Biomasses

Solar energy is stored in biomasses: the technological challenge lies in changing their form by means of a high-efficiency conversion, with the aim of making them easier to use for the production of electricity. Gasification is the process of thermal-chemical conversion of an organic mass into a gaseous fuel, syngas, which can be burned directly in combustion engines for the production of electricity and heat.

The types of biomass suitable for gasification are:
- forest residues
- wood industry scraps
- agriculture and silviculture wastes
- wood objects to be disposed of
- contaminated wood to be incinerated
- fast-rotation (short-cycle) crops
- municipal prunings and biowastes

Typical composition of the wood: 52% C; 6% H; 41% O; 1% Ash.

Main components of woody biomasses from the thermogravimetric standpoint (i.e. of the temporal changes in composition and weight of the biomass during controlled pyrolysis): moisture and highly volatile substances, hemicellulose, cellulose, lignin, and inorganic substances (alkaline earth metals, sulfates, carbonates). (See figure.)

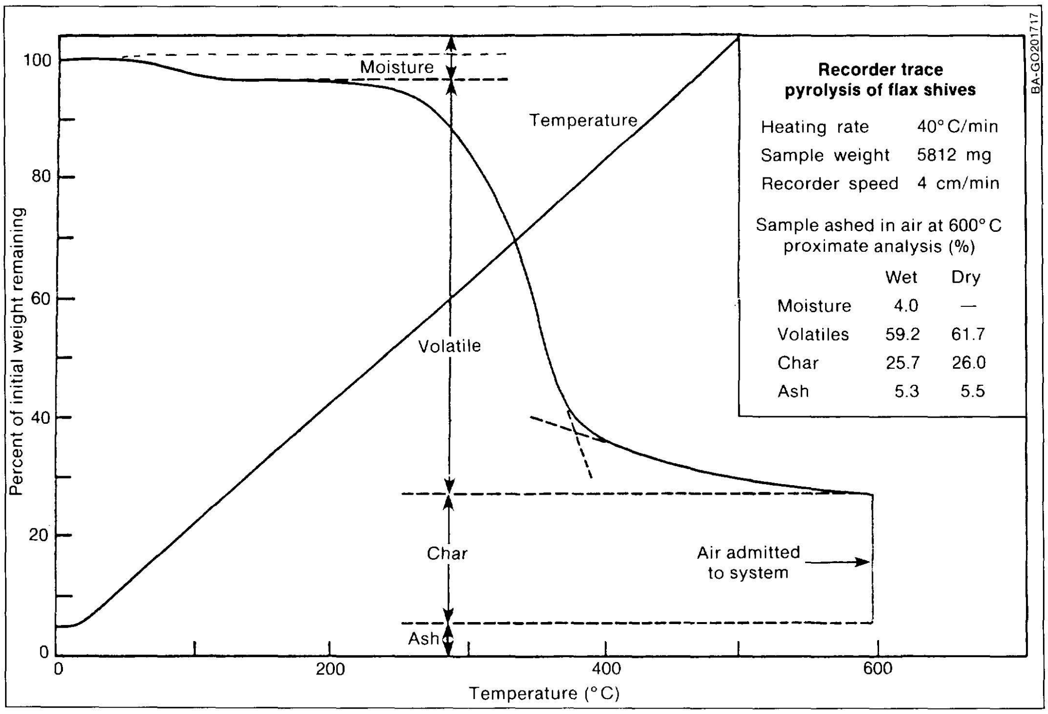


Fig. 4-3. Thermogravimetric analysis of a typical biomass sample heated in the absence of air (Source: Reed 1981, Fig. 5-2)

Particle size: wood chips (dim. XxXxX) or pellets.
Moisture: X

Gasification: a centuries-old challenge

Gasification is a process known since the late 18th century.
The first applications, dating from 1850, concerned coal for the production of gas in cities, for public lighting and household uses.

It spread rapidly to America from Europe, in particular from England and France, until it started to be replaced in around 1930 by the cheaper natural gas from Texas, transported across the country by the new gas pipelines.
In England, city gas continued to be used until the early 1970s, when oilfields were discovered in the North Sea.
Starting from the World War I years, small coal- or biomass-run gasifiers were built for driving means of transport (land and sea) and for fueling small electric generators.
In the years between the two World Wars, the development of these systems slowed down because of the more convenient and easier use of gasoline (petrol). But starting in 1939 the oil supply to Europe came to a halt due to the war, with oil products being reserved solely for military operations, thus creating a new interest in, and boost to, alternative fuels.
Thanks to the new plants based on the Fischer-Tropsch process (1923) which synthesized liquid fuels by means of a large-scale gasification of coal, Nazi Germany was able to meet 57% of its fuel needs during the war. It is believed that it is precisely this technology that brought Hitler to believe that the time was right for him to implement his plans.
Sadly, starting from 1948, the Fischer-Tropsch process was also at the basis of the apartheid regime in South Africa, in spite of the international sanctions against it.
At the end of World War II there were more than 700,000 wood-run gasifiers (of the Imbert type: see figure) used for means of transport in Europe, and over one million worldwide, with the exception of North America, where gasoline continued to be convenient and easy to obtain, as it had been even during the war.

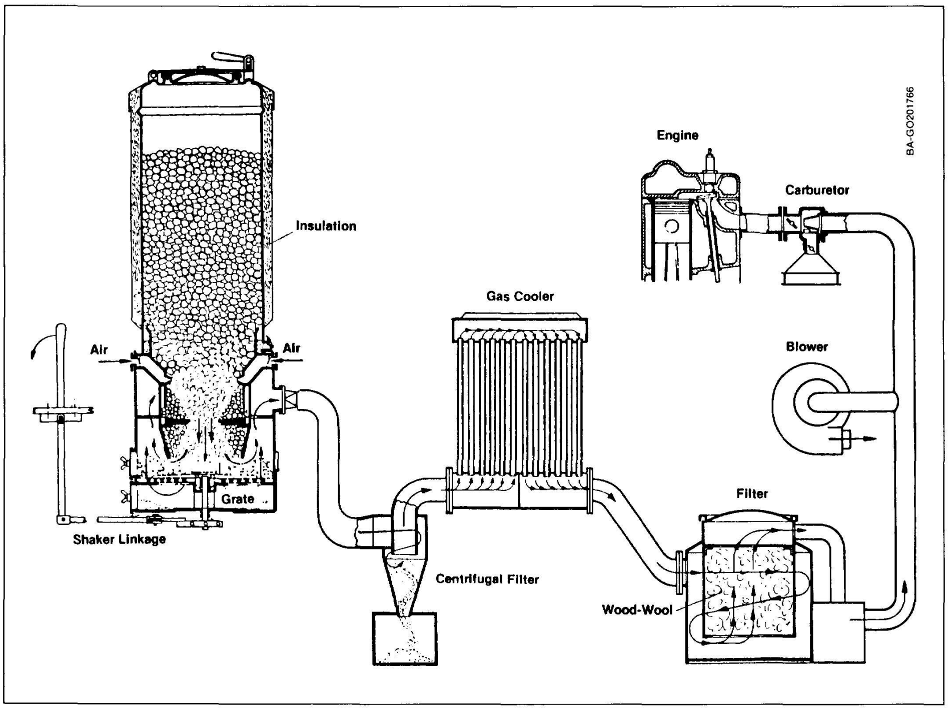


Fig. 8-3. Typical vehicle gasifier system showing cyclone and gas cooler (Source: Adapted from Skov 1974)

After the 1973 embargo, alternative energies once again acquired interest and appeal, especially for their use in large-scale plants, for the production of synthetic fuel gas, in particular from coal.
Small gasifiers (from 10 KW to 1 MW) are considered of great interest by international organizations running development programs in industrially backward countries, which have large quantities of biomasses but no extensive electricity distribution networks.
Furthermore, the attention to biomasses as a renewable source has recently been leading numerous individuals and groups of professional researchers to build and run demo gasification systems.
Unfortunately, the compilation of the information needed for handling systematically and jointly the critical factors involved in the production of clean and high-quality gas with minimal system maintenance has always met with great difficulty, in spite of the fact that lately there has been an increase in the efforts by a number of institutions to publish articles and promote conferences involving the world's top experts.
The spread and success of this technology are based on considerations of an economic and political nature.

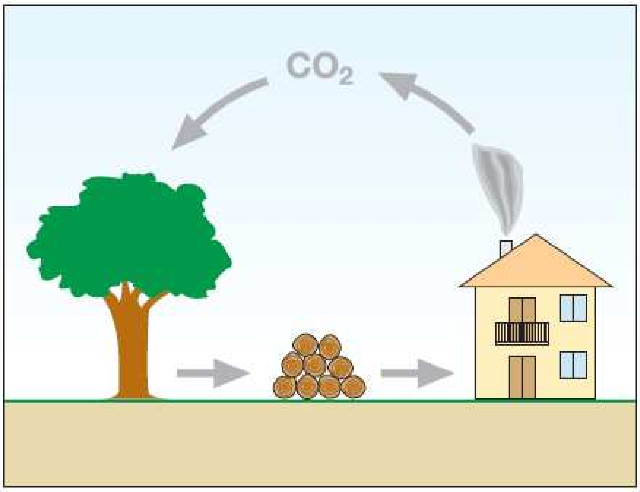
The main factors determining the economic feasibility of a gasification plant for the production of electricity are:

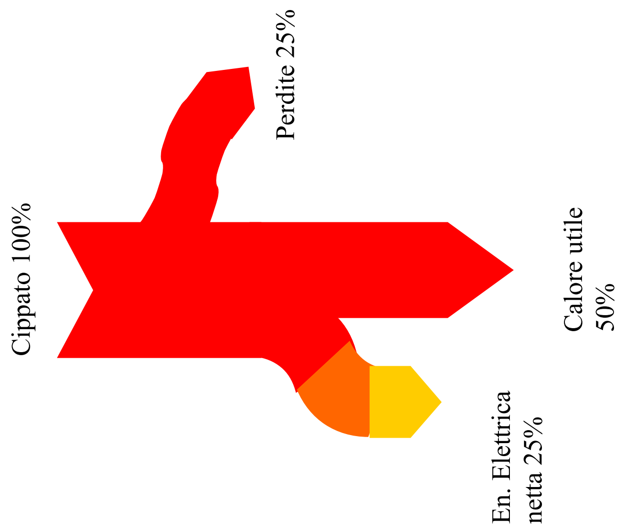
- cost and availability of the biomass (chipping or pelleting costs, sifting, drying, and storage);
- initial investment, recovery time, and lifetime of the plant;
- interest rate on money;
- management and maintenance costs;
- waste disposal cost (ash and tar);
- cost of purchasing electricity;
- value of the energy produced;
- value connected with the heat recovery (cogeneration);
- benefits from the use of renewable sources (tax incentives).

Why gasify?
Energy and the environment

In spite of its problematic history, today gasification is a mature, reliable, and high-efficiency technology:
- total yield: 75%
- net electrical yield: 25%
- net thermal yield: 50%

Biomasses are a renewable energy source with numerous positive features:
- large quantities at low cost, since they are a natural byproduct of agriculture and silviculture;
- low ash and sulfur content;
- no increase in the level of carbon dioxide – the principal greenhouse gas – in the atmosphere, provided their consumption does not exceed their production (moreover, many of the world's countries have implemented reforestation programs).





Chips 100% - Losses 25% - Net electrical power 25% - Useful heat 50%

The state of the art and beyond:
our multi-stage Pyrogasifier

At the present time, there are several varieties of gasification plants, each with its own construction peculiarities, connected in particular with the thermal potential, the type of fuel to be processed, and the way the syngas is used (Turbogas, MCI, ORC).
For plants of a power up to 1 MWel, the most appropriate system to use with an internal combustion engine or gas turbine, especially due to the high cleanness of the gas produced in terms of particulate and tar, is the downdraft fixed-bed gasifier.

Air gasification of wood generates a syngas with the following average composition: 15% H_2; 21% CO; 13% CO_2; 2% CH_4; 47% N_2; 2% other compounds; with a lower calorific value from 5 to 7 MJ/Nmc.
The addition of modest percentages of oxygen and/or water vapor to the gasification air produces significant increases in the percentages of hydrogen (over 25%) and methane (over 10%), also due to the effect of the lower nitrogen content, with a consequent increase of the lower calorific value, which may exceed 10 MJ/Nmc, as well as a greater cleanliness of the raw gas from tar and particulate.
Gasification is a high-temperature energy conversion process that entails a consumption of fuel to generate the heat necessary for fueling the endothermic reactions.
In a fixed-bed reactor, four zones may be identified:

- drying;
- pyrolysis;
- flaming pyrolysis, i.e. partial oxidation by means of the gasifying agents;
- reduction of the pyrolysis gases through the charcoal bed.

With the aim of producing a syngas with a low tar and particulate content, several effective solutions have been developed, such as the separation of the air into "primary" and "secondary" within the same reactor, or the physical separation of a pyrolysis section from a gasification section, since techniques minimizing formation upstream of the process are always preferable to reduction techniques downstream.
Our gasification plant has been conceived with the idea of combining the main elements of success of the existing systems, adding important design innovation elements to the two-stage structure.
This concept is fully expressed in the name of the machine: Multi-stage Pyrogasifier, indicating that there are two distinct modules:

- a pyrolyzer for recovery of the heat from raw syngas for drying and pyrolyzing the biomass before it enters the reactor;
- a gasifier with a multilevel introduction of the gasifying agent, in which the partial oxidation and, afterwards, heat reduction reactions take place.

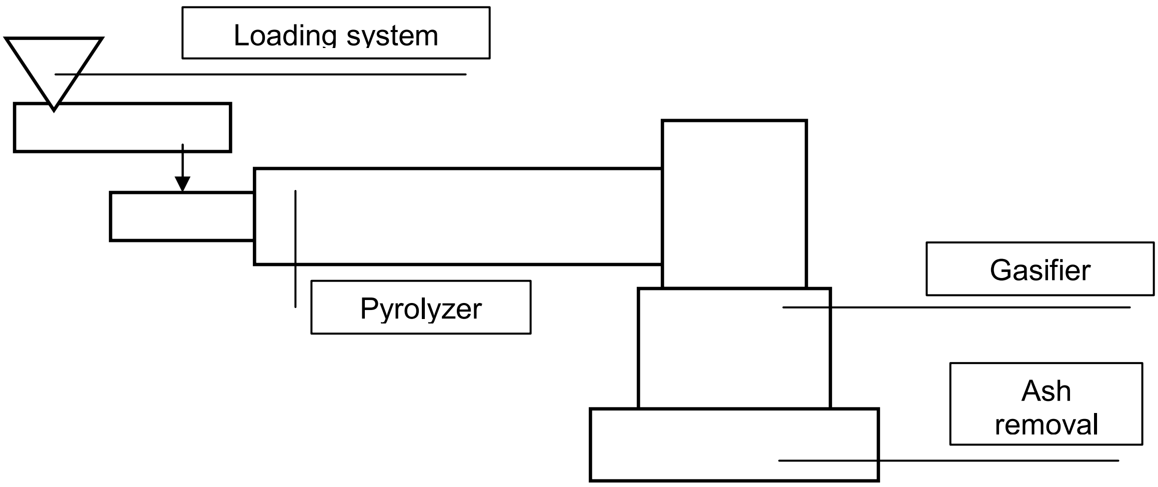
The presence of an initial thermal treatment unit (in absence of oxygen) serves to transform a generic biomass (chips or pellets) into a product with constant, uniform characteristics when entering the next gasification unit, so as to guarantee stable conditions for an optimum functioning, thus maximizing the performance of the entire system.
The compact configuration of the whole system, combined with a thorough insulation of the hot surfaces, minimizes heat loss, contributing to the achievement of high conversion yields.

Research and development of the pilot plant: some goals reached

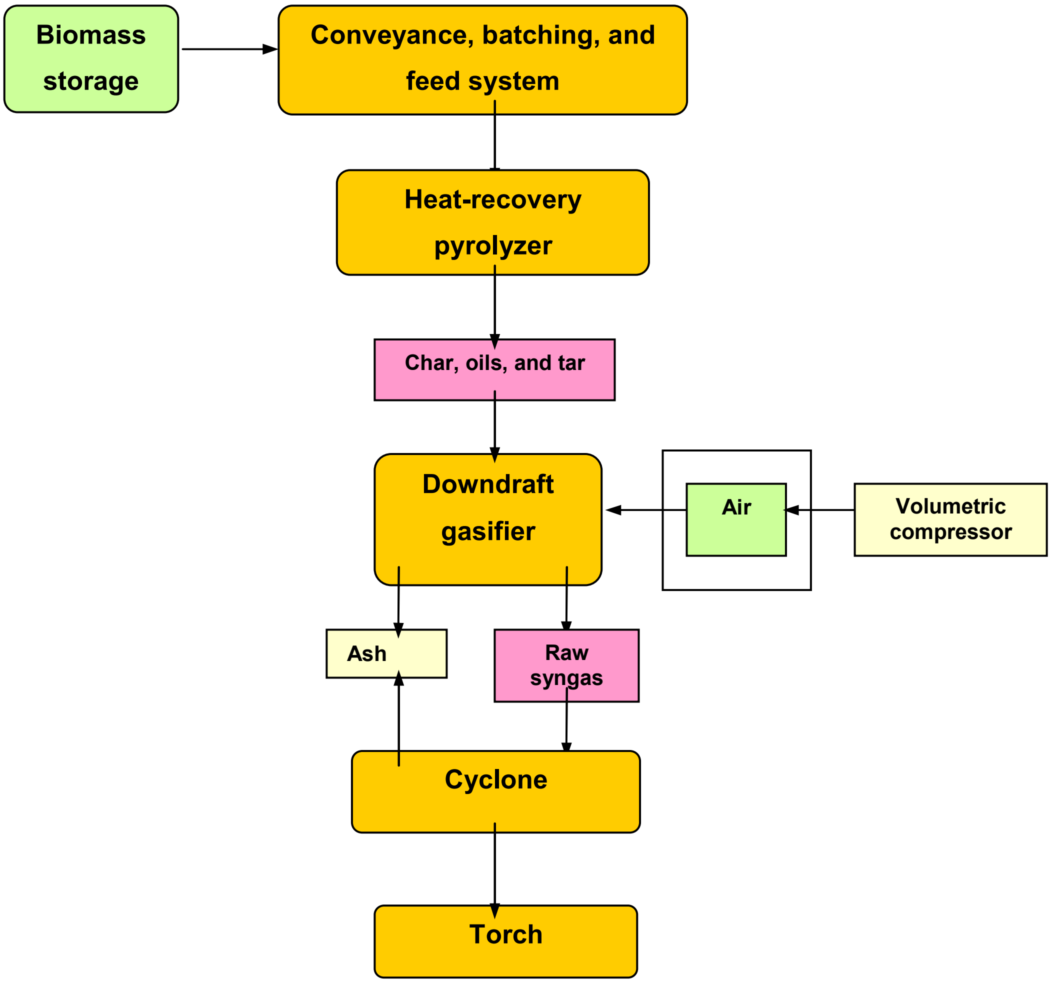
Since November 2011, an intense experimental activity has been generating a series of positive results that are in keeping with expectations.
Furthermore, an analysis of the data collected has made it possible to respond promptly and effectively to each of the problems that arose during testing, leading to stronger design solutions and a greater operational reliability of the whole system.

In fact, it is worthwhile to dwell on a diagram of the plant for a better understanding of its organization.

1) biomass storage
2) loading conveyor
3) batching hopper
4) sealed feed system
5) pyrolyzer
6) gasifier
7) gasifying agent supply system
8) ash removal system
9) gas cleaning system
10) syngas user (combustion torch)



Block diagram of the main system elements

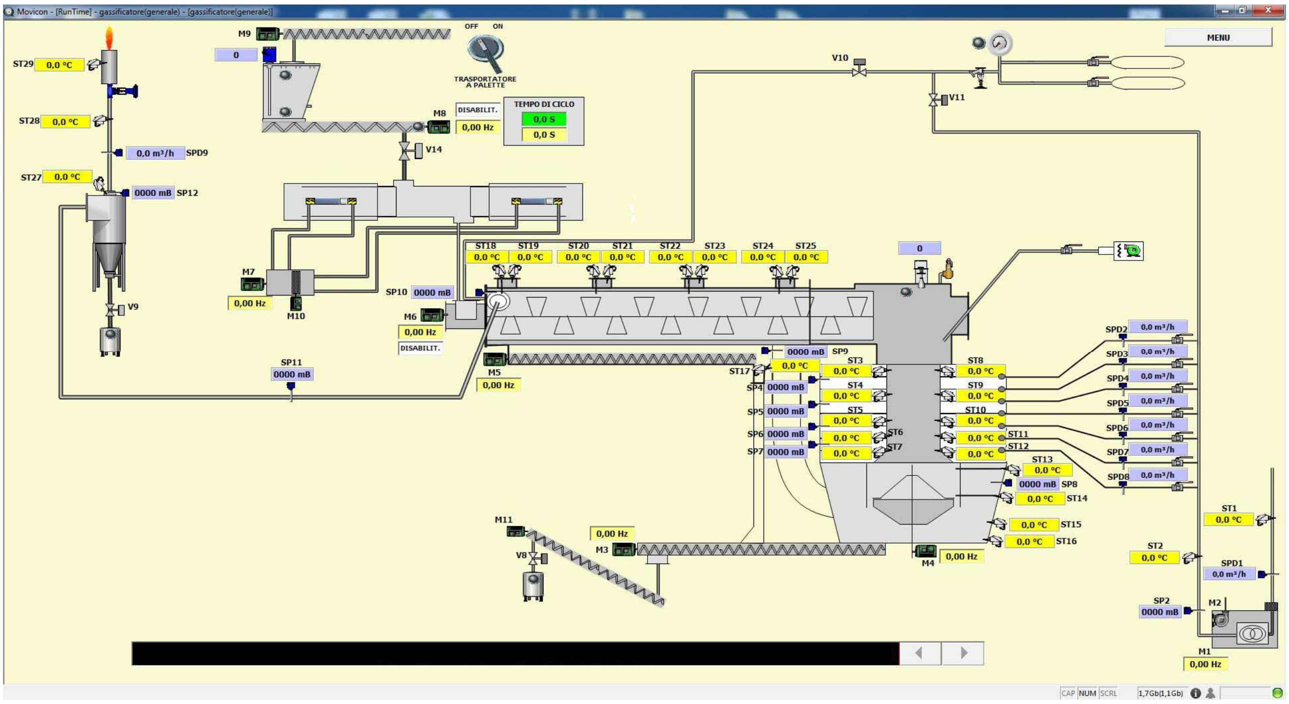


Simplified flowchart of the downdraft pyrogasification plant.

A high level of automation has made it possible to manage the complexity safely and easily from the first startup.

The plant is governed by a SCADA (Supervisory Control And Data Acquisition) system made up of:
- two programmable logic controllers (PLCs), which independently handle the process control and safety management, interacting through a DeviceNet type certified fieldbus.
- a PC-resident supervisor, connected via Ethernet to the controllers, which periodically collects the data and stores them in the database, displays the current values onscreen, produces temporal charts and, if necessary, generates alarms.

The main display of the supervisor is a mimic panel of the plant, graphically showing its composing elements, characterized by sensors and actuators whose status is monitored in real time.
The supervision and management program has a parametric architecture, by which it can run the plant autonomously on the basis of default or auto-generated values, be configured from the outside according to a fixed set of parameters or, in exceptional situations, be run manually, always in compliance with the automated safety procedures.



At the present time, the pyrogasifier has proven to be capable of processing biomass flows (wood chips, pellets, or mixed) at over 250kg/h with relative humidity of up to 25%, reaching maximum gasification temperatures of over 1000°C, with a production of gas with medium-high energy characteristics (over 5500 KJ/Nmc) and waste percentages always less than 10% of the incoming flow, over week-long time periods and with minimal external corrective measures.

Next goals: Cogeneration

The design and creation of a section for cleaning the raw gas will permit its usage for the production of electrical power using a dual-fuel (diesel oil-syngas) internal combustion engine.
Furthermore, the heat that can be recovered from the fumes and engine coolant may be profitably used to pretreat the biomass going into the plant, reducing its moisture content and improving the overall energy efficiency.

In fact, green wood may have relative moisture contents of up to 50%, and it is known that high quantities of water in fuel heavily penalize the pyrolysis and gasification processes from the energy standpoint.

In order to produce syngas mixes with high calorific value, richer in hydrogen and methane, it will be indispensable to create a circuit for the addition of oxygen and heated water vapor to the gasification air. A further advantage of this technique is a reduction in tar formation.
High hydrogen contents in the syngas could make it interesting and worthwhile to adopt subsequent enrichment and purification treatments of this type for feeding fuel cells which, today, are the subject of numerous studies focusing on their development, especially in combination with renewable sources.

Wood chips

Chipper

Olive tree prunings

Grapevine prunings