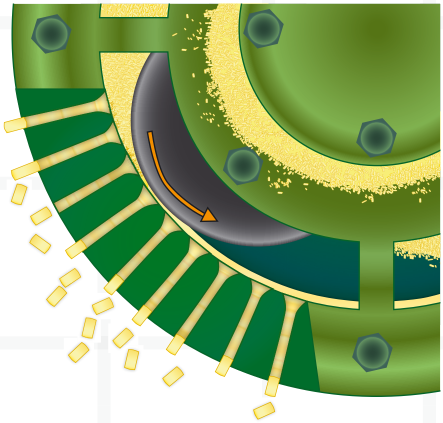
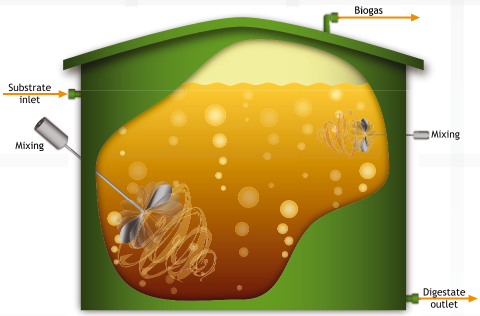
By-products and Waste to Energy:

Technologies





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INTRODUCTION

A growing concern in relation to the impacts of global warming and the decrease in conventional fossil fuel sources is enhancing interest in renewable energy. Also the EU Waste Framework Directive has created challenges in the handling of waste e.g. by requiring energy recovery from waste when recycling and reuse of materials are not applicable. The European Union is aiming to diversify its energy supply, reduce the reliance on imported energy and decrease greenhouse gas emissions across Europe by promoting renewable energy production for transport, electricity and heating purposes.

Waste can be divided into several categories including municipal solid waste, construction and demolition waste, institutional, commercial and industrial waste, medical waste, hazardous, radioactive or electronic waste, and biodegradable waste.

Waste can be converted to energy by thermochemical, biochemical, mechanical, chemical and electrochemical processes, depending on the original material. Thermochemical conversion processes include gasification, pyrolysis and combustion, biochemical processes include fermentation and anaerobic digestion, and mechanical conversion processes include pelletization. Thermochemical and biochemical conversion technologies are well suited to a wide range of feedstock, while the others have more limitations. Thermochemical conversion methods are best suited for relatively dry woody or herbaceous feedstock whereas biochemical technologies can also handle material with high moisture content.

Material properties can vary widely depending on the original material, but generally the following properties are important with regard to energy production: moisture content, calorific value, proportions of fixed carbon and volatiles, ash/residue content, alkali metal content, cellulose/lignin ratio, carbohydrate/sugar content, lipid/fat content, protein content, and pH.

This booklet focuses on anaerobic digestion, fermentation, gasification and pelletization. Gasification and anaerobic digestion are commercially the most mature technologies for small-scale decentralised energy production where numerous enterprises offer different applications. Fermentation applications are also offered commercially, but the technology is less mature.

Supply of pelletization equipment ranges from small household scale to industrial plant scale.

Anaerobic digestion technology has originally been used for low solid applications in the waste water treatment sector. Currently, thousands of facilities operate with sewage sludge or biowaste as the primary feedstock, and numerous technology providers supply technology for biomass feedstock. The scale ranges from laboratory scale to over 200 000 tonnes of feedstock per year, and energy production up to several MW.

First-generation bioethanol is produced commercially by **fermentation** in several plants throughout the world. The first demonstration plants producing second-generation bioethanol have been operating in Sweden and Canada since 2004. The full capacity of the cellulosic ethanol production is 400–500 dm^3 (feedstock 2 t/d) or 5000–6000 dm^3 (feedstock 20–30 t/d) per day, respectively. A plant using 15 000 tonnes of municipal biowaste as feedstock has been established in Finland in 2009, producing 1 million dm^3 of bioethanol annually. The investment costs of 120 million Euros are calculated for a plant with the capacity of 75 millions dm^3 of ethanol per year (based on pilot plants).

Most of the **gasifiers** in operation are located in India and China where they are used for power generation from wood and rice husk. The scale of plants supplied commercially varies from 250 kW_e to 150 MW_e with bubbling fluidised bed technology, from 50 kW_e to 10 MW_e with fixed bed technology, and from 30 kW_e to 5 MW_e with circulating fluidised bed technology. Only a few commercial technology providers supply small scale biomass gasifiers.

The scale of pellet production varies from private **pelletizers** (< 100 t of pellets annually) to large plants in USA producing 500 000 tonnes of pellets per year. In northern Europe, Finland and Sweden, the average annual capacities of commercial pellet plants are 50 000 and 100 000 tonnes, respectively.

The legislation behind renewable energy production at the European Union level includes Waste Framework Directive (2008/98/EC), Integrated Pollution Prevention and Control (IPPC) Directive (1996/61/EC), Landfill Directive (1993/31/EC), Biofuel Directive (2003/30/EC), Directive on the promotion of electricity produced from renewable energy sources in the internal energy market (2001/77/EC), Directive on the incineration of waste (2000/76/EC), and Directive on ambient air quality and cleaner air for Europe (2008/50/EC). Other regulations include for example restrictions on the use of certain animal by-products to energy before they are treated (REG 2002/1774/EC).

Summary of the properties and usability of selected technologies

	Alcohol fermentation	Anaerobic digestion	Gasification	Pelletization
Scale	Ethanol yield 10^2 –10^6 m^3 annually	Reactor size 50–10 000 m^3	1 kW_e–150 MW_e depending on the technology used	Pellet yield 10^2 –10^5 t annually
Input (prefer-able)	Food crops, by-products, forest residues, energy crops, biowaste	Biowaste & waste waters, by-products, energy crops	Forest products, energy crops, biowaste	Woody, herbaceous and fruit biomass, blends & mixtures
Requirements for input	Homogenous input, sufficient sugar content, nutrients	Total solids up to 40 %	Moisture 6-45 % Ash < 15 %	Moisture 10–25 % Particle size < 20 mm
Inhibitors	Ash; furfurals, levulinic acid, aromatic compounds (arising during the process)	Antibiotics & other organic compounds, ammonia, sul-phide, ions, heavy metals	Alkali metals, trace impurities (S, Cl, N), particulates (inorganics, fly ash)	
Output (useful)	Ethanol, butanol & other alcohols	Methane	Product gas (syngas)	Pellets
Output (others)	Liquid & solid residues, gases	CO_2, digestate	Gaseous impurities, char, tars	Dust
Post-treatment	Purification & distillation	Depends on the usage	Particulates & tars removal	Dust removal
Applications & use	Transportation fuel, CHP; residues as fertilizer or animal feed	Transportation fuel, CHP; digestate as fertilizer or soil conditioner	CHP, synthetic fuel production	Small scale combustion, CHP, fuel for gasifiers, animal bedding

ALCOHOL FERMENTATION

Fermentation of biomass is a process where microbes use sugars as food and simultaneously produce alcohols as a product of their metabolism. The fermentation process is usually anaerobic but can also be aerobic, depending on the microbes.

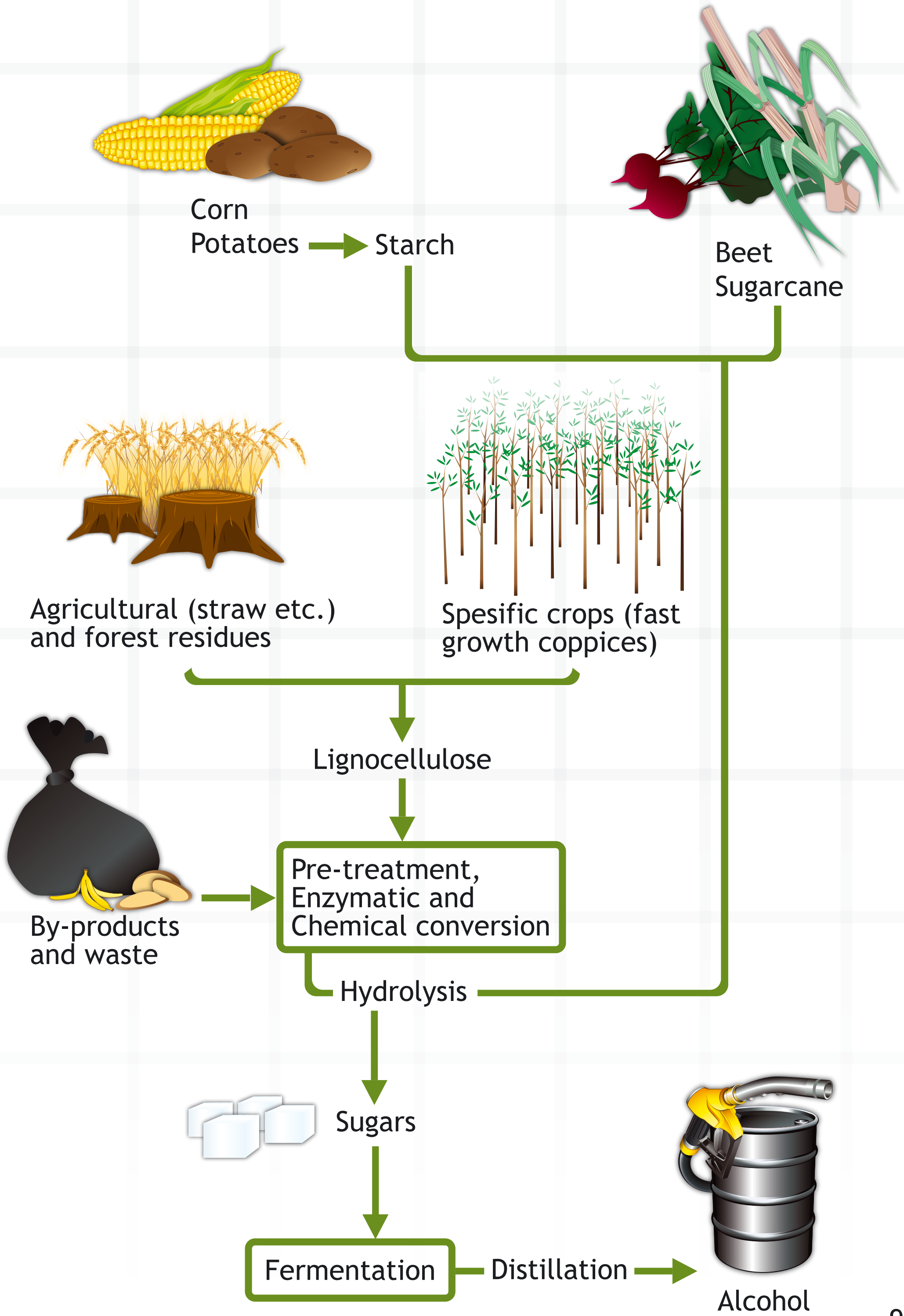
Crops with high sugar or starch content, such as sugar beet and corn, are most suitable feedstock for fermentation. Also cellulose containing biomass, like wood and straw, can be utilized after acid or enzyme pre-treatment. In the fermentation process, microbes (fungi, yeast or bacteria) split organic matter, producing alcohols (usually ethanol) as a final product.

First-generation biofuels made from agricultural crops are produced commercially on a large scale and the industry is growing throughout the world. Second-generation biofuels made from wood and by-products (i.e. lignocellulosic material) are more promising in the long term since they do not use material suitable for food. Various companies and research groups work intensively to produce second-generation biofuels commercially.

The alcohol production process consists mainly of pre-treatment or hydrolysis, fermentation, separation and purification. Milling and, when using lignocellulosic feedstock, acid or enzyme pre-treatment is the first step of the process. The sugars produced are then fermented and solid residues are separated. Ethanol is toxic to fermenting organisms at concentrations above 15 %, so that ethanol is continuously siphoned off at about 6 % and purified to fuel-grade (over 99 %).

Distillation is a conventional and widely used method for the purification of the fermented product to a fuel-grade ethanol, but it is not effective regarding energy and economy. Therefore, cheaper low-energy separation techniques are being developed, including precipitation, chemicals-based techniques, membrane separation and pervaporation.

Alcohol fermentation is a multi-stage process requiring carefully balanced production logistics.


Corn
Potatoes
Starch
Beet
Sugarcane
Agricultural (straw etc.)
and forest residues
Spesific crops (fast
growth coppices)
Lignocellulose
By-products
and waste
Pre-treatment,
Enzymatic and
Chemical conversion
Hydrolysis
Sugars
Fermentation
Distillation
Alcohol

Specifications for Alcohol Fermentation:

Possible biomass feedstock for the production of first-generation biofuels (input):
- Food crops: Cereals, sugars, corn, potatoes
- Food processing by-products: Molasses, whey, etc.

Possible biomass feedstock for the production of second-generation biofuels (input):
- Forest products: wood, logging residues, tree and shrub wood residues, sawdust, etc.
- Energy crops: Short rotation and herbaceous woody crops, grasses, starch crops, etc.
- Wastes: Agricultural production wastes, agricultural processing wastes, other plant residues, crop residues, mill wood wastes, urban wood wastes, etc.

Requirements for input:
- Raw material input has to be homogenous
- Sufficient sugar content
- Nutrients (such as nitrogen source) must be present
- Moisture
- pH

Possible inhibitors:
- Ash
- Other extractives

Output:
- Ethanol, butanol, other alcohols (depending on the microbes used)
- Gaseous by-products (biogas)
- Liquid residues
- Solid residues

Possible use for alcohols:
- Mix with gasoline and use as fuel for vehicles
- Combined heat and power production

Possible use for gaseous by-products (biogas) after purification:
- Combined heat and power production
- Fuel for methane-using vehicles

Possible use for liquid residues:
- As fertilizer
- As landscape cultivations

Possible use for solid residues:
- As fertilizer
- As animal feed
- Lignin can be separated and used for combined heat and power production or as material.

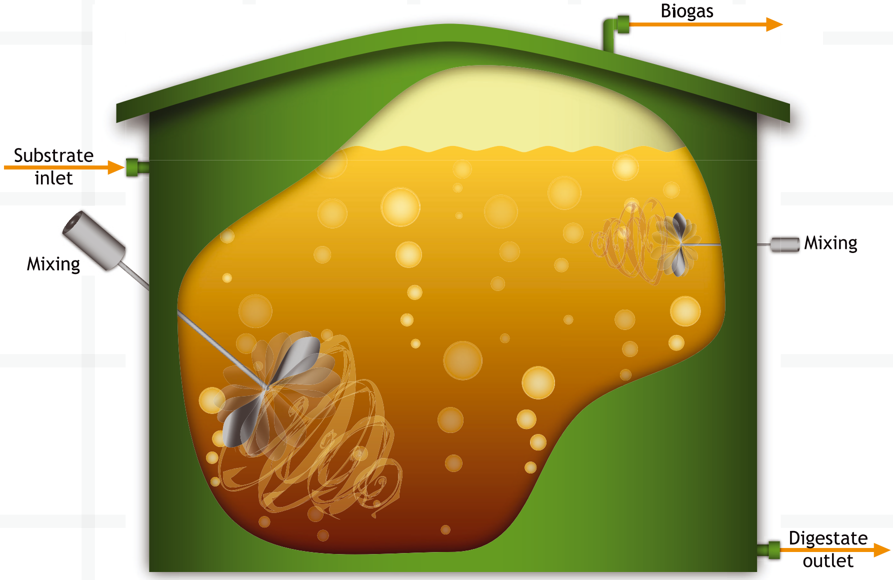
ANAEROBIC DIGESTION

Anaerobic digestion is the decomposition of organic matter by micro-organisms in the absence of oxygen.

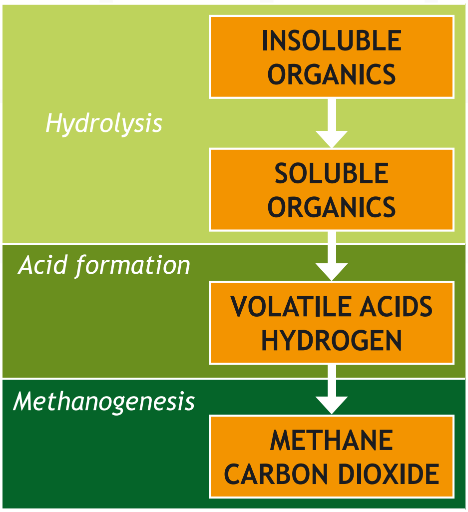
Anaerobic digestion produces biogas and digestate. The main product, biogas, consists mainly of methane and carbon dioxide. Biogas can be used for heat and power production, or the methane can be used as fuel for cars after carbon dioxide removal. The digestate contains all the water and all the nutrients from the incoming materials, and can provide further benefits as a fertilizer.

Anaerobic digesters can use almost any organic material as feedstock: manure, waste water sludge, energy crops, garden waste and biowaste. Use of woody material containing high quantities of lignin can be problematic, and some raw materials also need pre-treatment. Through anaerobic treatment the odour problems and greenhouse gas emissions of manure and biowaste are lowered and the purity of waste is improved at the same time as clean energy is produced.

In general, anaerobic digesters are divided into wet and dry reactor types. Wet reactors are commonly used with manure and sludge, while dry reactors are convenient for municipal organic waste and vegetable waste. In most anaerobic digestion reactors, mesophilic or thermophilic temperatures (with the optima at 35°C and 55°C, respectively) are used. Thermophilic reactors can usually manage a shorter retention time, but require more energy to maintain the high temperature. The size of the reactor varies from 50 m^3 to 10 000 m^3.



Biogas contains several contaminants, which must be removed prior to use. For H_2S reduction, chemicals-based systems using ferric chloride as an additive or systems using biological techniques can be used. Ammonia can be removed by catalytic destruction or wet scrubbing.



Specifications for AD:

Possible feedstocks (input):
- Agricultural and municipal waste, industrial by-products
- Energy crops and plant residues
- Municipal and industrial waste waters

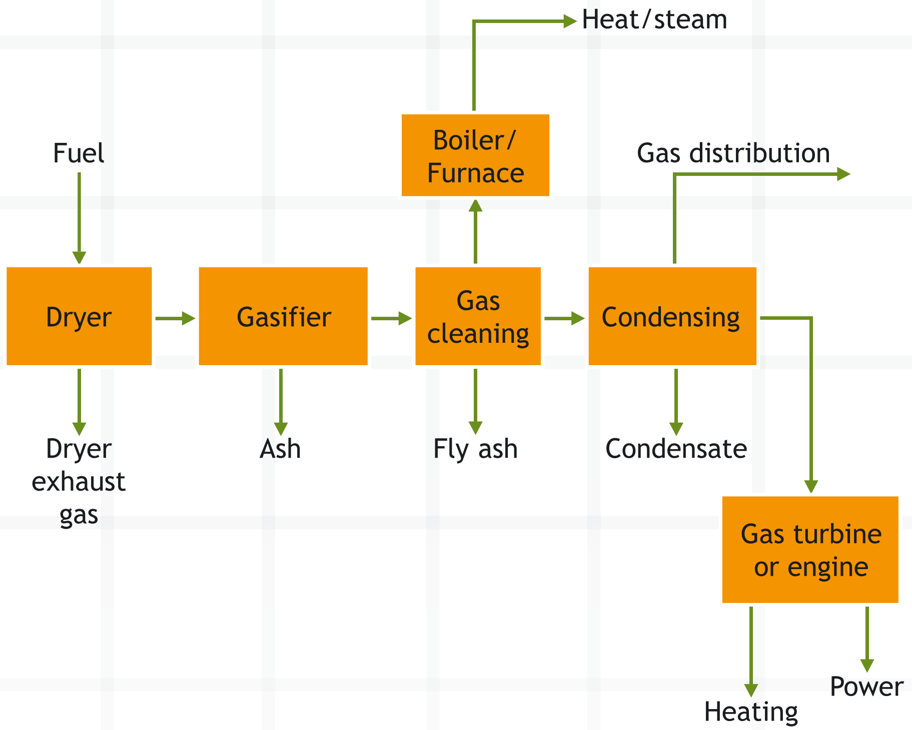
Output:
- Methane CH_4 (45–65 %)
- Gaseous impurities: CO_2 (36–41 %), N_2, O_2, H_2S, traces of other gases
- Digestate (solid and liquid residues)

Possible use for methane CH_4:
- Combined heat and power production
- Fuel for methane-using vehicles

Possible use for digestate:
- Fertilizer
- Soil conditioner

GASIFICATION

In the gasification process, biomass is converted into a gas mixture by partial oxidation at high temperature. This gas product can be used as a fuel in an internal combustion (IC) engine or gas turbine. Gasification can be used for heat and power production, beginning from 1 kW_e micro-scale applications.

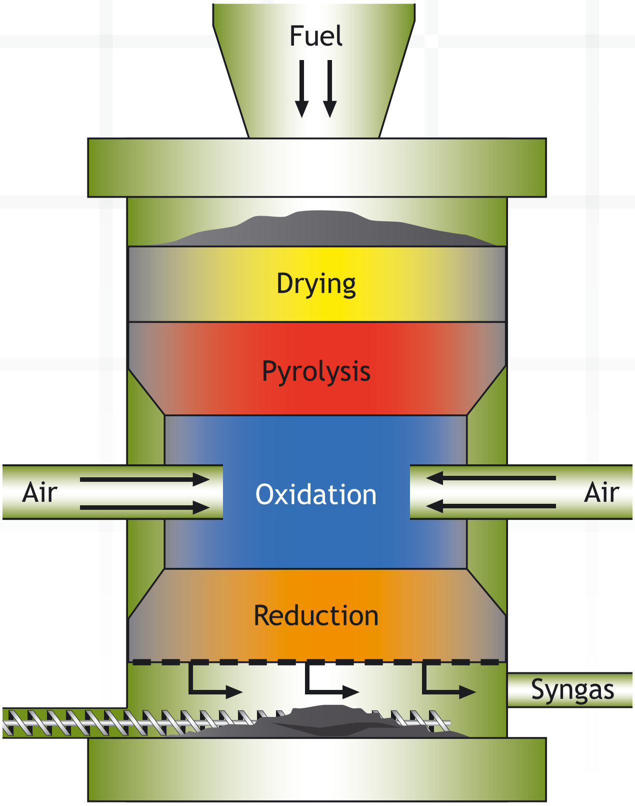


Fuel is introduced into the gasifier via the drying chamber where hot gases (< 250°C) are drying the biomass. In the pyrolysis chamber the biomass is heated at high temperatures (400-650°C) in the absence of oxygen. In this chamber, volatile compounds of biomass are separated from the char. Combustion reactions take place in the oxidation chamber (900–1200°C) where heat is produced for endothermic pyrolysis and gasification reactions. Inside the reduction chamber gas is formed through various reactions. The tar content of the gas decreases in thermal treatment at temperatures over 850°C.

In small-scale applications, a downdraft gasifier is the best choice for combined heat and electricity production. The potential advantage of a downdraft gasifier is the fact that pyrolysis products flow concurrently through the hot combustion and gasification chambers, where most of the tars are decomposed and oxidized. Therefore, the gas produced by an efficient downdraft gasifier can be used as fuel in an IC engine after simple filtration and cooling.

The ash by-product can be used as fertilizer or as an additive in construction materials.

If conditions are good, no post-treatment of the product gas (syngas) is needed. Particulates and tars are the most significant contaminants, which need to be removed prior to use - methods include cyclones, filters, electrostatic precipitators (ESPs) and scrubbers. Also, catalytic tar destruction, thermal cracking and plasma techniques have been developed.



Specifications for Gasification:

Possible biomass feedstock (input):
- Forest products: Wood, logging residues, trees, shrubs and wood residues, sawdust and bark from forest clearings.
- Energy crops: Short rotation woody crops, herbaceous woody crops, grasses, starch crops, sugar crops and oilseed crops.
- Wastes: Agricultural production wastes, agricultural processing wastes, crop residues, mill wood wastes, urban wood wastes and urban organic wastes.

Requirements for input:
- Moisture: 6–45 %, typical process includes drying of biomass
- Ash: < 15 %

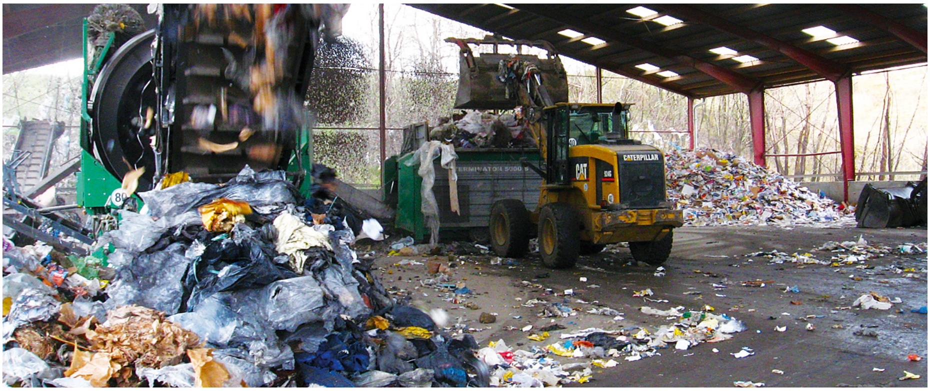
Possible inhibitors:
- Alkali metals
- Trace impurities (sulphur, chlorine, nitrogen)
- Particulates (inorganic, fly ash)

Output with air as gasifying medium:
- CO (17–25 %), H_2 (13–25 %), CH_4 (1–5 %)
- Impurities: CO_2, H_2O, tars, light hydrocarbons, N_2
- Process output temperature > 700 °C

Possible use for purified gas (synthetic gas CO + H_2):
- Combined heat and power production
- Synthetic gas (CO + H_2) to produce gaseous or liquid synthetic fuels
- Fischer-Tropsch-, methane-, methanol- or DME-synthesis

Product gas requirements for engine use

		Internal Combustion engine	Gas turbine
Particles	mg/Nm³	< 50	< 30
Particle size	µm	< 10	< 5
Tar	mg/Nm³	< 100	
Alkali metals	mg/Nm³		< 0,24



PELLETIZATION

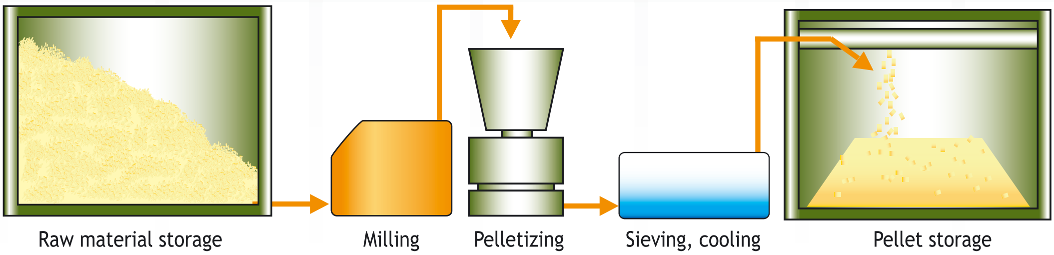
Pelletization is a process in which biomass is dried and compressed under high pressure into cylindrical shaped fuel products with a diameter of 6 to 25 mm and a length of 5 to 50 mm. Pellets are usually produced from milled wood materials, such as cutter shavings, saw dust and grinding dust. Pellets can also be produced from alternative materials, like agro biomasses or forest chips.

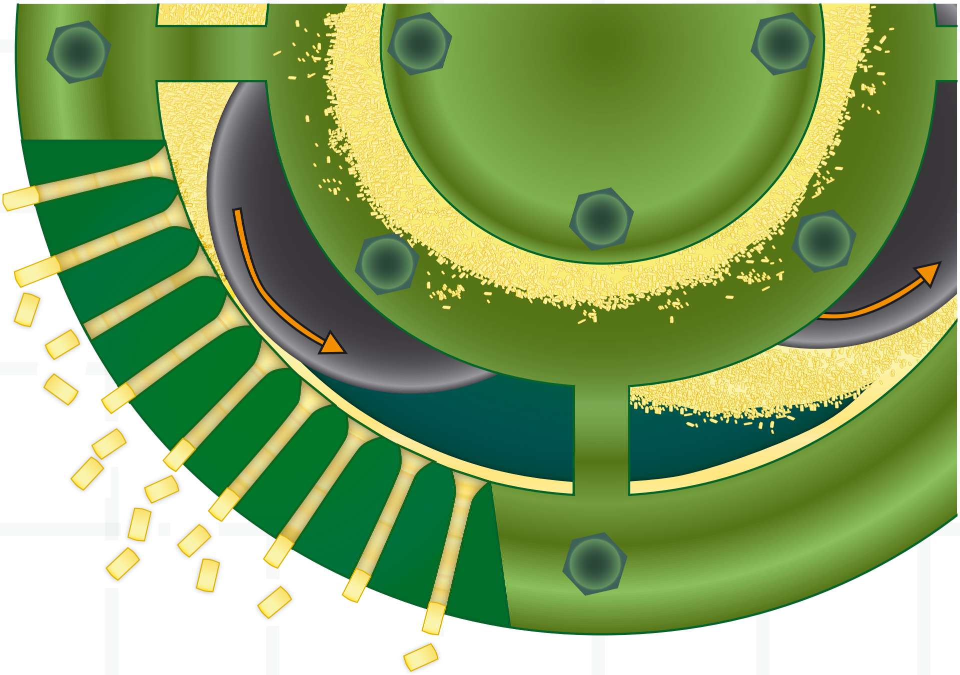
Pellets have higher energy density and a smaller volume compared to uncompressed solid biofuels, such as wood chips. Pellets are efficient to store and transport, especially in long distances. End-uses are in large scale co-firing, municipal heating plants, household boilers (from 5 to 50 kW) and non-fuel uses, such as animal feed and beddings.

The production process comprises drying of the raw material (for moist biomass), cleansing, grinding, pelletizing, cooling, fine separation and storing or packaging.

The raw material is dried to about 10 % moisture content (MC) before pelletizing. Usually, woody raw material with MC above 15 % is difficult to pelletize. On the other hand, Reed Canary Grass, for instance, does pelletize easier in MC closer to 15 %. Cleansing means removal of unwanted materials, such as metals, with help of magnets and screen. This is especially important when the purity of raw material can not be guaranteed.

After drying and cleansing, the raw material is ground with a hammer mill to make it homogenous wood flour with a particle size typically below 5 mm. Steam can be added before pelletizing to increase the raw material temperature releasing the wood lignin that binds particles together in the final compressed product.





Pellet presses have either a ring shape die or plane-type dies. In the pellet press raw material forms a layer that rolling wheels compress through the press channel. The pressing increases the raw material temperature, softens the lignin and binds particles together. For successful pelletizing, there are many specific raw material and press dependent conditions, such as press channel dimensions, the frequency of compression and distance set between die and rolling press.

The cooling of pellets increases the durability and decreases the dust formation in further transportation and handling. After cooling, pellets are screened to remove dust and fine particles. Pellets can be stored and delivered either as bulk or packaged.

Specification of pellet properties:

European EN standard for wood pellets (EN 14961-1 and EN 14961-2) is entering into force and defining the quality parameters and property classes of pellets. The following specifications are adopted and simplified from the draft standard. The original standard should be followed in any application.

Specifications for Pelletization:

Origins:
Woody biomass, herbaceous biomass, fruit biomass, blends and mixtures

Dimensions of pellets (mm):
Diameter 6 mm – 25 mm, length 5 – 50 mm

Moisture (w-% as received):
10 % – 15 %

Ash, A (w-% of dry basis):
A≤ 0.5 – A≤ 3.0+

Mechanical durability, DU (w-% pellets after testing):
DU ≥ 97.5 – DU < 95.0–

Amount of fines, F (w-%, < 3.15 mm) after production:
F ≤ 1.0 - F > 5.0

Additives (w-% of pressing mass):
Type and content of pressing aids, slagging inhibitors or any other kind additives have to be stated. Maximum amount of additive is 20 w-% of pressing mass. If amount is greater, then the raw material is a blend.

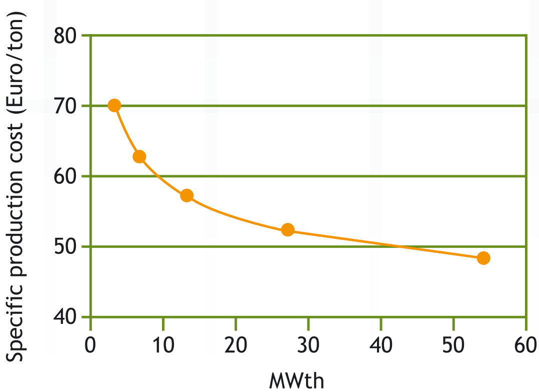
Bulk density (BD) as received (minimum kg/m³ loose):
BD550 – BD700+

Net calorific value as received:
Q ≥ 13.5 – 16.5 MJ/kg

Sulphur, Nitrogen and Chlorine (w-% of dry basis):
Maximum value to be stated

Target properties of 1st class pellets.

Diameter / length	< 8 mm / < 32 mm
Moisture content	< 10 %
Ash content	< 0.7 %
Volume mass	> 600 kg / bulk-m³
Energy content	> 4.7 kWh / kg
Mechanical strength	> 97.5 %



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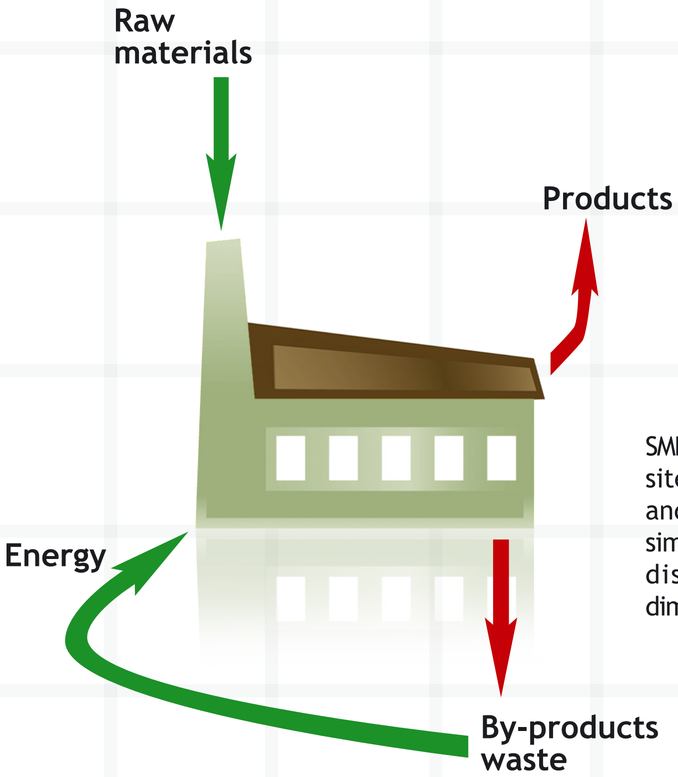
- Micro Energy to Rural Enterprise -



SME can generate energy on site from it's own wastes and by-products, solving simultaneously the waste disposal problems and diminishing GHG emissions.

Innovative energy solutions

MicrE develops and promotes innovative small scale renewable energy solutions for rural SME's in the Europe's Northern Periphery.

Energy from by-products and waste

MicrE energy solutions will use economically feasible and viable technologies, especially those which generate energy from by-products and waste.

Business concept

The goal of MicrE is to enhance the capacity for self-sustaining business in rural Northern Periphery regions. MicrE will provide a service that exploits technologies for renewable energy solutions, as well as energy generation from by-products and waste, which can be adapted for rural SME's.

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