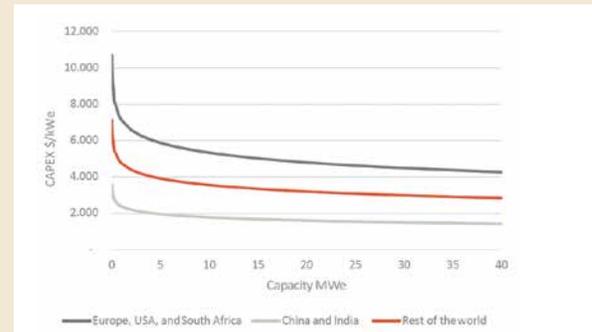
- The biomass applied for the energy production has no current alternative use that will cause social impact if removed (for example, as food, feed, or fuel).
- The biomass supply is based mainly on residual biomass (secondary and tertiary biomasses), in order to realize climate and environmental benefits.

### 13.1 FINANCIAL ANALYSIS OF BIOMASS PROJECTS

A financial analysis estimates the overall financial viability of a project from an investor's perspective. This section describes general key assumptions for a financial analysis, the theoretical methodology, results, and outputs, along with practical examples.

#### Economies of scale for biomass projects:

There are significant economies of scale, varying across technologies, when comparing small and large biomass-to-energy plants. It is important to be aware of this when conducting financial and economic feasibility analyses. The marginal costs of producing one kilowatt hour decrease as the capacity of the plant increases, as illustrated in the graph below of steam-cycle plants. This is also described in detail in Chapter 12.



Source: Danish Energy Agency and Energinet.dk, 2015; Ea Energianalyse, 2014; IRENA, 2015; COWI.

Hence, subject to availability of sufficient volumes of biomass and demand for the produced energy, a larger plant will, all other things equal, be more cost efficient.

A financial analysis of a biomass project will include a range of indicators in order to allow developers, lenders, investors, and relevant government bodies to assess the project's financial viability.

An investor considers a project to be a viable investment if the internal rate of return is higher than the weighted average cost of capital. Investors will have access to capital at a cost (hurdle rate of return); the return from the investment of that capital must be enough to meet these costs. Furthermore, the investment should generate a profit, compensating the risk levels of the project.

#### Risks related to the financial viability of biomass projects:

- Unstable supply of biomass
- Insufficient quality of biomass
- Poor market access for end products
- No access to finance at competitive terms (for example, due to an inexperienced finance market that is unfamiliar with investments in biomass projects)
- Need for collection, transport, and pretreatment of biomass feedstock.

### 13.1.1 METHODOLOGY AND KEY ASSUMPTIONS

The methodology used in a financial analysis applies a series of assumptions relating to the biomass-to-energy sector. This section presents the sector-specific methodology and the assumptions and explains their origin and importance. It is important to perform a sensitivity analysis on all crucial assumptions of the analysis, as explained in Section 13.3.

The overall approach to a financial analysis is to compare the costs of the project to the expected revenue over the project lifespan, including the costs of financing and taxes/subsidies. Figure 13–1 illustrates the approach to a financial analysis.

Figure 13–2 illustrates investment costs, operation and maintenance costs, biomass purchase, and sales of heat and power.

#### WACC

The return of a project shall be compared to the alternative return, given that the money is invested elsewhere. Therefore, the appropriate discount rate for a financial assessment is the **weighted average cost of capital**, often referred to as the WACC.

The WACC is calculated using the following formula:

$$\text{WACC} = \text{Share of Equity} \times \text{Cost of Equity} + \text{Share of Debt} \times \text{After-tax Cost of Debt}$$

where the corporate tax shield is deducted from the cost of debt.

The discount rate of the project is very important, as it affects the present value of future costs and benefits.

A project is considered a viable investment if the internal rate of return (IRR) is higher than the weighted average cost of capital (WACC). This is explained further in the following section regarding the financial results/outputs.

#### REVENUE

The financial analysis must consider the market demand for the products, how tariff regimes function for each product, and how this will affect the cash flow. The revenue consists of the sale of one or more of the following production outputs, depending on whether the plant is on-grid or off-grid:

##### On-grid:

- Electricity
- Heat
- Gas
- Potentially bio-residue used as fertilizer.

##### Off-grid:

- Savings from avoided fuel costs (coal, oil, or gas)
- Potentially bio-residue used as fertilizer.

The amount and price of each of these production outputs is crucial to the financial viability of the project. Attention also should be paid to the potential difference in tariff and subsidy regimes, as these may differ depending on whether the plant is on-grid or off-grid.

#### COST OF BIOMASS SUPPLY

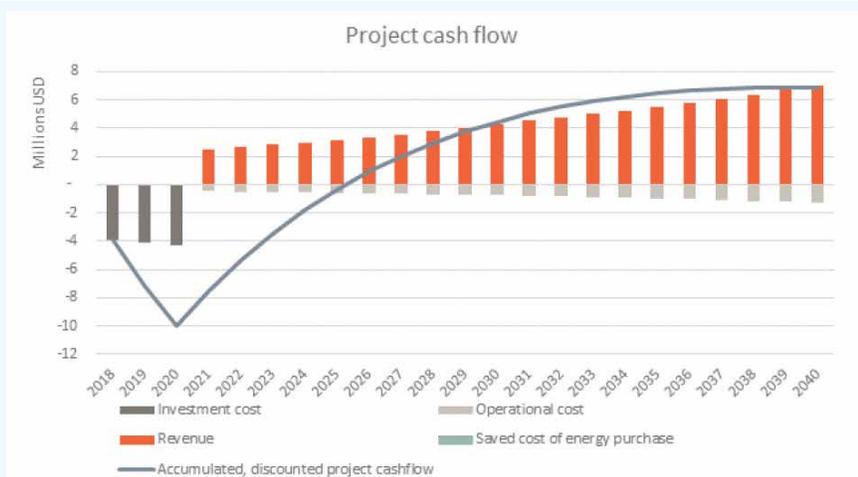
Biomass is the main production input. This is why a stable and secure supply of quality biomass is essential for obtaining a reliable financial analysis result.

**Figure 13-1:** Approach to Financial Analysis



Source: COWI.

**Figure 13-2:** Example Illustration of Project Cash Flow



Source: COWI.

A main assumption of this guide is that the biomass used for energy production is residue from either forestry, agriculture, or the food processing industry. If the biomass currently has no alternative use, the costs of applying it for energy production will amount to the following cost components:

- Cost of collection
- Cost of transport
- Cost of pretreatment (drying)
- Cost of storage.

If the biomass has an alternative use, it will generate a price, in addition to the aspects mentioned above. A project with access to otherwise unused biomass of sufficient quality therefore has a more promising project economy than a project that is forced to purchase and import its biomass.

The supply of secondary or tertiary biomass also depends on factors related to production of the primary biomass product. Residues from crop production are sensitive to weather, climate, and seasonal variations. Other types of biomass, such as residues from dairies or manure from livestock, are much less prone to seasonal variations.

#### CAPITAL EXPENDITURES

A financial analysis defines the capital expenditures as the total investment costs needed to procure the biomass plant,

including property, industrial buildings, equipment, and machinery. Table 12–3 shows an estimate of how the main investment costs are distributed on the main CAPEX items. The estimates are based on experience from a number of European projects.

A capital expenditure must be capitalized. This requires the owner to spread the cost of the expenditure (the fixed cost) over the useful life of the asset.

#### ECONOMIC LIFESPAN

The average lifespan of a biomass-to-energy plant is assumed to be 20 to 30 years, which also is the length of the financial analysis. It is important to include the residual value of the energy plant if a shorter analysis period is selected.

#### 13.1.2 RESULTS AND OUTPUTS

A financial analysis presents the project’s financial viability from the investor or lender’s perspective over the project lifetime, based on the assumptions presented above. To evaluate a project’s financial viability, the analysis presents the project’s balance sheet and cash flow, based on the CAPEX and OPEX. Furthermore, the analysis should clearly present the underlying assumptions such as the WACC and lifetime, and report results such as the net present value, the internal rate of return, the debt service coverage ratio, and the payback period.

The investor or lender will determine the project's financial performance, based on the following financial ratios:

**NPV:** The net present value is a measure of profitability used in corporate budgeting to assess a given project's potential return on investment. The NPV is the difference between the present value of cash inflows and the present value of cash outflows. Due to the value of time, the NPV takes into account the discount rate (here the WACC) over the lifetime of the project, thus presenting the annual cash flows in present values.

The interest rate applied for calculating the NPV is the WACC. The NPV is calculated using the following formula:

$$NPV(i, N) = \sum_{t=0}^N \frac{C_t}{(1+i)^t}$$

Where

$i$  = Financial discount rate (WACC)

$t$  = Time

$C_t$  = Net cash flow at time  $t$

$N$  = Total number of time periods

A NPV of zero (0) implies that the return on the investment equals the WACC. Therefore, a negative NPV can be found for a project with a positive return, but where this return is lower than the investor's required return.

**IRR:** The internal rate of return is a measure used for assessing the profitability of potential investments. The internal rate of return is the discount rate that makes the net present value of all cash flows equal to zero.

**LCOE:** The economic levelized cost of electricity is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operation and maintenance, cost of biomass, cost of capital. The LCOE is calculated as the NPV of all costs divided by the NPV of electricity generation, and is the price per unit of energy that causes the project to break even.

**DSCR:** The debt service coverage ratio is the ratio of cash available for debt servicing to interest, principal, and lease payments. The DSCR is a measurement of an entity's ability to earn enough cash to cover its debt payments.

The higher this ratio is, the lower the risk of the lender. To be confident that the investor or project owner can repay his debt, financial institutions (lenders) will demand that the DSCR is larger than one (1) by a certain margin.

**Payback period:** This is the period necessary to earn back the initial capital investments. The shorter the payback period, the stronger the financial viability of the project.

$$\frac{\text{Net Operating Income}}{\text{Total Debt Service}}$$

The case example in Box 13–1 presents the methodology approach and the results of a financial analysis.

## 13.2 ECONOMIC ANALYSIS OF BIOMASS-TO-ENERGY PROJECTS

A financial analysis does not cover all costs and benefits from a biomass project. This section elaborates the economic effect to society from biomass projects and provides investors and authorities with the necessary welfare economic perspective before final approval and implementation.

An economic analysis is usually conducted based on a request from the public authorities (for example, in connection with an investment grant request), to provide knowledge about the impacts that the project will have on society. The importance of this type of analysis varies significantly with the project size.

- Smaller biomass projects in developing countries, decoupled from the national grid, will have mainly a local economic impact. The social and environmental impacts also are of local scale.
- Larger biomass projects, connected to national energy grids, will have a bigger economic impact on society as a whole. The larger amounts of biomass applied in the project, the larger the environmental and potentially social impact.

An economic analysis estimates the net benefit of the project by incorporating all benefits and costs, including external effects, which are quantified and expressed in monetary terms. The following section elaborates the general

### Box 13-1: Example Case of Financial Analysis (Fictional Data)

A cooperation of farmers in Kenya produces 15,000 tons of corn residuals and 30,000 tons of wood residuals per year. This case exemplifies the financial analysis of an investment in a medium-scale conversion plant with a grate boiler.

#### Assumptions

Transport costs are not included in the analysis.

Electricity is sold at \$0.20 per kWh, whereas the process heat is used at a local industry, saving them \$0.06 per kWh.

The plant constructed has an annual capacity of 50,000 tons of biomass and an energy production capacity of 120,000 gigajoules (output).

The project is financed with equal parts of debt and equity raised by the cooperation of farmers. The debt has an interest rate of 12 percent, a 1 percent financing fee, and a maturity of 10 years. The required return on equity is assumed to be 15 percent.

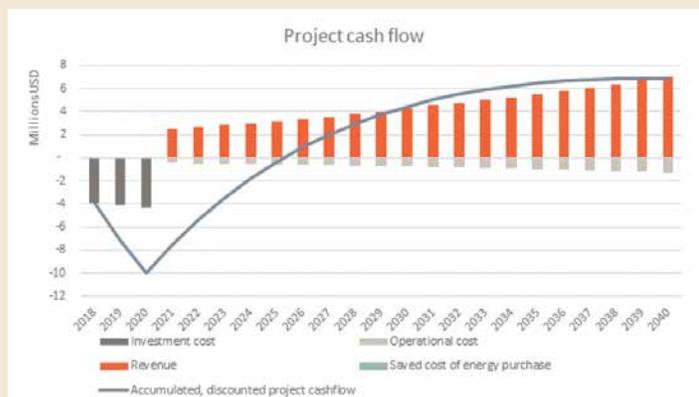
#### Results

The financial result of the project is a **net present value of \$77 million with an internal rate of return of 28 percent**. The **simple payback period** of the project is slightly more than five years.

The energy conversion reduces the carbon dioxide emission from other energy production, corresponding to 65,000 tons of carbon dioxide.

#### Calculation of LCOE

The NPV of the total costs of the project amount to \$120 million and a discounted electricity output of 283 million kWh. The LCOE where the project NPV breaks even is therefore \$0.018 per kWh of electricity.



Source: COWI.

assumptions of an economic analysis and draws parallels to the financial analysis. A case example illustrates a practical application of an economic analysis.

### 13.2.1 METHODOLOGY AND KEY ASSUMPTIONS

Table 13-1 presents the overall assumptions for an economic analysis.

As mentioned, an economic analysis estimates the net benefit of a project to society, meaning quantifying effects occurring locally, nationally, and globally over the project's entire lifecycle. It evaluates the effect of the project using economic opportunity costs or shadow prices.

When performing an economic analysis, the financial costs are not included and neither are taxes, tariffs, subsidies, etc.,

as these costs do not add to economic productivity and are merely transactional.

#### Typical benchmarks for key financial parameters in biomass projects:

Internal rate of return on the project: > 10 percent

Net present value of the project: > 0 percent, dependent on the risks related to the project

Payback period: < 10 years

Debt service coverage ratio: 1.2 to 1.5

The above-mentioned estimates are generalized results and will differ across borders and project-specific conditions. Domestic benchmarks for these criteria often depend on the economy's underlying interest rate, country risk, and general level of economic development and are subject to changes over time.

Table 13-1: Assumptions for Economic Analysis	
Scope	Assumptions
Analysis perspective	State and/or national and community perspective
Evaluation method	Economic life of project, including decommissioning
Adjustment for inflation	Exclude inflationary effects; price changes different from inflation can be included (escalation)
Project input valuation	Project inputs valued, using their economic opportunity costs, derived by excluding taxes, tariffs, subsidies, etc.
Discount rate	Economic discount rate; real rate of return (excluding inflation) that could be expected if money were invested in another project
Interest paid for borrowed funds during construction	Not included (financial cost)

Source: COWI.

The appropriate discount rate when performing an economic analysis is the rate of return of the entire economy, that is, the national opportunity cost of capital. In comparison, the WACC applied in the financial analysis is only relevant to a specific investor, as the WACC calculation is based on a single investor's cost of equity and debt. The economic discount rate is typically lower than the WACC.

After identifying the costs and benefits at both the local and national levels, the net benefits are estimated to assess the project economic viability, as illustrated in Figure 13-3.

#### LOCAL ECONOMIC BENEFITS AND COSTS

A biomass project potentially can have important impacts on the local economy, or it might function without affecting

the local area at all. The potential positive and negative local effects of a biomass project are as follows:

#### Benefits:

- A possible increase in income for local farmers as a result of local demand for biomass
- A local source of stable energy from the biomass plant
- The creation of local jobs (either at the plant or in the agricultural sector)
- Possible infrastructure improvements, such as grid connection or improved roads for biomass transport.

#### Costs:

- Negative environmental effects due to emissions from plant
- Social effects should be carefully considered. If the biomass to be used for energy production is currently used by locals for human consumption, animal consumption, or income generation, removing the biomass may cause social problems.

#### PUBLIC ECONOMIC BENEFITS AND COSTS

Biomass projects may have an impact on the macroeconomy, and can provide several other macroeconomic benefits, such as:

#### Benefits:

- A stable energy supply
- Fewer subsidies for fossil fuels in public budget
- Improved opportunities for industrial production, and thereby job generation, due to the stable energy supply
- National increased security of energy supply, making the country less dependent on import of foreign energy

Figure 13-3: Approach to Economic Analysis



Source: COWI.

- Reduction of greenhouse-gas emissions, as energy from bio-waste implies less emissions compared to alternative fossil-based energy sources
- More environmental benefits from reducing alternative fossil fuel-based electricity generation
- Reduced health costs and better overall air quality from pollution externalities.

**Costs:**

- No negative environmental effects, unless primary biomass is used for energy generation. This would undermine the sustainability of the project, causing an overall global increase in greenhouse-gas emissions.
- Negative economic effects: Capital expenditures and operation and maintenance costs, potential risk posed by foreign currency exposure to exchange rate volatility.

**13.2.2 RESULT AND OUTPUTS**

An economic analysis presents the project’s viability from society’s perspective over the project lifetime and given a series of assumptions, as presented in the previous section. To evaluate a project’s economic viability, the analysis

presents the project’s net present value based on the estimated costs and benefits to society

Furthermore, the analysis should clearly present the underlying assumptions such as the national discount rate and project lifetime and report results such as the net present value, the internal rate of return, and the cost/benefit ratio. The case example in Box 13–2 presents the methodology and results of an economic analysis.

As in the financial analysis, a project’s viability can be assessed using the following indicators:

- Economic net present value
- Economic levelized cost of electricity
- Economic internal rate of return (the economic IRR should be compared to the economic discount rate, not to the WACC as in the financial analysis)
- Economic cost/benefit ratio: The ratio should be larger than one (1), indicating that the project’s benefits outweigh the costs.

**Box 13-2: Example Case of Economic Analysis (Fictional Data)**

A cooperation of farmers in Kenya produces 15,000 tons of corn residuals and 30,000 tons of wood residuals per year. This case exemplifies the economic analysis of an investment in a medium-scale conversion plant with a grate boiler.

**Assumptions**

Transport costs are not included in the analysis.

Electricity is sold at \$0.20 per kWh, whereas the process heat is used at a local industry, saving them \$0.06 per kWh. The constructed plant has an annual capacity of 50,000 tons of biomass and an energy production capacity of 120,000 GJ (output).

The carbon dioxide quota price is \$3.2 per ton.

The value of a job is equivalent to \$10 per day.

**Results**

The net benefit of the project is an NPV of \$45.2 million.

	Amounts	Value Over Project Lifetime (million dollars)
Investment costs		73.4
Operation and maintenance costs		44.7
Revenues from electricity generation		92.1
Revenues from heat generation		66.1
Greenhouse-gas emission reductions (carbon dioxide-equivalent)	167,000 tons	3.2
Creation of local jobs	25 field workers	1.9
<b>Net benefits</b>		<b>45.2</b>

Source: COWI.



Source: COWI.

### 13.3 SENSITIVITY ANALYSIS

A sensitivity analysis assesses the impacts of risks by varying each risk parameter while all other variables remain constant. This approach will enable changes in the results of the financial or economic analysis, indicating the importance of specific risk parameters. Usually, the effects of input parameter variations are observed through the following indicators:

- The internal rate of return
- The net present value
- The debt service coverage ratio.

Typical parameters exposed to sensitivity analyses are the following:

- The investment costs
- The tariff levels (in case of feed-in to the grid without a fixed-price power purchase agreement); these are usually uncertain in the long term, as they are subject to political decisions
- The supply and price of biomass. The entire production of energy is based on the assumption that biomass is available at a reasonable price. The biomass production

depends on the weather and on the general development of the agricultural sector.

- The electricity prices are important factors for the viability of the project, and they are formed by a fluctuating market. The electricity price is important for the expected energy revenue.

### 13.4 CONCLUSION

The financial analysis assesses the project’s viability from an investor’s perspective; the economic analysis assesses the viability from society’s point of view. The financial analysis includes the costs and benefits on a company level, whereas

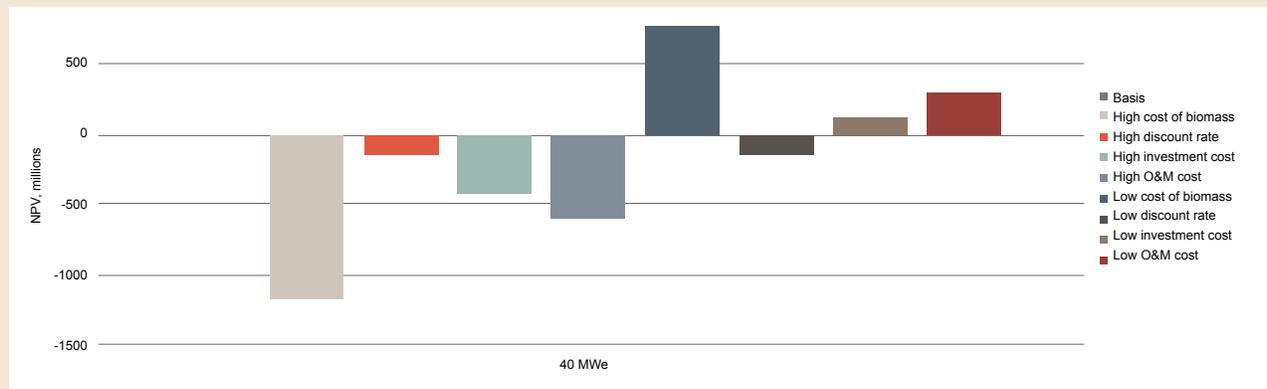
the economic analysis includes the overall costs and benefits to society, including the value of external effects.

Financial analysis uses the following parameters for reporting the results:

- Net present value
- Financial internal rate of return
- Financial levelized cost of electricity
- Debt service coverage ratio
- Simple payback period.

#### Box 13-3: Example of a Sensitivity Analysis

The sensitivity analysis indicates that the project is relatively robust in response to small changes in the selected parameters. However, if the project cannot connect to the electricity grid, a significant reduction in revenue would result.



#### Common pitfalls and issues to anticipate:

- Underestimating the time it takes to locate and secure financing for the project
- Underestimating the importance of supplier agreements and power purchase agreements when applying for financing
- Assuming that the biomass is free. Once external suppliers learn about the project, their bio-waste will gain a value.

#### Issues to consider when applying for financing

- Factors affecting project cash flow (energy prices, security of biomass supply, costs of residual disposal, technological risks, stability of regulatory regime including feed-in-tariffs)
- Factors affecting asset values (increased stability of primary production from enterprise, reduced risks of technological obsolescence, reduced pollution and environmental liabilities).

The results of the economic analysis are usually reported through the following parameters:

- Net present value
- Economic internal rate of return
- Economic cost/benefit ratio
- Sensitivity analysis that presents the robustness of results through variations in the input parameter.



Source: COWI.

In the initial phases of a biomass project, the main activities of the project developer relate to concept identification and technical prefeasibility studies, as illustrated in Figure 2–3. However, when reaching phase 1.3 (Feasibility Study) of project development, the developer will have to identify sources of finance and initiate contact with them. The technical complexity of a project can often absorb much of the initial focus of the project developer, but the difficulties of assuring the necessary financing should not be underestimated.

The purpose of this chapter is to provide inspiration for the project developer on how to identify and secure finance for his or her biomass project.

Before initiating the search for finance, the project developer should bear in mind the following:

- The process of acquiring finance can be time consuming.
- The technical, contractual, and permitting aspects of a biomass project all affect the opportunities for securing financing.
- Project lenders will carefully assess all aspects of the project, with specific attention to the risks involved. Therefore, attention to detail, risk mitigation, and anticipation of lender concerns are very important.

### 14.1 GENERAL FINANCING CONSIDERATIONS

A project developer is usually required to raise a significant amount of finance to realize a biomass-to-energy project. It is important to evaluate the available financing options early in the process, so that the project as a whole is structured accordingly. When applying for finance, the project developer should have anticipated the concerns of the lenders, so the project structure and elements appear to be financial viable and robust, with low risks for the lender. Key characteristics

of biomass-to-energy projects that should be considered before approaching a potential source of finance include:

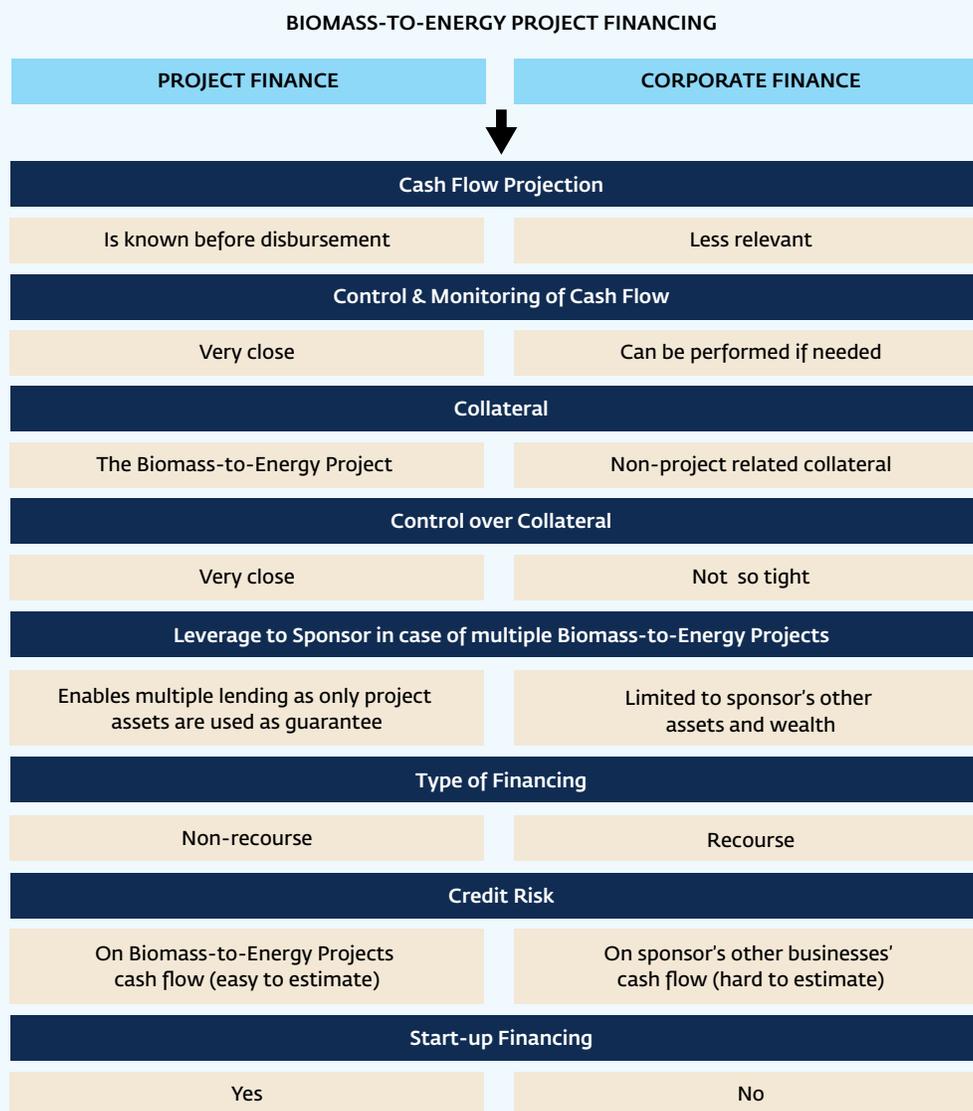
- A stable and sufficient supply of sufficient quality biomass is available within a reasonable distance.
- The project is based on own-use of generated heat and power or has easy access to grid connection or a large local user.
- The proposed technology is proven and suitable in the local circumstances.
- Capital costs and operation and management costs are estimated.
- The project lifespan allows for recovery of the investment.
- Environmental/social considerations are identified and adequately mitigated.

### 14.2 TYPES OF FINANCING

Each biomass-to-energy project is unique, but generally, a project developer can choose to finance the project through either corporate financing or project financing (Figure 14-1). The difference between corporate and project financing is presented below, along with key issues to consider when selecting a financing structure.

- **Corporate finance by sponsor:** A sponsor or financial institution offers financing to corporations that will implement the biomass project and assume responsibility for debt servicing, interest, and capital repayments. The financial institution will evaluate the financial viability and the risks associated with the entire corporation, not only those aspects associated with the biomass project. The assets and cash flow of the entire corporation are the lender's main security for the loan ("full recourse").

**Figure 14-1: The Difference Between Corporate Finance and Project Finance**



Sources: IFC, 2015; COWI.

This approach requires a strong balance sheet and no competition for CAPEX for other purposes.

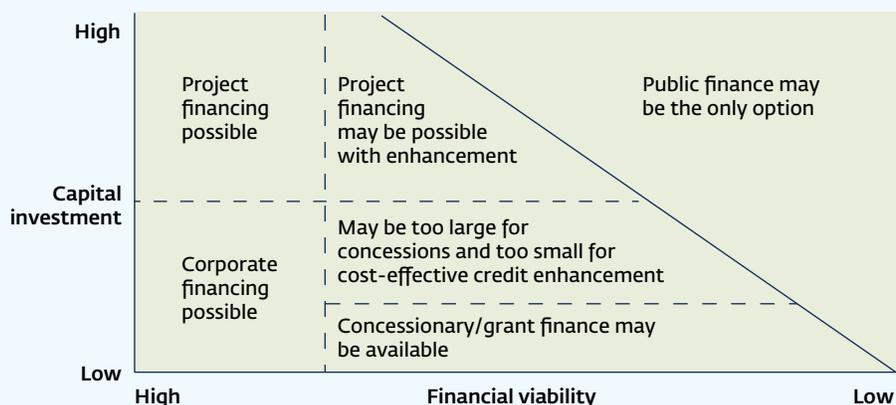
- **Project finance by investor(s):** The focus of the financial institution here is the viability of the specific biomass-to-energy project, because the project will rely mainly on project-generated cash flow to cover the borrower's obligations (non-recourse or "limited recourse"). Under this scheme, project assets will serve as collateral to reduce lender risks.

The difference between corporate and project finance is furthermore expressed through a possible difference in

interest rates. If the project developer is a large corporation with solid financing, it may be able to get much lower rates by accepting corporate finance than standalone project financing. These differences in rates could make a large difference in the project's financial viability.

Selecting an appropriate source for financing biomass-to-energy projects is dependent on the project's financial robustness and viability, the project size, and the project risks. Figure 14-2 illustrates how project size and financial viability relate to the choice of financing.

**Figure 14-2: Financial Viability**



Source: IFC, 2015.

Besides financial institutions, other external investors may be an option for the project developer. The following presents the three most common external investors:

- **Investment by technology supplier:** Technology suppliers have an incentive to promote the use of their technology. Therefore, they sometimes are willing to provide the necessary capital/loans to the developers.
- **Investment by biomass suppliers:** The suppliers of biomass have an interest in promoting the project. They

could be providing capital, while assuring their long-term commitment to supplying high-quality biomass.

- **Build–Operate–Transfer (BOT):** A Build–Operate–Transfer contract transfers the task of designing, building infrastructure, financing, and operating the plant for a fixed period (for example, 20 years) to a third party (BOT contractor). During the contract period, the BOT contractor will collect all project-generated revenue, which should be sufficient to provide a reasonable

### Box 14-1: Sources of Financing

There are many different ways of securing financing for a biomass project. The most common ways are described below, along with a brief assessment.

- **Own Equity:** Must be able to ensure a reasonable return on investment, but also should take into account the overall benefits to the owner (for example, the use of biomass from existing production).
- **Bank loans:** International commercial banks, local banks, and development banks or multilateral financing institutions (for example, IFC, KfW, EBRD, ADB, AfDB, IDB, EIB, Green for Growth Fund). Financing through commercial banks often entails high interest rates, whereas development banks may offer interest rates that are more favorable.
- **Investment by technology supplier:** As the technology supplier has interests in seeing the project development succeed, the technology supplier may be willing to offer loans at interest rates lower than the banks can offer.
- **Investment by biomass supplier:** Biomass suppliers could typically be cooperatives of farmers or biomass processing companies with significant bio-waste amounts. The chance of being able to sell their bio-waste provides an incentive for the suppliers to contribute to the success of the project, for example by providing capital as investments or loans at reasonable rates.
- **Build–Operate–Transfer:** In a Build–Operate–Transfer framework, a third party (BOT contractor) takes responsibility for financing, designing, building infrastructure, and operating the plant for a fixed period.
- **Private equity funds:** Capital for private equity is raised from retail and institutional investors, and can, for example, be used to fund new technologies. The majority of private equity funds consist of institutional investors and accredited investors, who can commit large sums of money for long periods of time.

Source: COWI.

profit and justify the risks assumed. When the concession agreement ends, the BOT contractor transfers the biomass plant back to the owner without further remuneration.

- A project developer should not underestimate the difficulty of raising finance on reasonable terms for a biomass-to-energy project, especially project developers with no previous experience from similar projects or with limited resources.
- Developers who find that they have a potentially viable project, but one that they will not be able to exploit with their own resources, could consider co-developing the project with a stronger partner that is better able to raise the required finance.

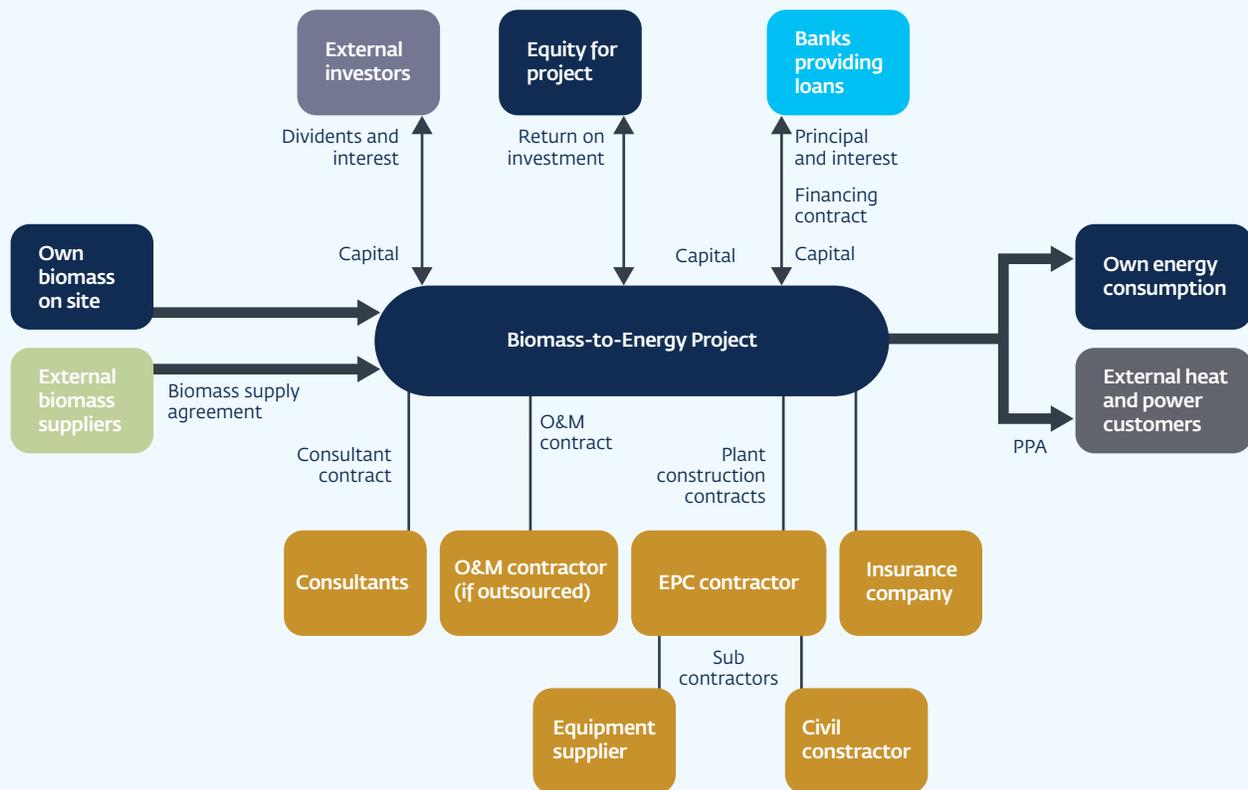
### 14.2.1 KEY PLAYERS

It is important for the project developer to have the full overview of the different stakeholders and their contractual relations. The following section explains the role of the different stakeholders in the financing structure.

Figure 14–3 presents the key project players, the finance structure, and the most necessary contracts essential for a reliable project, and thus a prerequisite for obtaining loans from financial institutions.

When securing finance for the project, the project developer must be able to present a financially solid project. Figure 14–3 illustrates the organizational setup and the corresponding agreements necessary to present a solid project case.

**Figure 14-3: Setup and Agreements**



Source: COWI.

- **The project owner:** The majority stakeholder is usually the main sponsor who is leading the project. For biomass-to-energy projects, private investors often are the sponsors.
- **Banks:** The source of finance for this type of project is normally a financial institution. Lenders are typically international commercial banks, local banks, and development banks or multilateral financing institutions (IFC, KfW, EBRD, ADB, AfDB, IDB, EIB, GGF, among others).
- **Energy consumers:** The energy consumer is usually a national or regional power utility. The energy also could be sold directly to a local end-user under a bilateral agreement, or used for own-consumption by the project owner. Typically, biomass-to-energy plants will sell electricity to the national grid under feed-in tariff schemes, which guarantee a fixed price. The consumer's creditworthiness is crucial for the financial robustness of the project.
- **Biomass suppliers:** The supplier of biomass can be the project owner, who has available bio-waste to use as free fuel for energy production. Alternatively, it could be external biomass suppliers (such as cooperatives of farmers in the region or the local biomass processing industry) who have excess bio-waste that they are willing to sell.
- **Contractors:** During the project construction phase, contractors and equipment suppliers are the primary focus of the project developer. The contractors are



Source: COWI.

responsible for delivering a fully functional plant to the project developer within the agreed time.

- **Operating company:** If the project company will not be responsible for the operation and maintenance of the plant, an agreement with an operating company must be undertaken. The operating company could, for example, be the owner, the EPC contractor, or a third party.
- **Insurance company:** Insurance is essential both during construction and in the operation phase, covering:
  - Construction phase—construction risks (for example, accidents, delays), environmental, social, and political risks.
  - Operation phase—operation and maintenance risks (operational failures), environmental and political risks, late or non-payment from energy customers, and transfer risks.

Based on the risk information presented above, the importance of risk mitigation becomes clear. The following section describes different risk mitigation measures for a biomass-to-energy project.

### 14.3 MITIGATING RISK

The risks related to a biomass-to-energy project should, as best as possible, be mitigated, both to reduce the risks of the project company and to demonstrate to financial institutions that the project is financially robust. Because financial institutions are risk-averse, unmitigated risks will decrease the attractiveness of the project to lenders. If project risks are too high, external financing might not be feasible.

If risks are mitigated, the lender's required interest rate should be lower than if the risks remained unattended. Mitigation measures vary depending on the type of risk. Therefore, financial modeling, including sensitivity analysis, should be performed to reveal the effects of the risks identified. Early engagement with potential financing partners will facilitate the later access to finance, as it may identify issues that are better addressed upfront in the project design. Table 14–1 presents the key risks for a biomass-to-energy project as well as suggestions for mitigation measures.

### 14.4 CONCLUSION

Finding and acquiring finance for a biomass project is a complex procedure, which requires professional handling of the following factors:

- Identifying the appropriate financing approach
- Identifying the key players
- Identifying and mitigating the project risks (biomass availability and energy market security).

The most common sources of financing are:

- Bank loans, from international commercial banks, local banks, and development banks or multilateral financing institutions (for example, IFC, KfW, EBRD, ADB, AfDB, IDB, EIB, GGF).
- Investment by technology suppliers, who have an incentive to promote the use of their technology and thus might be willing to provide the necessary capital/loans to the developers
- Investment by biomass suppliers, who have an interest in promoting the project. They could be providing capital, while assuring their long-term commitment to supplying high-quality biomass.
- Build–Operate–Transfer. In a BOT contract, a third party (BOT contractor) takes the task of designing, building infrastructure, financing, and operating the plant for a fixed period.
- Private equity funds, where a group of investors makes combined investments in a biomass-to-energy project.

**Table 14-1: Assumptions for Economic Analysis**

Risk	Mitigation Strategy
Biomass availability	The project company should own the biomass resource, thereby controlling the supply, or biomass supply contracts with external suppliers should be in place.
Energy offtake security	If the project company cannot utilize the power, a power purchase agreement with, for example, a power utility company, should be in place.
Construction costs	To mitigate the risks of exceeding the planned construction costs, a high-quality feasibility study should be conducted in advance, as illustrated in Figure 2–3 in Chapter 2.
Operational performance	To ensure that the plant operates as expected, the project developer should choose a proven technology and reliable suppliers under best-practice contracts.
Financial viability	To ensure financial viability, the security of biomass supply at a known and reasonable price must be in place, as should the security of energy sale at a known and reasonable price. A way to secure a fixed price for the energy is via feed-in tariffs.
General political risk	The risks of shifting political focus could be reduced by partial risk guarantees.
Sector-specific regulatory risks	Government endorsement of biomass-to-energy projects has great importance if the projects' financial viability depends on, for example, subsidies or feed-in tariffs. The government may eventually change the regulation retroactively, thus affecting signed power purchase agreements. The developer should assess the sustainability of the regulatory framework and the energy customer's ability to pay.
Environmental and social risks	To avoid environmental and social risks, international best practice should be adopted, and these aspects should be covered in a high-quality feasibility study.

Source: COWI.



Source: COWI.

This chapter introduces and provides a methodology for screening and assessing environmental and social (E&S) risks and impacts. Guidance on this topic also can be found in IFC Performance Standard 1 on Assessment and Management of Environmental and Social Risks and Impacts (IFC, 2012) (see Section 6.2.6) and in Performance Standards 2 through 8 (and the associated Guidance Notes), which are an integral part of IFC's Sustainability Framework and define developers' responsibilities for managing their environmental and social risks.

This chapter guides the reader through the screening of E&S issues that potentially could arise from a biomass-to-energy plant, and therefore is a resource for developing all the required E&S assessments.

Biomass provides an alternative to fossil fuels, and biomass-to-energy projects often are implemented at least in part due to possible greenhouse-gas benefits. However, a number of social and environmental issues should be examined when biomass is considered as a source for energy generation, and their negative and positive consequences on affected communities and other stakeholders should be assessed.

The use of biomass for energy generation can impact the local environment, for example by affecting air quality, biodiversity, habitats and ecosystems, and water quantity and quality, and by changing the local use of land. Social impacts also may arise, notably by affecting local community livelihoods (for example, access to and use of land and resources), food security, and economic parameters such as employment and poverty. Box 15–1 presents a brief example of such potential impacts.

#### Box 15-1: Examples of Environmental and Social Impacts of Biomass Projects

A biomass plant project is developed to use agricultural residues, such as straw, for electricity production. This could have a number of environmental impacts, such as:

- **Air quality:** Emissions from combustion of bio-residues can lead to air pollution.
- **Nutrients:** Removal of residues from the agricultural ecosystem can lead to depletion of nutrients in soil if the ashes are not returned to the soil.
- **Biodiversity:** If demand for residues increase beyond supply, new agricultural areas can be created from conversion of, for example, wetlands, shrub land, or forest, which can negatively impact biodiversity.
- **Water:** Both water quality and quantity can be affected, for example by discharge of wastewater or increased use of groundwater for production of biomass.
- **Land:** If only secondary resources are used, local impacts on land are probably small. However, if other users already utilize the feedstocks, environmental consequences could arise if these users pursue other feedstocks.

A number of social consequences also can arise from the development of biomass plants, such as:

- **Employment:** The bioenergy plant can generate employment in the region.
- **Economy:** The plant can benefit the local economy.
- **Food security:** Depending on existing uses of the feedstock, potential food security issues can arise if food or feed crops are used for energy generation.

While not exhaustive, this list provides a brief overview of potential impacts and shows that a number of these (positive and negative impacts) should be considered when developing biomass projects.

Source: COWI.

The scale, timing, and magnitude of these impacts are always context specific and highly dependent on the local conditions and the type of biomass. As a starting point, however, one can assume that biomass projects relying on primary resources (for example, biomass harvested for energy purposes, such as round wood or food crops) often result in more severe environmental and social impacts.

This section provides an overview of environmental and social risks and impacts that can arise from the use of biomass for energy. The section covers:

- Water
- Biodiversity
- Soil and land
- Air quality
- Food security
- Community development
- Energy security and access
- Gender
- Employment, wages, and income
- Greenhouse gases.

## 15.1 ENVIRONMENTAL SCREENING OF THE BIOMASS RESOURCE

The process of identifying, prospecting, and procuring biomass entails a number of environmental issues that should be screened for. Some of these are off-site relative to the plant and take place in the project area of influence, including fields, forests, or watercourses that are supplying or will supply biomass to the project. Table 15–1 gives an overview by providing a number of guiding questions to help in identifying potential issues for further investigation. The screening should take into consideration a number of biogeographical and climatic aspects, although these will differ depending on the type of biomass or feedstock (primary, secondary, or tertiary). Once the types of biomass involved are identified, each biomass type should be screened on its own using the table.

The questions are structured around four main topics: water, biodiversity, soil and land, and air. After using the table to identify potential issues based on the type of biomass and relevant topics, the subsequent sections of the guidelines are aimed at guiding further investigations. Each question provides examples of potential issues and mitigation actions. The purpose of the topic-based screening is to sort out issues

### Tools Available and Reporting

Seeking co-financing for a biomass project from international financial institutions such as IFC will require an Environmental and Social Impact Assessment (ESIA). The ESIA assesses the potential environmental and social risks and impacts that are likely to arise from the activities of the project. The ESIA is the framework for screening and understanding environmental and social aspects of the project.

Some tools already exist for project developers who are interested in gaining further information on a framework for environmental and social screening. These tools include guidance for project developers on the typical environmental and social issues pertaining to biomass projects and on the process of assessing them and identifying mitigation measures.

Relevant policies and tools:

- **IFC Performance Standards:** Environmental and Social Performance Standards and Guidance Notes define IFC clients' responsibilities for managing their environmental and social risks. Available at: [http://www.ifc.org/wps/wcm/connect/Topics\\_Ext\\_Content/IFC\\_External\\_Corporate\\_Site/IFC+Sustainability/Our+Approach/Risk+Management/Performance+Standards/](http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/IFC+Sustainability/Our+Approach/Risk+Management/Performance+Standards/).
- **Equator Principles:** A risk management framework, currently adopted by 83 financial institutions in 36 countries, covering 70 percent of international project finance debt in emerging markets. The principles are used to determine, assess, and manage environmental and social risk in projects, primarily intended to provide a minimum standard for due diligence to support responsible decision making. Available at: <http://www.equator-principles.com>.
- **Bioenergy Decision Support Tool:** Planning Strategically and Assessing Risks in Investment Choices, developed by UN-Energy, the UN Food and Agriculture Organization, and the UN Environment Programme. Available at: <http://www.bioenergydecisiontool.org>.
- **RASLRES Bioenergy Tool,** developed by the EU European Regional Development Fund. Available at: <http://www.rasres.eu/>. Note that this tool is developed for the Nordic region and is mainly applicable in similar settings.

that should be assessed in detail as part of the Environmental and Social Impact Assessment (ESIA).

The issues for consideration given below are not exhaustive and may not be relevant in all projects. As indicated, they should serve as guidance during the phase of preliminary screening of environmental issues.

## 15.1.1 WATER

With unsustainable use of water remaining a threat to environment and human development alike, the use of water for bioenergy projects must be sustainable and must not compromise water quality and quantity.

	Questions Concerning Environmental Aspects	Primary Feedstock	Secondary Feedstock	Tertiary Feedstock
Water	Will the use of water for bioenergy production or conversion of feedstock impact water availability or security of supply in the watershed?	●	●	●
	Will the use of water for bioenergy production or conversion of feedstock affect water quality, use, or discharge?	●	●	●
	Will the use of water for bioenergy production or conversion of feedstock change stream or river flows and water availability for downstream users?	●	●	●
Ecosystems and biodiversity	Will the biomass project affect rare or threatened species?	●	n.a.	n.a.
	Will the biomass project affect threatened ecosystems or habitats, for example through degradation, conversion, loss, or fragmentation?	●	●	n.a.
	Will the biomass project lead to introduction of non-endemic and/or invasive species?	●	●	n.a.
	Will the biomass project affect or change ecosystem services in the area, including: <ul style="list-style-type: none"> <li>• Provisioning (for example, food, wood)</li> <li>• Regulating (for example, protection against flood, droughts)</li> <li>• Supporting (for example, water purification, cycling of nutrients, primary production)</li> </ul>	●	●	●
	Will the biomass project affect or change cultural sites (for example, religious services, recreation and tourism, education)	●	●	●
Soil and land resources	Will the biomass project lead to the conversion of land uses, such as the conversion from forest to agricultural land, to meet demand for the bioenergy feedstock selected for this project?	●	n.a.	n.a.
	Will the anticipated changes in land management, use, or intensity that are needed to produce biomass or feedstock for the project affect neighboring or more distant lands or landowners?	●	●	n.a.
	Will bioenergy production affect soil quality or lead to degradation of soil and land?	●	●	●
	Is artificial fertilizer and/or manure needed to grow the feedstock in sufficient quality and quantity? If so, their use, and discharge to the land and water, should be monitored in order to avoid negative environmental effects.	●	●	n.a.
Air	Will production, conversion, or transport of the feedstock cause emissions of chemical air pollutants, such as nitrogen oxides, particulate matter, sulfur oxides, ozone, aerosols, soot, or volatile organic compounds?	●	●	●
	Will production, conversion, or transport of the feedstock cause emission of physical air pollutants, such as smell and odorous emissions, thermal heat, or radiation?	●	●	●
	Will production, conversion, or transport of the feedstock cause emission of biological air pollutants, such as pollen, fungi, or bacteria?	●	●	●

Source: COWI.

- Will the use of water for biomass production or feedstock conversion affect water availability or security of supply in the watershed?
  - If additional or new irrigation is needed to produce the bioenergy crop, a local water balance should quantify how the project impacts local water resources.
  - If biomass or feedstock producers that are connected to local water distribution networks plan to increase their water use, the impact on security on water supply may be substantial and should be assessed.
- Will the use of water for production of biomass or conversion of feedstock affect water quality?
  - Consider, for example, if production of the crop drives changes in land management, clearing of land, or removal of trees. If so, there may be a risk of loss of topsoil through erosion, which could end up having an impact on streams and rivers.
  - If additional or new fertilizers or pesticides are to be used, this may have implications for water quality. Consider both groundwater and surface water resources.
  - If the biomass or feedstock producer will use additional or new water resources because of the project, the capacity and quality of local water treatment systems should be evaluated and taken into account in the design.
- Will the use of water for biomass production or feedstock conversion change water flows and water availability for downstream users?
  - If any streams, pipes, or reservoirs are impacted or changed because of biomass or feedstock production, this could affect local water supply.

If the answer to any of the above questions is “yes” (also summarized in Table 15–1) one or more issues of concern will need further investigation and assessment.

### 15.1.2 ECOSYSTEMS AND BIODIVERSITY

An ecosystem consists of all living things—from plants and animals to microscopic organisms—that share an environment. The Convention on Biological Diversity defines “ecosystem” as a “dynamic complex of plant, animal and micro-organism communities and their

#### Mitigation Measures for Impacts on Water

Water impacts generally concern quantity and quality, and mitigation measures should be taken to minimize impacts on both aspects. These can be incorporated throughout the supply chain, from production of biomass to conversion and utilization.

##### Production stage

Some crops consume significant amounts of water, and thus selection of bioenergy feedstock should be matched to geoclimatic conditions (for example, available water resources and rainfall patterns). Lack of water also can be mitigated by more efficient irrigation if this is needed (for example, drip irrigation) or by harvesting rainwater. Minimizing fertilizer and pesticide use can mitigate impacts on water quality, which can be complemented by practicing mixed production systems (for example, double cropping). Finally, excess irrigation can lead to the runoff of salts, fertilizers, and pesticides and can pollute surface waters, and thus should be monitored closely.

##### Conversion stage

In many cases, substantial amounts of water are needed to convert the feedstock to bioenergy; as such, the decision on the end product used should take into account water availability. At the plant, cleaner production technologies should be considered, such as plant water recycling or on-site physical, chemical, and biological treatment of wastewater. Finally, natural systems for wastewater treatment, such as the construction of wetlands, can be considered.

*Sources:* UNEP, 2009; UNEP et al., 2011; UNEPa, n.d.

non-living environment interacting as a functional unit.” Ecosystem services are the benefits that humans obtain from ecosystems. Such ecosystem services, including water purification, pollination, food, and protection against floods and droughts, are important for humans, human livelihoods, and development. The expansion of agriculture or the use of natural resources for bioenergy can risk compromising some of these services, and the impact on these services must be considered when developing biomass projects.

Similarly, development of bioenergy can have adverse impacts on biodiversity by causing habitat loss, fragmentation of areas, and loss of species. Biodiversity not only has value as a provider of services to humankind (for example, food, medicine, religious), but also has value in itself. Furthermore, diverse, connected, and well-functioning habitats are most resilient against external threats such as climate change or pollution. Therefore, it is important that the impact on

biodiversity from the development of bioenergy is assessed, and, as needed, prevented or mitigated and minimized.

- Will the biomass project affect rare or threatened species?
  - The risk to any rare or threatened species should be assessed. This is particularly critical if natural habitats (forests, wetlands, etc.) are modified or if production is intensified on currently farmed areas. At the global level, rare or threatened species are listed on the IUCN Red List of Threatened Species, which can be accessed at: <http://www.iucnredlist.org>. Consideration of regional-level lists of threatened species should also be included in the assessment.
- Will the biomass project affect threatened ecosystems or habitats, for example through degradation, conversion, loss, or fragmentation?

#### Mitigation Measures for Impacts on Biodiversity

Biomass projects can affect biodiversity and ecosystem services in numerous ways.

##### Production stage

Primary biomass sources, and to some extent secondary biomass sources, can greatly affect biodiversity and ecosystem services through the conversion of natural areas to agriculture. Therefore, such conversion should be avoided to minimize risk of biodiversity loss. This includes avoiding any significant impact on rare, unique, endemic, or geographically restricted species or habitats, and minimizing overall impact on the area by reducing the size of area impacted or by focusing site activities in less-sensitive areas. Impact over time also can be reduced by preserving and maintaining buffer zones of local vegetation, while loss of ecosystem services can be compensated by considering the use of stakeholder engagement approaches to help identify locally preferred or important services. Finally, valuing the key ecosystem services in the affected area can help to safeguard them, even if this is merely a screening and accounting exercise without any actual transfer of money. Nutrient leakage and the use of pesticides, fertilizers, and other chemicals should be appropriately managed to avoid negative impacts on flora and fauna, as should using genetically modified organisms (GMOs) and introducing feedstocks that can be considered invasive species, as these can pose a threat to biodiversity and ecosystem services; any use of these should be closely followed.

##### Conversion stage

Correct treatment of effluents (through physical, chemical, and biological treatment) can minimize impact on the local environment and biodiversity.

Source: UNEPb, n.d.

- If land is cleared for cultivation, there is a risk that ecosystems or habitats can be lost or fragmented, which can have adverse impacts on species in those regions.
- Intensification of production, loss of nutrients, or excessive pollution can lead to degradation of natural habitats surrounding the project area.
- Will the biomass project lead to the introduction of non-native and/or invasive species?
  - The risk of invasive species should be considered in those situations where non-native flora (such as a new energy crop) is introduced to the region.
- Will the biomass project affect or change ecosystem services in the area?
  - Ecosystem services comprise a host of different services, and modifications to natural landscapes generally put one or more of these at risk. It is therefore necessary to assess for impact on ecosystems.
  - Care should be taken that ecosystem services that provide vital services to the region are not put at risk (for example, protection against flood or water purification performed by mangrove forests).
  - Ecosystem services are often not part of the formal economy (that is, the value provided by these services is not valued in economic terms), but they provide important functions for the local region and the affected communities. Care therefore should be taken to ensure free, prior, and informed consultation and participation by the affected communities.

It also should be ensured that those ecosystems that are of special importance to cultural services (such as religious areas or tourism) are not compromised, as this would affect the livelihood of local stakeholders.

If the answer to any of the above questions is “yes,” one or more issues of concern will need further data collection and assessment.

#### 15.1.3 SOIL AND LAND RESOURCES

Land use denotes the use of land for a particular purpose, such as infrastructure, agriculture, or forest. Because land is a scarce resource, its use becomes important for social, environmental, and economic reasons. Sustainable use of

productive areas is important for food production and for the delivery of a range of ecosystem services, such as purification of water, carbon storage, protection against erosion, and as habitat for plants and animals.

Given population and economic growth, additional food, energy, and resources will be needed in the coming decades, making sustainable and intensive use of land resources necessary. Therefore, use of feedstocks for bioenergy generation should take into account impacts on land.

- Will the biomass project lead to the conversion of land uses, for example, the conversion from wetlands and/or forest to agricultural land, to meet demand for the bioenergy feedstock selected for the project?
  - If the project involves a call for suppliers in the local area, landowners may be enticed to change land use, for example by clearing shrub land or forests to make way for a plantation or other productive land. In such cases, there could be risk of loss of biodiversity and carbon.
  - The sourcing of primary or secondary biomass or feedstock may cause a risk of land conversion. For waste-based systems, this risk should be minimal.

#### **Mitigation Measures for Impacts on Soil and Land Resources**

Similar to agricultural production, biomass feedstock for bioenergy production, whether primary or secondary, can lead to soil degradation if soils are not managed properly. Furthermore, effluents from conversion of biomass feedstock can lead to pollution of the soil resource.

##### **Production stage**

Mitigation measures include no-till practices, use of cover crops to avoid erosion and build soil organic matter, and growth of different crops and use of manure or fertilizer to ensure nutrient levels in soils and avoid depletion. Similarly, planting of riparian buffer zones can minimize erosion and nutrient leakage to water bodies. No-till practices and irrigation can help maintain soil moisture. Excess use of pesticides, herbicides, and other chemicals can lead to soil, groundwater, and surface water pollution.

##### **Conversion stage**

Adequate treatment of water effluents can minimize impact on soil resources, and waste disposal should not take place outside dedicated facilities.

*Source:* UNEP et al., 2011; UNEPc, n.d.

- Will anticipated changes in the land management, the use of the land, or intensified use of the land to produce biomass or feedstock for the project affect neighboring or more distant areas or landowners (for example, if current production shifts to other lands)?
  - If the project entails increased demand for a primary or secondary biomass in the host region, landowners may shift from food or feed crops, resulting in decreasing supply of these. This may lead to the conversion of new land elsewhere to supplement the lost production. In such cases, due care should be taken, and impacts on supply and demand in the region should be subject to further analysis.
- Will production of biomass affect the soil quality or lead to degradation of soil and land?
  - Consider if the provision of biomass for the project entails changes in land management, for example, increased tillage or the use of heavy machinery. This may impact the soil, possibly resulting in degradation.
  - When secondary biomass resources are used, soil degradation and loss of nutrients can occur if ash and other residues are not returned to the soil.
  - If the project is linked to the production of cattle or other grazing animals, additional demand may lead to farmers increasing the number of animals. This, in turn, can lead to overgrazing, which in some areas can cause erosion, and, in other areas, can start desertification processes.
- Are artificial fertilizers or pesticides needed in order to grow the feedstock in sufficient quality and quantity?
  - The use of fertilizers or pesticides may negatively impact soil and water quality, soil productivity, and soil biodiversity.

If the answer to any of the above questions is “yes,” one or more issues of concern will need further data collection and assessment.

#### **15.1.4 AIR**

Clean air is important for humans, animals, and the environment, and air pollution is detrimental for health and food production, among others. Care therefore should be taken to avoid air pollution from the production or conversion of feedstock for bioenergy production. Air pollution can be biological (pollen, fungi), physical (smell,

thermal, radiative), and chemical (ozone, nitrogen oxides, sulfur oxides) and could result from plant emissions and changes of management practices (such as intensification) on agricultural land or in forests.

- Will production, conversion, or transport of the feedstock cause emissions of air pollutants, such as nitrogen oxides, particulate matter, sulfur oxides, ozone, aerosols, soot, or volatile organic compounds?
  - Use of heavy machines or some types of trucks for transport of biomass or feedstock (or other necessary inputs) may result in pollutant emission.
  - Burning of field residues or waste at the biomass production site may lead to pollutant emission.
- Will production, conversion, or transport of the feedstock cause emission of smell and odorous emissions, thermal heat, or radiation?
  - If the feedstock for the project is manure, chicken litter, or waste from food industry treatment, storage and transport of the feedstock may lead to nuisance or pollution if not handled well.
- Will production, conversion, or transport of the feedstock cause emission of biological air pollutants, such as pollen, fungi, or bacteria?

#### Mitigation Measures for Impacts on Air Quality

Growth and subsequent conversion or combustion of biomass feedstocks can have adverse impacts on air quality and should be minimized.

##### Production stage

Spreading of manure can lead to odorous emissions and should be kept to a minimum of time over the year.

##### Conversion stage

Use of efficient trucks and minimization of transport distances can reduce impacts. The facility should be fitted with adequate abatement systems to ensure reduction and removal of, for example, nitrogen oxides, sulfur oxides, and other pollutants, as well as particles (particulate matter) from air emissions. Combustion of some biomass feedstocks can lead to significant local pollution, such as soot particles and carbon monoxide. Efficient plants will minimize these risks. Storage, transport, and treatment should use adequate facilities to minimize the spread of bacteria.

Source: UNEP, 2009.

- If the feedstock is biological waste or if the digested remains from biogas production are used on fields as fertilizer, there may be risk of spread of bacteria and pollutants.
- If the feedstock is biological waste, then transport, treatment, and storage must be organized so that the risk of spreading bacteria is minimized.
- Some agricultural systems, mostly where livestock are involved, can spread spores, which in rare cases may cause health risks if concentrations are high.

If the answer to any of the above questions is “yes,” one or more issues of concern will need further data collection and assessment.

## 15.2 ENVIRONMENTAL SCREENING OF THE BIOMASS-TO-ENERGY OPERATION

Environmental issues related to the operation of the biomass plant itself, include, but are not limited to:

- Odor
- Air pollutant (e.g., nitrogen oxides, sulfur oxides, particulate matter) emissions from the stack
- Wastewater and odor from storage of biomass
- Wastewater from flue gas condensing
- Disposal of waste
- Noise emission
- Operational hazards (for example, risk of fire).

While sourcing of biomass rarely involves permitting, the building and operation of the biomass-to-energy installation usually does. Storage of feedstocks, and the entire supply chain for a biological waste-based energy system, may also require permits that often relate to the environmental impact of the installation. Permits presume regulatory compliance and are the basis for giving the license to operate at all. Therefore, the screening and documentation of environmental issues should be an integrated part of the permitting process.

## 15.3 SOCIOECONOMIC ISSUES

Alongside environmental issues, the development of a biomass project may entail social risks and impacts, especially on local communities affected by the project. This can include impacts on livelihoods, cultural heritage, access to or ownership of land, and access to natural resources. It may also require consideration of gender issues; child labor and vulnerable groups; and food security, especially in those areas where food insecurity is endemic. Finally, it can include impacts on the economic well-being of the affected parties, including employment opportunities, income, and wealth.

In summary, issues to be examined include:

- Food security
- Land acquisition, titling, and tenure
- Access to assets and natural resources
- Community health and safety
- Energy security and access
- Gender and vulnerable groups
- Labor issues, labor rights, employment, wages, and income.

The following stepwise approach to a preliminary screening will allow the project developer to identify the resulting socioeconomic effects of sourcing the particular biomass resource and constructing the plant.

The project developer should systematically screen for socioeconomic issues linked to the type of biomass concerned (primary, secondary, tertiary), as the socioeconomic impacts may vary depending on the feedstock type.

Section 6.2 (Permitting) also includes a list of E&S issues specific to the site and the installation.

Adequate engagement with affected communities throughout the project cycle on issues that could potentially affect them and to ensure that relevant environmental and social information is disclosed and disseminated should be actively sought and implemented by the project proponent. In addition to affected communities, a preliminary list of other potential stakeholders includes:

- Central government authorities and ministries
- Representatives of regions, local governments, and regulatory bodies
- Nongovernmental organizations, including conservation organizations
- Labor organizations, trade organizations, farmers groups, and community-based organizations
- Private sector, research agencies, universities, and consulting firms
- Financing institutions, small-scale finance providers, and insurance companies
- Religious and cultural organizations.

### Guidance on SIAs

A number of guidance and policy documents as well as performance standards on social impact assessment (SIA) could be consulted before deciding if and how to conduct an SIA. These include, for example, the International Association for Impact Assessment's (IAIA) 2015 guidance document for SIA (IAIA, 2015), as well as IFC's Performance Standards on Environmental and Social Sustainability (IFC, 2012).

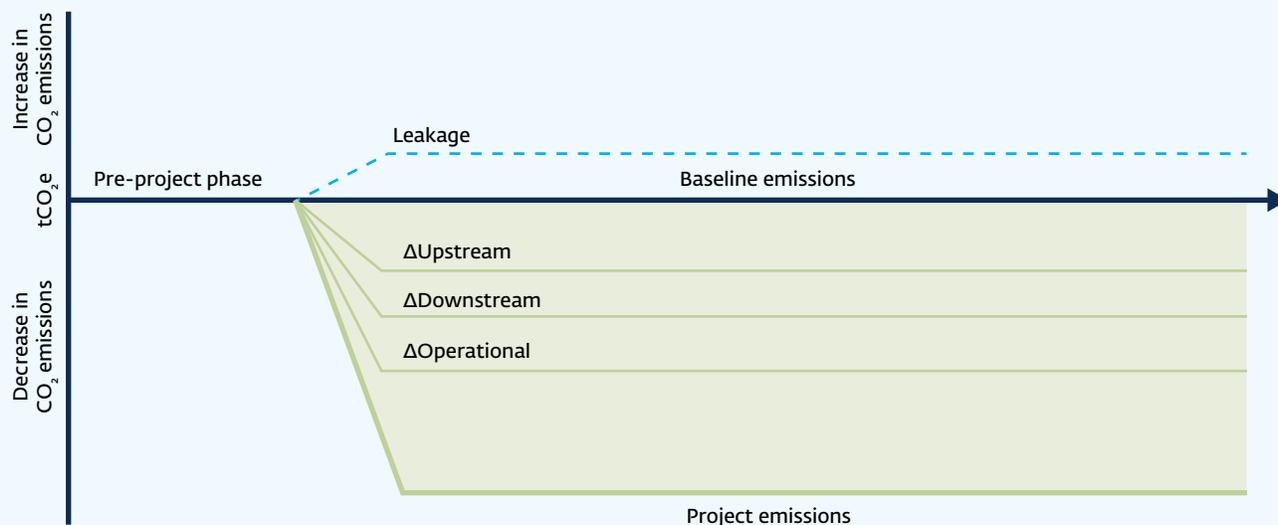
An example of guiding E&S questions can be seen on the following pages in Table 15–2.

## 15.4 GREENHOUSE-GAS EMISSION ESTIMATES

Estimation of greenhouse-gas benefits of a biomass-to-energy project is based on existing IFC guidelines, as shown below, and is complemented, where relevant, with existing methodologies. These include the United Nations Framework Convention on Climate Change Clean Development Mechanism, the Intergovernmental Panel on Climate Change Good Practice Guidance on Greenhouse Gas Reporting, and the European Union Renewable Energy Directive (RED) methodology, as well as related tools, such as BioGrace-II.

Following the approach in IFC *Definitions and Metrics for Climate-Related Activities* (June 2013), greenhouse-gas emission reductions are calculated from a baseline scenario (that is, the scenario that would take place had the biomass project not been implemented). Figure 15–1 illustrates this.

**Figure 15-1: Project Emission Reductions<sup>a</sup>**



Source: IFC, 2013.

a The emission reductions are calculated from a baseline, which signify the emissions in the absence of the biomass project. The emissions are calculated as differences,  $\Delta$  (reductions or increases), in upstream, downstream, and operational emissions, between the baseline scenario and the biomass project, and any emissions resulting from leakage. The total emissions reductions are given in tons of carbon dioxide-equivalent per MJ. Figure based on IFC (2013)

As a general rule, all greenhouse-gas emission sources that change due to the biomass project should be calculated, although those that are negligible can be excluded from the calculation. The default calculation will be based on the following steps:

1. Upstream emissions
2. Operational emissions
3. Downstream emissions
4. Leakage.

Each of the steps of the value chain is associated with emission of greenhouse gases. Therefore, the total emissions of the project are equal to:

$$\text{Project Emissions} = \text{Upstream Emissions} + \text{Operational Emissions} + \text{Downstream Emissions} + \text{Leakage}$$

The total greenhouse-gas emission reduction achieved because of the biomass project are equal to:

$$\begin{aligned} \text{Greenhouse-gas reduction} &= \text{Baseline Emissions} \\ &\quad - \text{Project Emissions} \\ &= \Delta\text{Upstream Emissions} \\ &\quad + \Delta\text{Operational Emissions} \\ &\quad + \Delta\text{Down-stream Emissions} \\ &\quad + \text{Leakage} \end{aligned}$$



Source: COWI.

**Table 15-2:** Overview of Proposed Questions to Screen for Environmental and Social Issues on Biomass-to-Energy Projects, based on IFC Performance Standards

Assessment and Management of Environmental and Social Risks and Impacts (PS1)	
Introduction	PS1 underscores the importance of identifying environmental and social risks and impacts, and managing these according to an Environmental and Social Management System (ESMS) throughout the lifetime of a project. ESMS entails a methodological approach to managing environmental and social risks and impacts in a structured way on an ongoing basis.
Objectives	<ul style="list-style-type: none"> <li>• To identify and evaluate environmental and social risks and impacts of the project.</li> <li>• To adopt a mitigation hierarchy to anticipate and avoid, or where avoidance is not possible, minimize and, where residual impacts remain, compensate/offset for risks and impacts to workers, affected communities, and the environment.</li> <li>• To promote improved environmental and social performance of clients through the effective use of management systems.</li> <li>• To ensure that grievances from affected communities and external communications from other stakeholders are responded to and managed appropriately.</li> <li>• To promote and provide means for adequate engagement with affected communities throughout the project cycle on issues that could potentially affect them and to ensure that relevant environmental and social information is disclosed and disseminated.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• Conduct, if necessary in coordination with government agencies, a process of environmental and social assessment, and establish and maintain an ESMS appropriate to the nature and scale of the project and commensurate with the level of its environmental and social risks and impacts.</li> <li>• The ESMS will incorporate the following elements:               <ul style="list-style-type: none"> <li>• Policy</li> <li>• Identification of risks and impacts</li> <li>• Management programs</li> <li>• Organizational capacity and competency</li> <li>• Emergency preparedness and response</li> <li>• Stakeholder engagement</li> <li>• Monitoring and review.</li> </ul> </li> </ul>
Questions	<ul style="list-style-type: none"> <li>• Has a process for identifying the environmental and social risks and impacts of the project been established and measures to ensure its implementation and maintenance enacted?</li> <li>• Have all relevant stakeholders been identified and consulted in relation to project development? This includes local, national, and international organizations that are likely to have an interest in the project.</li> <li>• Have stakeholder expectations been clarified? Have areas where accidents and emergency situations may occur been identified? Is there an emergency preparedness and response system/plan?</li> <li>• Does the project negatively affect local communities in the project's area of influence?</li> <li>• How will potential conflicts be resolved? Is there a grievance redressal mechanism?</li> <li>• Could the project cause migration or otherwise displace people?</li> </ul>
Labor and Working Conditions (PS2)	
Introduction	PS2 recognizes that the pursuit of economic growth through employment creation and income generation should be accompanied by protection of the fundamental rights of workers.
Objectives	<ul style="list-style-type: none"> <li>• To promote the fair treatment, non-discrimination, and equal opportunity of workers.</li> <li>• To establish, maintain, and improve the worker-management relationship.</li> <li>• To promote compliance with national employment and labor laws</li> <li>• To protect workers, including vulnerable categories of workers such as children, migrant workers, workers engaged by third parties, and workers in the client's supply chain.</li> <li>• To promote safe and healthy working conditions, and the health of workers.</li> <li>• To avoid the use of forced labor.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• Implement policies and procedures relating to Working Conditions and Management of Worker Relationship, Protection of the Work Force, Occupational Health and Safety, and Supply Chain considerations, including Terms of Employment, Workers' Organizations, Non-Discrimination and Equal Opportunity, Child and Forced Labor.</li> </ul>

**Table 15-2:** Overview of Proposed Questions to Screen for Environmental and Social Issues on Biomass-to-Energy Projects, based on IFC Performance Standards (*continued*)

Labor and Working Conditions (PS2) ( <i>continued</i> )	
Questions	<ul style="list-style-type: none"> <li>• Have human resources policies and procedures been adopted and implemented?</li> <li>• Is there freedom of association and do collective bargaining agreements exist and have these been respected?</li> <li>• Could potential risks to worker rights arise due to the project?</li> <li>• Have an appropriate engagement process and a grievance mechanism been implemented?</li> <li>• Is there an occupational health and safety management system in place?</li> </ul>
Resource Efficiency and Pollution Prevention (PS3)	
Introduction	PS3 recognizes that increased economic activity often generates increased levels of pollution to air, water, and land and consumes finite resources in a manner that may threaten people and the environment at the local, regional, and global levels.
Objectives	<ul style="list-style-type: none"> <li>• To avoid or minimize adverse impacts on human health and the environment by avoiding or minimizing pollution from project activities.</li> <li>• To promote more sustainable use of resources, including energy and water.</li> <li>• To reduce project-related greenhouse-gas emissions.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• Consider ambient conditions and apply technically and financially feasible resource efficiency and pollution prevention principles and techniques that are best suited to avoid, or where avoidance is not possible, minimize adverse impacts on human health and the environment</li> <li>• The principles and techniques applied during the project lifecycle will be tailored to the hazards and risks associated with the nature of the project and consistent with good international industry practice.</li> </ul>
Questions	<ul style="list-style-type: none"> <li>• Could the project development or activities necessary to support the project impact water use, electricity consumption, sewage, and other services?</li> <li>• Have alternatives and technically and financially feasible and cost-effective options to reduce project-related greenhouse-gas emissions during the design and operation of the project been considered?</li> <li>• Have direct emissions from within the physical project boundary, as well as indirect emissions associated with the off-site production of energy used by the project, been quantified?</li> <li>• Have measures that avoid or reduce water usage been implemented, so that the project's water consumption does not have significant adverse impacts on the local environment, including affected communities?</li> <li>• Have measures to avoid the release of air pollutants and wastewater or, when avoidance is not feasible, minimization and/or control of the intensity and mass flow of their release, been implemented?</li> <li>• Have measures or technical installations to avoid the generation of hazardous and non-hazardous waste materials been implemented?</li> <li>• Has an integrated pest management approach, including the use of chemical pesticides, been formulated and implemented? (Relevant only to projects using primary feedstock).</li> </ul>
Community Health, Safety, and Security (PS4)	
Introduction	PS4 recognizes that project activities, equipment, and infrastructure can increase community exposure to risks and impacts.
Objectives	<ul style="list-style-type: none"> <li>• To anticipate and avoid adverse impacts on the health and safety of the affected community during the project life from both routine and non-routine circumstances.</li> <li>• To ensure that the safeguarding of personnel and property is carried out in accordance with relevant human rights principles and in a manner that avoids or minimizes risks to the affected communities.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• Evaluate the risks and impacts to the health and safety of the affected communities during the project lifecycle and establish preventive and control measures consistent with good international industry practice.</li> </ul>

(*continued*)

**Table 15-2:** Overview of Proposed Questions to Screen for Environmental and Social Issues on Biomass-to-Energy Projects, based on IFC Performance Standards (*continued*)

Community Health, Safety, and Security (PS4) ( <i>continued</i> )	
Questions	<ul style="list-style-type: none"> <li>• Could the project negatively affect community social or human capital?</li> <li>• Could production of the feedstock in question adversely affect local production of or access to food?</li> <li>• Could utilization of the feedstock in question restrict or limit access to energy by local communities and stakeholders?</li> <li>• Could the project adversely affect women and girls?</li> <li>• Could the project negatively affect disadvantaged and vulnerable groups?</li> <li>• Could the use of the feedstock in question negatively affect local agricultural markets, and what are the impacts of these changes?</li> <li>• Will the use of the feedstock in question cause local food prices to increase?</li> <li>• Could the use of the feedstock in question negatively affect poverty in the local area?</li> <li>• Has the use of hazardous materials and substances been avoided or minimized to the extent possible?</li> <li>• Could the impact of the biomass-to-energy project on local ecosystem services result in adverse health and safety risks and impacts to Affected Communities?</li> <li>• Has the community exposure to water-borne, water-based, water-related, and vector-borne diseases and communicable diseases been avoided or minimized to the extent possible?</li> <li>• Have preparations to respond effectively to emergency situations been made and procedures established?</li> <li>• Could the project negatively affect economic growth in the region?</li> <li>• Could the development of the project or the use of the feedstock in question negatively affect employment in the region?</li> </ul>
Land Acquisition and Involuntary Resettlement (PS5)	
Introduction	PS5 recognizes that project-related land acquisition and restrictions on land use can have adverse impacts on communities and persons that use this land. PS5 does not apply to resettlement resulting from voluntary land transactions (i.e., market transactions in which the seller is not obliged to sell and the buyer cannot resort to expropriation or other compulsory procedures sanctioned by the legal system of the host country if negotiations fail).
Objectives	<ul style="list-style-type: none"> <li>• To avoid, and when avoidance is not possible, minimize displacement by exploring alternative project designs.</li> <li>• To avoid forced eviction.</li> <li>• To anticipate and avoid, or where avoidance is not possible, minimize adverse social and economic impacts from land acquisition or restrictions on land use by 1) providing compensation for loss of assets at replacement cost and 2) ensuring that resettlement activities are implemented with appropriate disclosure of information, consultation, and the informed participation of those affected.</li> <li>• To improve, or restore, the livelihoods and standards of living of displaced persons.</li> <li>• To improve living conditions among physically displaced persons through the provision of adequate housing with security of tenure at resettlement sites.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• Consider aspects related to Compensation and Benefits for Displaced Persons, Community Engagement, Grievance Mechanism, Resettlement and Livelihood Restoration Planning and Implementation, and Displacement.</li> </ul>
Questions	<ul style="list-style-type: none"> <li>• Can feasible, alternative project designs avoid or minimize physical and/or economic displacement, and have these been considered?</li> <li>• Are there risks of resettlement and use of land by stakeholders or affected communities due to project development?</li> <li>• If so, has a Resettlement Action Plan that covers, at a minimum, the applicable requirements of this Performance Standard, been developed?</li> <li>• How is the impact on project-displaced persons monitored?</li> <li>• Could access to or use of land by local stakeholders be affected by the use of the feedstock?</li> <li>• Has ownership of land resources in the area from where biomass feedstock is procured been assessed?</li> <li>• Could the project negatively affect access to or use of land by local stakeholders?</li> <li>• Has a grievance mechanism consistent with Performance Standard 1 been established?</li> </ul>

**Table 15-2:** Overview of Proposed Questions to Screen for Environmental and Social Issues on Biomass-to-Energy Projects, based on IFC Performance Standards (*continued*)

Biodiversity Conservation and Sustainable Management of Living Natural Resources (PS6)	
Introduction	PS6 recognizes that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development.
Objectives	<ul style="list-style-type: none"> <li>To protect and conserve biodiversity.</li> <li>To maintain the benefits from ecosystem services.</li> <li>To promote the sustainable management of living natural resources through the adoption of practices that integrate conservation needs and development priorities.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>Consider direct and indirect project-related impacts on biodiversity and ecosystem services and identify any significant residual impacts</li> <li>Avoid impacts on biodiversity and ecosystem services. When avoidance of impacts is not possible, measures to minimize impacts and restore biodiversity and ecosystem services should be implemented.</li> <li>If the project involves the utilization of primary biomass resources, certain requirements exist. These are specified in paragraphs 26 through 30 of PS6. Further, if a project relies on purchasing primary production that is known to be produced in regions where there is a risk of significant conversion of natural and/or critical habitats, systems and verification practices will be adopted as part of the client's ESMS to evaluate its primary suppliers.</li> </ul>
Questions	<ul style="list-style-type: none"> <li>Could the project directly or indirectly significantly convert or degrade natural habitats or ecosystems?</li> <li>Have relevant threats to biodiversity and ecosystem services, including habitat loss, degradation and fragmentation, invasive alien species, overexploitation, hydrological changes, nutrient loading, and pollution, been considered?</li> <li>Have the values (economic and otherwise) attached to biodiversity and ecosystem services by affected communities and other stakeholders been taken into account?</li> <li>Have mitigation measures been designed to achieve no net loss of biodiversity and ecosystem services?</li> <li>Are there any critical habitats within the area, which the project will affect? Critical habitat areas and/or areas with high biodiversity value, including: 1) habitat of significant importance to critically endangered and/or endangered species; 2) habitat of significant importance to endemic and/or restricted-range species; 3) habitat supporting globally significant concentrations of migratory species and/or congregatory species; 4) highly threatened and/or unique ecosystems; and/or 5) areas associated with key evolutionary processes. If so, PS6 outlines a number of considerations that must be adhered to.</li> <li>Could the project intentionally or accidentally introduce alien, or non-native, species of flora and fauna into areas where they are not normally found?</li> <li>If the project utilizes primary resources, has land-based agribusiness and forestry projects been located on unforested land or land already converted?</li> </ul>
Indigenous Peoples (PS7)	
Introduction	PS7 recognizes that Indigenous Peoples, as social groups with identities that are distinct from mainstream groups in national societies, are often among the most marginalized and vulnerable segments of the population. The following section only applies if Indigenous Peoples are among the Affected Communities.
Objectives	<ul style="list-style-type: none"> <li>To ensure that the development process fosters full respect for the human rights, dignity, aspirations, culture, and natural resource-based livelihoods of Indigenous Peoples.</li> <li>To anticipate and avoid adverse impacts of projects on communities of Indigenous Peoples, or when avoidance is not possible, to minimize and/or compensate for such impacts.</li> <li>To promote sustainable development benefits and opportunities for Indigenous Peoples in a culturally appropriate manner.</li> <li>To establish and maintain an ongoing relationship based on Informed Consultation and Participation (ICP) with the Indigenous Peoples affected by a project throughout the project's lifecycle.</li> <li>To ensure the free, prior, and informed consent (FPIC) of the affected communities of Indigenous Peoples when the circumstances described in this Performance Standard are present.</li> <li>To respect and preserve the culture, knowledge, and practices of Indigenous Peoples.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>Avoid adverse impacts on Indigenous Peoples and ensure participation and consent.</li> <li>If the project is located on, or seeks to commercially develop natural resources on lands traditionally owned by, or under the customary use of, Indigenous Peoples, and adverse impacts can be expected, specific requirements apply.</li> </ul>

(*continued*)

**Table 15-2:** Overview of Proposed Questions to Screen for Environmental and Social Issues on Biomass-to-Energy Projects, based on IFC Performance Standards (*continued*)

Indigenous Peoples (PS7) ( <i>continued</i> )	
Questions	<ul style="list-style-type: none"> <li>• Have all communities of Indigenous Peoples within the project area of influence who may be affected by the project been identified?</li> <li>• Where adverse impacts are unavoidable, have measures to minimize, restore, and/or compensate for these impacts in a culturally appropriate manner commensurate with the nature and scale of such impacts and the vulnerability of the affected communities of Indigenous Peoples been implemented?</li> <li>• Has an engagement process with the affected communities of Indigenous Peoples (as required in PS1) been undertaken?</li> <li>• Are there circumstances requiring Free, Prior, and Informed Consent of the Affected Communities of Indigenous Peoples?</li> <li>• Have feasible, alternative project designs to avoid the relocation of Indigenous Peoples from communally held lands and natural resources subject to traditional ownership or under customary use been considered?</li> </ul>
Cultural Heritage (PS8)	
Introduction	PS8 recognizes the importance of cultural heritage for current and future generations.
Objectives	<ul style="list-style-type: none"> <li>• To protect cultural heritage from the adverse impacts of project activities and support its preservation.</li> <li>• To promote the equitable sharing of benefits from the use of cultural heritage.</li> </ul>
Requirements	<ul style="list-style-type: none"> <li>• To protect Cultural Heritage in Project Design and Execution.</li> </ul>
Questions	<ul style="list-style-type: none"> <li>• Could the project negatively affect community cultural capital?</li> <li>• By ensuring that internationally recognized practices for the protection, field-based study, and documentation of cultural heritage are implemented, has cultural heritage been identified and protected?</li> <li>• If the project site contains cultural heritage, have measures been taken to ensure continued access to the cultural site?</li> </ul>

Source: IFC, 2012.

### 15.4.1 BASELINE EMISSIONS

The approach applied by IFC for calculating baseline emissions follows that of the international financial institution *Approach to GHG Assessment in the Renewable Energy Sector*, where a default greenhouse-gas emission factor for the electricity sector in the country is calculated as:

$$\text{Electricity Factor} = [0.50 \times \text{Operating Margin}] + [0.50 \times \text{Build Margin}]$$

The **Operating Margin (OM)** is the average carbon dioxide emission per unit of electricity generated (tons of carbon dioxide per MWh) in the area, as published by the International Energy Agency (IEA). The **Build Margin (BM)** is carbon dioxide emission per unit of electricity generated (tons of carbon dioxide per MWh) using the most efficient fossil fuel electricity generation available in the country (according to the IEA) (IFC, 2013).

If such calculation cannot be performed, either of the following two approaches can be used instead:

1. A country grid emission factor for electricity, calculated using the approach of the United Nations Framework Convention on Climate Change Clean Development Mechanism, which is no more than two years old and has been validated by a third party.
2. A transparent, project-specific study.

For non-grid connected energy, the baseline is calculated using the combustion factor for the fossil fuel (for example, diesel oil) that is used to generate electricity or heat and that will be displaced following the installation of the biomass project.

### 15.4.2 UPSTREAM EMISSIONS

The calculation approach applicable for upstream emissions depends on the source of feedstock used for the biomass project.

For **tertiary feedstock** (waste biomass), upstream greenhouse-gas emissions associated with production of the feedstock can generally be excluded.

For **primary and secondary feedstock** (non-waste biomass), upstream greenhouse-gas emissions associated with

production, land use, and harvest of biomass need to be included in the calculation.

### PRODUCTION EMISSIONS

For primary and secondary feedstock, the emissions resulting from the use of mineral fertilizer and manure will have to be calculated using the Global Nitrous Oxide Calculator (GNOC).<sup>12</sup>

In order to calculate the emissions of nitrous oxide, the information to be entered into the GNOC is given in Table 15–3.

### LAND-USE EMISSIONS

For secondary and tertiary feedstocks, calculation of land-use emissions (resulting from direct and indirect land-use change) are not performed.

For primary feedstock, the emissions resulting from land-use change must be included if forested areas, natural grasslands

or shrub lands, or wetlands are used for feedstock. The loss of carbon from conversion of land will have to be performed using either of these methodologies (in order of preference):

1. Calculation using a common, acknowledged tool (for example, CDM methodology, BioGrace-II, or EX-ACT)
2. Use of figure (tons of carbon per hectare) for a given region, soil type, and biome given in Winrock International or Woods Hole Research Center databases
3. Use of figure (tons of carbon per hectare) for a given region, soil type, and biome published in peer-reviewed literature
4. Use of figure (tons of carbon per hectare) for a given region, soil type, and biome published in official reports and publications (by, for example, IFC, EU, national governments).

<sup>12</sup> Available at <http://gnoc.jrc.ec.europa.eu/>

	Information to Be Entered into GNOC	Aspects to Consider
Place	Search for the location (such as Indonesia) or enter the coordinates of the crop production (x, y).	Most locations are available in the calculator. If the given region is not available, the country should be used.
Crop	Select the appropriate crop from the dropdown list. The list of crops to choose from includes: Barley, Cassava, Coconut, Cotton, Maize, Oil Palm Fruit, Rape Seed, Rye, Safflower Seed, Sorghum, Soy Bean, Sugar Beet, Sugar Cane, Sunflower Seed, Triticale, and Wheat.	If the selected feedstock is not available, calculation will have to be performed using either of these methodologies (in order of preference): <ul style="list-style-type: none"> <li>• Using IPCC Tier 1 Calculation method, using, for example, BioGrace-II tool.</li> <li>• Calculating a value in GNOC using a different crop.</li> <li>• Using a number given in peer-reviewed literature.</li> <li>• Estimating a value, using other means of calculation.</li> </ul>
Soil type	Select whether the soil is organic or mineral.	The definition of organic soil is given in GNOC. Consult this if soil type is unknown. If the soil type cannot be defined using the information in GNOC, select the soil most prevalent in the region. If this is also unknown, select mineral soil.
Irrigation	Select whether the crop is irrigated or not (yes/no).	Please select “yes” if the crop is irrigated (except drip irrigation), for which no nitrogen leaching is assumed (IPCC, 2006).
Fresh yield	Enter the fresh yield (in kilograms per hectare)	Coconut yield has to be given as yield of “husked coconut in shell” [KILOGRAMS PER HECTARE]. See GNOC for further information.
Mineral fertilizer	Enter the amount of mineral fertilizer applied (in kilograms of nitrogen per hectare)	Annual amount of synthetic nitrogen fertilizer applied to the field (in kilograms of nitrogen per hectare).
Manure	Enter the amount of manure applied (in kilograms of nitrogen per hectare)	Annual amount of managed animal manure applied to the field [IN KILOGRAMS OF NITROGEN PER HECTARE]. See GNOC for further information.

Source: COWI.

The total emission resulting from change of land will have to be annualized over the life of the project:

$$\text{Annual emissions} \left( \frac{\text{tC}}{\text{ha} \times \text{year}} \right) = \frac{\text{Total emissions} \left( \frac{\text{C}}{\text{ha}} \right)}{\text{Project lifetime (year)}}$$

The calculated figure (tons of carbon per hectare per year) must be added to the yearly emissions (upstream emissions) resulting from the project.

#### HARVEST, PROCESSING, AND STORING OF BIOMASS

Any emissions resulting from harvest of biomass must be included for primary and secondary feedstock sources.

This includes energy used by harvesting equipment and for compaction or processing of biomass.

For those feedstock types where significant processing is required (for example, for the production of wood pellets) or where handling takes place (for example, wood chipping or baling of straw), emissions from these activities must be included. If these activities take place on-site, they can be calculated under operational emissions, if energy use is part of the total operation.

If these emissions take place separately from the generation of energy, the emissions must be calculated using a validated tool or methodology, for example BioGrace-II or CDM



Source: COWI.

methodologies. Emissions resulting from the storage of feedstock (for example, leakage of methane from stored manure) must also be included in the calculation.

#### TRANSPORT OF BIOMASS

For all three feedstock types (primary, secondary, tertiary), emissions resulting from the transport of the feedstock must be included in the calculation. This includes emissions resulting from transport by truck, freight train, and bulk carrier. Transport must be given in kilometers and the total emissions resulting from this (in kilograms of carbon dioxide-equivalent per kilometer) must be added to the total upstream emissions.

#### 15.4.3 OPERATIONAL EMISSIONS

Operational emissions include emissions associated with on-site processes and activities on the biomass plant and emissions associated with (on-site or off-site) pretreatment of the feedstock (for example, wood pellet production). This includes any mobile or stationary fuel combustion (for example, for power or heating), as well as electricity purchased from the grid. Other relevant emission sources include onsite land use, waste, wastewater, and cooling and refrigeration, if applicable.

#### 15.4.4 DOWNSTREAM EMISSIONS

Downstream emissions are generally excluded from the calculation. However, in those situations where downstream emissions are larger than those downstream emissions

associated with the baseline scenario, these should be calculated and included.

For biomass operations, where significant waste products occur (for example, digested remains from biogas production), those emissions resulting from transport and disposal of these waste products must be included in the calculation. Similarly, emissions resulting from any downstream operations related to the biomass-to-energy project also should be included.

#### 15.4.5 EMISSIONS FROM LEAKAGE

Leakage are those emissions resulting from activities beyond the project boundary, for example by causing increases in greenhouse-gas emissions from an activity not directly related to the biomass project, or by displacing a source of greenhouse-gas emissions off-site.

Leakage is particularly relevant in those situations where the feedstock has other uses within the region. For example, straw can be used for local combustion or as feedstock for animals, and the use of the feedstock for energy generation in the biomass project risks forcing the current users of the feedstock to find alternatives for their current activities (such as importing feed instead of using straw). In situations where this takes place, the emissions resulting from displacement of current activities should be attributed to the biomass project.



Source: COWI.

This chapter presents key learnings and international best practice based on experience from the implementation of representative biomass projects. Because the variety and complexity of biomass projects is huge, not all learnings apply to all type of projects.

## 16.1 IMPORTANT CONSIDERATIONS WHEN INITIATING A BIOMASS PROJECT

The following illustrates typical initial considerations that any project owner or developer must ask when initiating a biomass project. Experience shows that a “no” to one or more of the following questions may stop or substantially delay a project.

- **Is sufficient biomass available at a uniform quality?** Sufficient quantities of biomass residues owned by the developer on-site is a less risky source than off-site biomass from third parties. However, if the available on-site biomass is insufficient, the developer should seek additional sources of biomass off-site within a reasonable distance of the intended plant and investigate whether the cost for the biomass fuel and its transport is competitive. For projects depending on biomass supplied by a third party, the ability to enter into long-term supply agreements with few and credible counterparts is the key to success.
- **Is the biomass fuel suitable for combustion without major risks?** Some biomass fuels, such as sugarcane residues, straw, and sorghum, can have very corrosive properties, and it therefore is important to ensure the application of a suitable technology and equipment quality.
- **Is there a well-defined market for the power and/or heat produced?** The ability to substitute in-house, fossil fuel-based energy with biomass may provide an easier business case than reliance on the sale of heat and power to third-party customers or to the national grid. If power sale to the grid is envisioned, it will be

important to have agreed standardized connection terms and a suitable grid connection point within a short distance. Heat-only production (process steam and/or hot water) may be the easier and right solution for many industries.

- **Does the project owner have sufficient strength and access to finance to bring the project to completion?** For small and medium companies in countries where the financial markets are unfamiliar with biomass projects, own funds (equity), funds from a parent company, or supplier finance may provide financing at better terms and conditions.
- **Is a suitable-sized site for the biomass plant identified?** A site in close proximity to the industrial consumer of steam/heat and to the source of biomass should be identified. The site must have an adequate size for the plant, including infrastructure such as roads, unloading facilities, etc. Additional land should be made available during the construction phase, but temporary land often can be rented from neighbors.

## 16.2 THE LOW-HANGING FRUIT IN BIOMASS PROJECTS

- Biomass processing industries or biomass producing companies, with biomass byproducts and residues, a demand for process energy, and/or proximity to an external energy consumer, may have a good basis for a biomass-to-energy project. Many successful projects exist within industries such as pulp and paper, wood, palm oil, sugar, olives, coconuts, instant coffee, etc.
- Substitution of expensive fossil fuels with biomass residues may be beneficial for some industries and enhances their competitiveness.
- The use of local biomass as a fuel eliminates or reduces the reliance on a stable fossil fuel supply. At the same

time, local production of energy is a catalyzer for the local economy in terms of extra jobs in the fuel supply chain.

- In-house production of electricity and steam/heat from biomass may be a more reliable energy source than unstable external supplies, and production interruptions at the enterprise may be avoided.

## 16.3 IMPORTANT LESSONS LEARNED

### BIOMASS AVAILABILITY AND SUPPLY CHAIN

- The most important question to ask is whether sufficient biomass residue of the proper quality is available from the industrial facility's own production, perhaps supplemented by local agricultural or forestry biomass wastes.
- For fuels sourced off-site, biomass must be secured by long-term contracts. The contracts must contain all relevant issues for the fuel supply, including quality requirements such as moisture range, sizing, and absence of foreign elements. In addition, the contract should specify all commercial aspects such as price terms, penalties, rejection right, and other conditions. The establishment of a stable and reliable supply chain for off-site fuels is one of the most critical and difficult aspects of the biomass project and requires careful analysis.
- When the energy production depends on agricultural or forestry production residues, the seasonal variation of biomass production becomes a determining factor for its availability (for example, delivery problems during the rainy season). It therefore is essential to map the seasonal variation for the most common crops that deliver the secondary or tertiary biomass for energy production. Furthermore, storage facilities may be established on-site at the plant or off-site at the premises of the biomass suppliers if storage is needed due to production or seasonal variations. In all cases, the on-site storage capacity must be determined and approved. Typically, storage capacity at the biomass plant site of a minimum of three to four days is needed.
- It is important to consider biomass flexibility, in terms of supply, delivery, storage, preparation, and feeding. Better flexibility with alternative biomass types may increase the industry's operating time and availability if there is a shortage of the preferred fuel. In any case, it is important

to identify a secondary biomass supply at an early stage of the project.

### TECHNOLOGY SELECTION AND DESIGN

- If the moisture content in the fuel is above 60 to 65 percent, anaerobic digestion may be the choice of technology. For drier biomass wastes, a combustion technology will be more suitable.
- Proven technologies are essential, but in order to reduce capital costs, a local low-cost supplier may supply the technology in cooperation with an international, reliable, and experienced supplier who is responsible for the process design.
- The intended fuels will determine the combustion technology to use, but they also must be evaluated in terms of suitability for handling and storage at the site. The fuel sizing and content of potential corrosive elements will influence the selection of boiler technology and materials in the boiler parts. It must be verified that internationally proven equipment suppliers can accept the chosen type of biomass and that acceptable warranties can be guaranteed. Selection of unproven technology or unexperienced suppliers may easily lead to delays, operational problems, and budget overruns.
- If power production and export to the grid is foreseen, it is important at an early stage to check that a grid connection is possible at the right voltage and within close proximity. It also should be determined who should erect and finance the connection. It is important to check emission limitations at an early stage, as this may influence the choice of technology, especially in the flue gas cleaning system.
- Fuel flexibility is important in case of a lack of supply of the intended biomass fuel.
- Handling and disposal and/or reuse of residues (bottom ash and fly/boiler/flue gas cleaning ash) must be assessed carefully, as this can substantially influence the project economy.
- Island operation (off-grid operation) is an important feature in many developing countries with daily dispatch of the electrical grid. Requirements for island-mode

operation must be part of the technical description in the tender specification/contract.

### CONVERSION OF EXISTING BOILERS TO PARTIAL OR FULL BIOMASS COMBUSTION

- If conversion of existing boilers is foreseen, the involvement of the boiler supplier at an early stage is very important. The original equipment supplier is best suited to determine potential consequences of converting the existing boiler to the selected biomass fuel.
- Careful consideration should be given to whether a conversion of the existing technology is the best long-term solution compared to a new plant.

### COMMERCIAL AND FINANCIAL VIABILITY OF PROJECTS

- The key driver of financial viability of biomass projects is a stable, low-cost supply of biomass in sufficient quantity and quality.
- If export of energy is anticipated, access to a market with acceptable prices for the heat and power produced is crucial. Sale of both electricity and steam/heat should improve the financial viability of the project, otherwise only in-house consumption should be assumed. It is important to check whether the feed-in tariff is guaranteed and for how long.
- Sale of process heat/steam to nearby industries or as district heating also may improve the financial viability of the project.
- Access to finance at competitive terms is important. For smaller projects in countries with less developed financial sectors, supplier finance may be a more competitive solution than bank finance.
- As a rule of thumb, biomass combustion projects typically face capital costs between \$1 million per MWe (as in China and India) and \$3 million to \$3.5 million per MWe (as in Europe and North America).

### PROJECT DEVELOPMENT

- Development of a biomass project should progress in well-defined stages, such as the pre-feasibility study, feasibility study, planning applications, procurement, etc. For each stage completed, a go or no-go decision should

determine the progress to the next stage. Improper planning and incorrect selection of technology is likely to lead to delays, operational problems, and budget overruns. Assistance to the owners from experts in planning and technical issues is recommended.

- The development process will require substantial assistance from specialists with experience in engineering, architecture, environment, legal issues, and economics/finance. No project will receive financing if the early development work is lacking in quality and scope.
- It is important to check whether national (and any regional or international) legislation is in favor of this type of project and that environmental approval can be expected. Time needed to prepare and obtain an environmental impact assessment and gain environmental approval is often underestimated, and this may jeopardize the time schedule.
- A proper site investigation is highly recommended. Detection of underground obstructions, the need for piling, archaeological issues, etc. may cause delays that should be identified and addressed.
- Availability of cooling water for the steam cycle (condensing of the steam) will increase plant efficiency and benefit the business case.

### PROCUREMENT

- It is crucial that owners do not sign contracts without assistance from advisers who are experienced in technical and legal aspects. Contracts often lack sufficient stipulations and regulations on issues such as performance guarantees, liquidated damages, delay damages, testing regime, how to remedy defects, etc.
- Development of a detailed technical specification as part of the contract is important. This includes topics such as the scope of supply, limits of supply, main design values of equipment, etc.
- It is important to base the tendering on internationally well-known contract specifications in order to attract the best suppliers for larger projects in anticipation of international competition.

- The contract document should include proper functional and performance testing schemes, and these should be verified and documented during plant commissioning.
- Contractual guarantee requirements linked to liquidated and delay damages should secure the timely delivery of a well-performing power plant.
- Availability and continuous operating time without manual cleaning stops must be demonstrated during the first year of operation. Agreements on this aspect must be part of the contract.

### OPERATION AND MAINTENANCE

- A biomass plant is a technically complex setup that requires staff with sufficient skills. A good and sound solution is to

engage the equipment supplier's supervisor for a period of one to two years in order to assist the owner's staff during the time of first operation. The operation and maintenance also may be outsourced to an operation and maintenance operator on a long-term contract.

- Training of staff must be planned in due time during construction (for example by the technology provider and the consultant). Training at similar facilities should be considered as an alternative.
- Maintenance according to the equipment supplier's instructions throughout the project life is crucial in order to maintain the plant's availability.

# APPENDICES

<b>APPENDIX A Biomass-to-Energy Screening List</b>		
<b>Project Information</b>	<b>Unit</b>	<b>Input</b>
Project name		
Client/owner		
City		
State/province		
Country		
Type of industry		
Type of project		
<ul style="list-style-type: none"> <li>• Steam technology</li> <li>• ORC technology</li> <li>• Biogas technology</li> </ul>		
<b>General Questions</b>		
Are employees with required skills readily available to manage and run the plant?	yes/no	
Is national (and any regional or international) legislation in favor of this type of project, and can environmental approval be expected? Does legislation allow such facilities?		
<b>Residual Biomass Fuel Data</b>		
Is the biomass waste appropriate as fuel for energy production?		
Type of biomass		
Is a potential corrosive behavior of the fuel acceptable by technology providers?		
Annual amount	tons	
Calorific value	MJ/kg	
Moisture content	%	
Other characteristics (particle size, etc.)		
Is the rainy season an obstacle if using forestry or agricultural biomass residues?		

(continued)

**APPENDIX A Biomass-to-Energy Screening List (continued)****Supplementary Biomass Fuel Data**

Type of biomass		
Is a potential corrosive behavior of the fuel acceptable by technology providers?		
Calorific value	MJ/kg	
Moisture content	%	
Other characteristics (particle size, etc.)		
Logistics (delivery by truck, etc.)		
Cost of fuel	\$/ton	
Is the rainy season an obstacle?		

**Energy Supply Data (to Industry)**

Requested power output	MW	
Requested heat output	MW	
Data heat output	bar/°C	
Requested steam output	tons/hour	
Data steam output	bar/°C	
Constant supply	yes/no	
Operating time	hours/year	

**Electrical Grid**

Is a well-defined market for export of energy (electricity and/or steam/heat) available with long-term secured prices, making the project feasible?	yes/no	
Distance to electric grid connection point	Km	
Voltage level	Volt	
Who would pay for the transmission line to the connection point?		

**External Heat/Steam Customers**

Possible heat supply	MW	
Data heat output	bar/°C	
Possible steam supply	tons/hour	
Data steam output	bar/°C	
What is the distance?	meters	
Who would pay for the connection?		

**Site Information**

Site available at the industry?	yes/no	
Size of the site	m <sup>2</sup>	

## APPENDIX A Biomass-to-Energy Screening List (continued)

### Environmental Requirements

Air emission limits		
• Dust	mg/Nm <sup>3</sup>	
• Carbon dioxide	mg/Nm <sup>3</sup>	
• Nitrogen oxides	mg/Nm <sup>3</sup>	
• Sulfur oxides	mg/Nm <sup>3</sup>	
• Hydrogen chloride	mg/Nm <sup>3</sup>	
Others		

### Cooling

Is seawater cooling possible (sea, river)?		
Is water available for cooling tower?	yes/no	

### Financing/Economy

Who will be the owner and operator of the project?		
Is financing available at reasonable terms and costs?	yes/no	
What is the feed-in tariff?	\$/MWh	
Can the feed-in tariff be guaranteed, and for how long a time?		
Are potential government incentives (for example, renewable energy certificates) available?		
What is the requested payback time of the project?	years	

Source: COWI.

**APPENDIX B** Characterization of Biomass

Number			1	2	3
Feedstock			Coniferous stem wood, without bark  <i>Source: DTI &amp; Biowaste4SP.</i>	Logging residues, coniferous  <i>Source: DTI &amp; Biowaste4SP.</i>	Wheat straw  <i>Source: DTI &amp; Biowaste4SP.</i>
Most Common Trading Form			chips	chips	bales
Conversion Technology			combustion	combustion	combustion / fermentation
Net Calorific Value (MJ/kg)			19.1 (18.5–20.5)	18.5–20.5	16.6–20.1
Biogas Potential (Milliliters of methane / grams of volatile solids)			not relevant	not relevant	240–440
Bulk Density (kg/m <sup>3</sup> )			300 (270–360)	300 (270–360)	20–40 (loose) 20–80 (chopped) 110–200 (baled) 560–710 (pelletized)
Chemical Composition	Elementary Analysis (w% dry)	Carbon	50 (48–52)	50 (48–52)	48 (41–50)
		Hydrogen	6.1 (5.7–6.2)	6.1 (5.7–6.2)	5.5 (5.4–6.5)
		Oxygen	40 (38–44)	40 (38–44)	39 (36–45)
	Lignocellulosic Constituents (w% dry)	Hemicellulose	25–25	25–25	23–30
		Cellulose	40–45	40–45	34–38
		Lignin	24–33	24–33	16–21
	Ash Content (% dry bulk)		3 (1–10)	3 (1–10)	2–10
Volatile Matter (% dry bulk)		86 (80–90)	84–86	77 (75–81)	
Moisture Content (Traded Form) (w-%)			30–55	35–55	10–30

4	5	6	7
Used wood (post consumer wood, recycled wood, untreated)	Bark, coniferous (debarking residues)	Broadleaved stem wood with bark	Poplar
			
<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>
hog fuel	shredded	chips	chips
combustion	combustion	combustion	combustion
18.6–18.9	17.5–20.5	15.0–19.2	18 (17.3–20.9)
not relevant	not relevant	not relevant	not relevant
200 (140–260)	240–360	220–260	340 (320–400)
49–52	50 (48–55)	42.6–52.0	49.7 (44.8–52.0)
5.9–6.4	5.9 (5.5–6.4)	5.7–6.4	6.0 (5.6–6.3)
38–44	38 (34–42)	41.4–51.1	43.9 (41.6–48.6)
25–30	10–15	21–32	25.3 (12.7–39.8)
40–45	20–30	28–49	44.4 (35.2–50.8)
20–30	10–25	30–32	22.9 (15.5–31.9)
0.5–2	1–5	0.3–1.5	1.2 (0.2–2.7)
84–86	70–80	83.1 (75.6–85.8)	82.6 (71.8–87.5)
15–30	50–65	10–50	4.8–15

(continued)

**APPENDIX B** Characterization of Biomass (*continued*)

Number			8	9	10
Feedstock			Cereal straw  <i>Source: DTI &amp; Biowaste4SP.</i>	Pruning from olive trees  <i>Source: DTI &amp; Biowaste4SP.</i>	Eucalyptus  <i>Source: DTI &amp; Biowaste4SP.</i>
Most Common Trading Form			bales	chips	chips
Conversion Technology			combustion / fermentation	combustion	combustion
Net Calorific Value (MJ/kg)			14.8–20.5	16.3 (16.0–18.5)	18.5 (17.0–21.6)
Biogas Potential (Milliliters of methane / grams of volatile solids)			245–445	not relevant	not relevant
Bulk Density (kg/m <sup>3</sup> )			20–40 (loose) 20–80 (chopped) 110–200 (baled) 560–710 (pelletized)	250 (220–270)	250 (220–260)
Chemical Composition	Elementary Analysis (w% dry)	Carbon	48.9 (43.7–52.6)	40.7 (39.0–45.0)	50.3 (46.2–55.2)
		Hydrogen	5.9 (3.2–6.6)	5.7 (5.0–6.0)	6.2 (4.9–6.9)
		Oxygen	43.9 (39.4–50.1)	41.0 (40.0–42.0)	43.3 (38.2–47.7)
	Lignocellulosic Constituents (w% dry)	Hemicellulose	25.0 (7.2–39.1)	11.5 (10.0–12.0)	25.3 (8.4–43.5)
		Cellulose	37.0 (14.8–51.5)	48.5 (47.5–49.5)	43.0 (8.8–57.5)
		Lignin	17.5 (5.0–30.0)	30.5 (29.5–31.5)	23.2 (9.37)
	Ash Content (% dry bulk)		6.7 (1.3–13.5)	30.5 (29.5–31.5)	1.2 (0.2–6.1)
Volatile Matter (% dry bulk)		81 (73–87)	76.2 (75.2–80.5)	83.4 (77.5–93.6)	
Moisture Content (Traded Form) (w-%)			15 (8–25)	25 (10–50)	10 (5–50)

11	12	13	14
Paulownia	Willow (Salix)	Reed canary grass	Barley straw
			
<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>
chips	chips	Bales chopped	bales
combustion	combustion	combustion / fermentation	combustion / fermentation
18.6 (18–20)	19.8 (19 – 21)	16.6 (14.6–17.5)	18.9
not relevant	not relevant	280–410	240–320
250 (220–260)	330 (300–390)	150–200 (bales)	20–40 (loose) 20–80 chopped 110–200 (baled) 560–710 (pelletized)
49.5 (47.9–50.0)	49 (47.1–50.3)	45.3 (44–48)	45.4 (39.9–47.5)
6.4 (5.8–6.7)	6 (5.8–6.2)	5.6 (5.2–6.2)	5.6 (5.3–5.9)
43.8 (43.2–45.0)	43 (41.3–45.3)	41.2 (38–44)	42.1 (41.2–43.8)
19.6 (19–25)	27 (23–32)	22–25	24–29
41.6 (40–49)	41.0 (38–45)	38–46	31–34
22 (21–23)	25 (23–29)	18–21	14–15
1.1 (0.5–3.5)	1.5 (1–3)	8 (3–22)	4.5–9
82.0 (81.5–84.0)	82 (81–86)	77 (74–81)	82.4
10 (5–30)	40 (35–50)	15 (5–35)	15 (5–35)

(continued)

**APPENDIX B** Characterization of Biomass (*continued*)

Number			15	16	17
Feedstock			Empty fruit bunch  <i>Source: DTI &amp; Biowaste4SP.</i>	Bamboo  <i>Source: DTI &amp; Biowaste4SP.</i>	Sugarcane bagasse  <i>Source: DTI &amp; Biowaste4SP.</i>
Most Common Trading Form			bales briquettes	chips	chopped
Conversion Technology			combustion / fermentation	combustion	fermentation / combustion
Net Calorific Value (MJ/kg)			11.5–14.5	16.9	16.7 (15–19.4)
Biogas Potential (Milliliters of methane / grams of volatile solids)			264	not relevant	72–200
Bulk Density (kg/m <sup>3</sup> )			100–200	200	130 (120–160)
Chemical Composition	Elementary Analysis (w% dry)	Carbon	43.8–54.7	46.7–52.0	46
		Hydrogen	4.4–7.4	5.1–5.6	5.7
		Oxygen	38.2–47.8	37.8–42.5	39.2
	Lignocellulosic Constituents (w% dry)	Hemicellulose	20.6–33.5	19.5	24.5 (24–32)
		Cellulose	23.7–65.0	49.3	35.2 (32–44)
		Lignin	14.1–30.45	22.4	22.2 (19–24)
	Ash Content (% dry bulk)		1.3–13.7	7.7	9 (4.5–25)
Volatile Matter (% dry bulk)		72–75	74.2	76.1–85.6	
Moisture Content (Traded Form) (w-%)			61–72	15 (5–30)	50 (48–53)

18	19	20	21
Corn cobs	Rice husk	Rice straw	Switch grass
			
<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>
chopped	bulk	bales	bales
fermentation / combustion	fermentation / combustion	fermentation / combustion	fermentation / combustion
14	12–16	14.5–15.3	15.7
330	49 (49–495)	280–300	246
160–210	100	20–40 (loose) 20–80 (chopped) 110–200 (baled) 560–710 (pelletized)	49–266 chopped)
47.1	37–44	38.4 (36–42)	43.6
5.8	4.8–5.6	5.2 (4.6–5.3)	6.4
40	33–49	36–43	44.8
31–33	29.3	33.5	31.7
40–44	34.4	44.3	43.1
16–18	19.2	20.4	11.3
15 (1–40)	17–24	14–16	4.3
87.4	61.8–74.3	65.5	87.4
8–20	10	10–20	8–15

(continued)

**APPENDIX B** Characterization of Biomass (*continued*)

Number			22	23	24
Feedstock			Chicken manure  <i>Source: DTI &amp; Biowaste4SP.</i>	Dairy manure  <i>Source: DTI &amp; Biowaste4SP.</i>	Swine manure  <i>Source: DTI &amp; Biowaste4SP.</i>
Most Common Trading Form			bulk / pellets	bulk / pellets	bulk / pellets
Conversion Technology			fermentation / combustion	fermentation / combustion	fermentation / combustion
Net Calorific Value (MJ/kg)			9–13.5	no data	no data
Biogas Potential (Milliliters of methane / grams of volatile solids)			156–295	51–500	322–449
Bulk Density (kg/m <sup>3</sup> )			230	depending on moisture content	depending on moisture content
Chemical Composition	Elementary Analysis (w% dry)	Carbon	35.9	37.6	34.8
		Hydrogen	5.1	5.1	4.7
		Oxygen	30.5	28.9	30.3
	Lignocellulosic Constituents (w% dry)	Hemicellulose	23.2	15.2	27.7
		Cellulose	20	19.5	11.3
		Lignin	1.6	17.4	4.3
	Ash Content (% dry bulk)		24	25.2	27.6
Volatile Matter (% dry bulk)		19.5	28.8	no data	
Moisture Content (Traded Form) (w-%)			6–22	10–75	10–85

25	26	27	28
Palm kernel shells (PKS)	Banana peel	Cassava peels	Tobacco leaves
			
<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>
bulk	bulk	bulk	bulk
combustion	fermentation	fermentation	fermentation / combustion
15.6–22.1	no data	no data	17.97
not relevant	223–336	272–352	289 (calculated)
450	no data	depending on moisture content	depending on moisture content
44.5–52.4	no data	39.96	41.2
5.2–6.3	no data	3.98	4.9
37.3–49.7	no data	no data	33.9
22.7	14.8	37.0	34.4
20.8	13.2	37.9	36.3
50.1	14	7.5	12.1
3.2–6.7	11.4	4.5	17.2
76.3–82.5	no data	95.5	82.8
no data	no data	28.5–66.3	~10 (dried)

(continued)

**APPENDIX B Characterization of Biomass (continued)**

Number			29	30	31
Feedstock			Tobacco stalk  <i>Source: DTI &amp; Biowaste4SP.</i>	Recycled paper  <i>Source: DTI &amp; Biowaste4SP.</i>	Sewage sludge  <i>Source: DTI &amp; Biowaste4SP.</i>
Most Common Trading Form			bulk	bulk	bulk
Conversion Technology			fermentation / combustion	combustion	fermentation / combustion
Net Calorific Value (MJ/kg)			19.02	12.77	7–15
Biogas Potential (Milliliters of methane / grams of volatile solids)			163	not relevant	249–464
Bulk Density (kg/m <sup>3</sup> )			depending on moisture content	431 (compacted)	depending on moisture content
Chemical Composition	Elementary Analysis (w% dry)	Carbon	49.3	52.3	28.0–45.0
		Hydrogen	5.6	7.2	4.0–6.2
		Oxygen	42.8	40.2	2.4–43.5
	Lignocellulosic Constituents (w% dry)	Hemicellulose	28.2	11.0	no data
		Cellulose	42.4	68.4	no data
		Lignin	27.0	11.4	no data
	Ash Content (% dry bulk)		2.4	89.2	12–34.6
Volatile Matter (% dry bulk)		97.6	10.8	65.4–88	
Moisture Content (Traded Form) (w-%)			6 (dried)	5	55–96.5

*Sources:* Lemus et al. (2013), Saidur et al. (2011), McKendry (2002), Kandel et al. (2013), Dubrovskis, Vilis, et al. (2012), Kim, Tae Hoon, et al. (2014), Kim, Sang-Hyoun, et al. (2013), Teh et al. (2010), Chang (2014), Papadopoulos (2004), Batalha et al. (2011), Rabelo et al. (2011), Rezende et al. (2011), Vivekanand et al. (2014), Pointner et al. (2014), Kaliyan & Morey (2014), Wang (2011), Mullen et al. (2012), Chandra et al. (2012), Li et al. (2013), Armesto (2002), Lam et al. (2008), Oliveira et al. (2012), Tiquia et al. (2002), McMullen et al. (2005), Otero et al. (2011), Husain et al. (2002), Kim et al. (2010), Okafor (1988), Kelly-Yong et al. (2007), Sharma et al. (1988), Tovar et al. (2015), Thomsen et al. (2014), Liu et al. (2015), Vounatsos et al. (2012), WRAP (2009), Francou et al. (2008), Cabbai et al. (2013), Caporgno et al. (2015), Jhosane Pages-Díaz et al. (2014), Göblös et al. (2008), Demirel et al. (2005), Kafle and Hun Kim (2013), Costa et al. (2013), Lee (2010), Zupan i and Grilc (Not available), Thiago Rocha dos Santos Mathias et al. (2014), Adela et al. (2014), Ahmed et al. (2015).

32	33	34	35
Residuals from slaughterhouse	Residuals from dairies	Residuals from breweries (brewery grain waste—BGW)	Palm oil mill effluent (POME)
			
<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>	<i>Source: DTI &amp; Biowaste4SP.</i>
bulk	bulk	bulk	no data
fermentation	fermentation	fermentation	no data
no data	no data	no data	0.47
no data	no data	no data	no data
no data	no data	no data	not relevant
no data	no data	no data	not relevant
no data	no data	no data	not relevant
no data	no data	no data	no data
no data	no data	no data	no data
no data	no data	no data	no data
no data	no data	no data	no data
no data	no data	no data	0.47
no data	no data	no data	not relevant
no data	no data	no data	no data

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IFC  
Energy & Water Advisory

2121 Pennsylvania Ave., NW  
Washington, DC 20433 USA  
[AskSustainability@ifc.org](mailto:AskSustainability@ifc.org)