

Decentralized energy production and cogeneration don't have to be fuelled with natural gas. Indeed some policymakers overlook the growing industry and potential of wood-fuelled cogeneration. The US Department of Energy has launched an R&D programme to develop biomass cogeneration, while COGEN Europe has calculated that biomass cogeneration plants could reach a total installed power of 11 GW by 2010, with another 8 GW being added by 2020. **Jeremy Hugues** surveys the technologies on offer and the markets they are expected to fill.

# Wood-fuelled cogeneration

## technologies and trends worldwide

**W**ood-fuelled cogeneration offers the advantages of natural gas cogeneration as well as those of wood energy: neutrality in the carbon cycle (no net carbon dioxide emissions), clean elimination of problematic wood wastes, an increase of regional energy independence, and direct and indirect creation of local jobs for fuel supply.

The market for wood cogeneration technologies is based on:

- paper mills
- electricity utilities that need to reach a minimum percentage of green electricity production
- sawmills and the wood processing industry that has waste elimination problems and drying needs
- ageing coal or gas cogeneration plants that need to reduce NOx emissions
- rural communities with no natural gas or electricity grid connection.

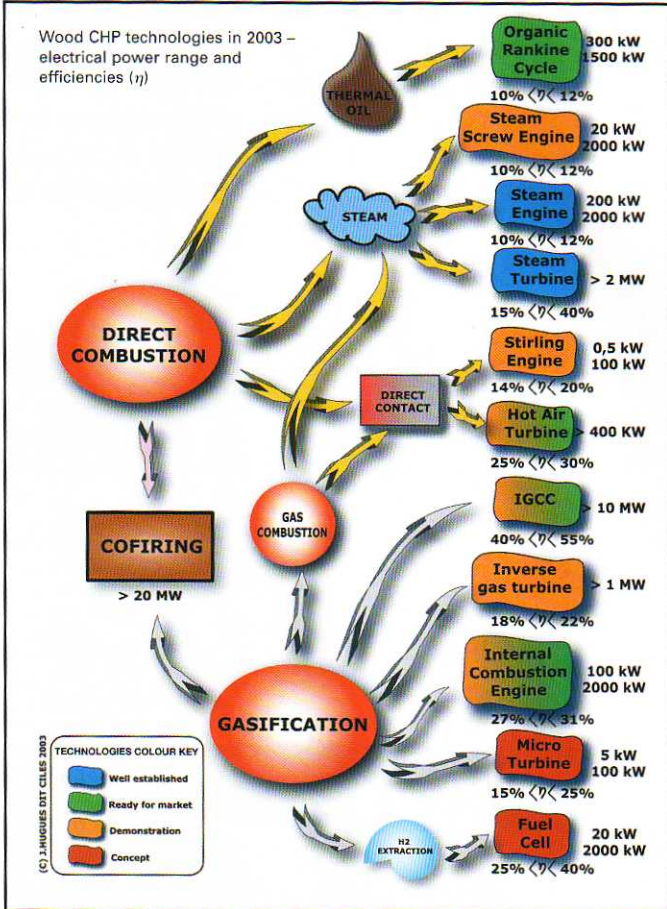
In Europe, to be viable, wood cogeneration projects require relatively high global buy-back rates of electricity in the range of €0.09–0.11/kWh (US\$0.11–0.13/kWh), as in Austria, Belgium, Denmark, or a carbon tax on fossil fuels, as in Sweden and the UK. This can be achieved by selling green certificates. The European carbon dioxide trading system should be standardized in 2004 and the average price of a carbon-free MWh of electricity should be around €65 (\$75).

The installed capital cost of wood-fuelled cogeneration plants varies from €1500/kW for large power plants, to less



Turboden 1100 kW ORC cogeneration unit commissioned in March 2002 at Bregenz, Austria

Wood CHP technologies in 2003 – electrical power range and efficiencies ( $\eta$ )



There are two ways of transforming solid wood fuel into energy: direct combustion in a boiler and gasification.

## DIRECT COMBUSTION SYSTEMS (BOILERS)

The most common way today is direct combustion in circulating fluidized bed (CFB) or moving grate boilers. CFB boilers, usually chosen for thermal requirements of over 25 MW, can burn wood fuels of a wide quality range. Moving grate boilers can also take high moisture-content wood fuels (up to 65%), but the window of quality is much narrower and has to be defined before sizing the plant.

To transfer the heat produced in the boiler to the device which transforms thermal energy into a mechanical energy driving the generator, there are two main fluids: steam and thermal oil.

## Steam technologies

Steam technologies powered the industrial revolution and they still hold the largest share of the world's electricity production. Since current wood-burning technologies derive from the coal industry, most installed wood-fuelled cogeneration is based on steam – the majority on steam turbines, but also on a new generation of steam engines.

## Steam turbines

Since the use of the waste heat requires higher temperatures and pressures than in a classic power plant where 60–70% of the energy is discharged into a river or the atmosphere, steam-cycle cogeneration plants require more complex technologies. Two types of turbines are usually used:

- **back-pressure turbines** – where the steam is expanded only to a back pressure required for the heat process (this option is preferable when constant heat is required)
- **extraction-condensing turbines** – they have a steam extraction valve located between the entrance and the rear. This means cogeneration can be run at any level from a full condensing turbine, by taking no steam from the extraction point (for an electricity priority production), to a full extraction of steam from the extraction point (for a heat priority production).

than €3000/kW for small- and micro-scale units. Under these conditions, a sawmill with constant heat needs and with an electricity production of 7000–8000 hours per year can pay off its investment within three years. A district heating plant working 3000–4000 hours per year can pay off its investment within six or seven years. However, it is important that wood electricity prices do not reach levels that would allow electricity production without heat valorization, now that energy efficiency has become a priority.

In warm climates, R&D work should find solutions to transform residual heat into cooling energy. Finally, it is essential that in countries with deforestation problems, the growth of biomass electricity systems should focus on agricultural wastes (rice husks, bagasse, etc.) so as not to worsen the situation.

The huge interest in cogeneration and biomass energy has produced a wide range of wood cogeneration technologies. While most large power technologies are well established, few medium- and small-scale systems are ready for the market and are mostly at a demonstration, pilot or conceptual stage.

The power range of steam cogeneration turbines is wide, since they can produce from 500 kW up to 240 MW (Alholmens Kraft, Finland – see COSPP, May–June 2002). However, below 5 MW, efficiency is low (10–20%) and maintenance costs are

relatively high due to steam regulations (most countries require a technician during the operating hours of pressurized steam systems). Between 5 MW and 20 MW, it is usual to get electrical efficiency of 25% and, in large plants of over 50 MW, it is possible to obtain over 30%. (In this article, electrical efficiencies are defined as the ratio of available electric power over the fuel power entry in cogeneration mode.)

The advantage of steam turbine cogeneration is that the technology is well known and can run reliably. It is often the choice of paper mills and very large district heating companies in northern Europe. The disadvantages are high operating costs and poor part-load performance although, in time, the efficiency of small turbines could be improved by using more expensive materials which are more resistant to the high temperatures and pressures (600°C, 170 bar) experienced in the boilers.

### Steam engines

The market for small-scale cogeneration has forced the German company Spilling ([www.spilling.de](http://www.spilling.de)), the only one in this market, to improve its now mature technology. Indeed, its new, oil-free engines do not require a daily cylinder oil check and condensate analysis for oil. Steam engines are well suited to a steam cycle between 200 kW and 2 MW. Their main advantages are the high flexibility in steam requirements (saturated to superheated steam), the excellent part-load performance (100% of nominal output at half load), and cheaper water treatment than for steam turbines. On the other hand, the electrical efficiency of steam engines is very low (10–12% unless using superheated steam) and the high noise levels make installation in inhabited buildings (such as hospitals and apartments) problematic.

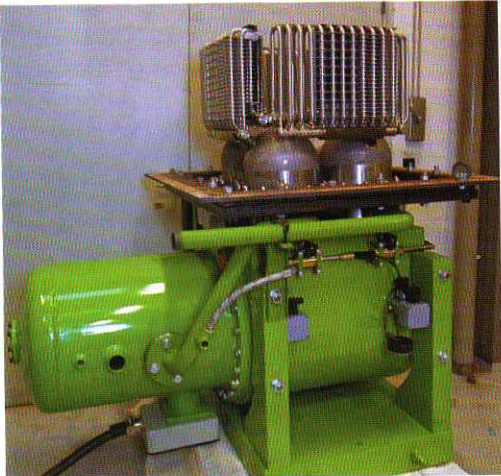
Today, approximately 300 units have been sold in the world, of which 200 are in biomass (mainly wood) cogeneration plants. About 30 units have been installed since 1999 when the oil-free engine was commercialized.

### Steam screw-type engine

Steam screw-type steam engines are a new cogeneration technology at a demonstration stage. A 760 kW unit has been operating in Hartberg (Austria) since 2001, together with a 710 kW unit in Sachsenburg (Austria) starting this year and a 250 kW unit at Dortmund University in Germany. The principle is of two imbricated spiral rotors in between which the working volume periodically changes. Pressurized steam is admitted by the continuous rotation of the screws. Once inside the variable working volume, the steam expands and powers the rotors which then drive the electric generator.

In terms of power and efficiency, screw-type steam engines are similar to classic steam engines, since they offer a power range from 20 kW to 2 MW, with a low overall electrical efficiency of 10–15%. In the near future, the capital cost should be similar to that of the steam engine. Advantages include high part-load efficiency, low maintenance and the possibility of using wet steam (the steam pressure is limited, however).

For more information on screw-type steam engines, visit [www.bios-bioenergy.at](http://www.bios-bioenergy.at).



This 35 kW Stirling engine, developed by the Technical University of Denmark, is expected to be on the market by the end of 2004



This 9 kW Stirling engine from the German company Dolo should be commercialized for wood pellet use in 2004

### *Pros and cons of steam*

Apart from the new steam screw-type engine, steam boilers and their associated thermodynamic machines are long established and reliable. They lead the large biomass cogeneration market. Because turbines suffer from poor part-load performance and rather high operating costs, steam engines are more suited to small- and medium-scale power production.

Yet, steam systems have some disadvantages. National steam regulations, which vary from country to country, induce minimum fixed operational costs. Although some small- and medium-scale steam engine cogeneration units can be left unattended for 48 or 72 hours with remote control, many countries require anything between a daily check to the 24-hour/day presence of a technician. Some regulations also require the installation to be checked annually by a certified company. Lastly, steam systems also require water treatment plants – indeed the water has to be desalinated and the abrasion mud must be discharged.

### **Thermal oil technology**

Another way to transform heat into mechanical power is the Rankine Organic Fluid Cycle (ORC) system. This is a mature technology developed and used for geothermal and some solar electricity production around the world. Due to the low-temperature vaporizing point of the organic working medium (silicone oil), ORC cogeneration units are well suited for biomass fuels. The first wood-fuelled ORC cogeneration unit was built in 1998 in Bière, Switzerland. Since then six others

**Table 1. Composition of gas produced from wood fuels**

Hydrogen	8–20%
Carbon monoxide	16–20%
Carbon dioxide	7–18%
Methane	2%
Nitrogen	48–52%

have been installed, in Austria, Italy and Switzerland. Another nine are planned for the coming year in Austria. The power range is between 300 and 1500 kW, with most projects in the region of 1 MW.

The principle is: a first thermal oil cycle is heated to 300°C in a wood boiler (this thermal oil cycle is necessary to ensure that the silicone oil is not heated beyond the temperature above which it would be damaged) and transfers its heat to the silicone fluid in a heat exchanger. The organic medium then vaporizes and expands in a two-stage turbine.

ORC technology presents several interesting advantages. Since the thermal oil medium is under atmospheric pressure, the cogeneration plant is freed from steam constraints. Adding ORC units to an existing wood-fuelled boiler is relatively easy. The working medium is non-corrosive, so it does not wear the turbine blades and does not age. Such plants do not need water treatment, are relatively quiet and, like the steam engines, give very good part-load performance. Yet, since the silicone oil is highly flammable, an excellent leakage security system is required. Investment costs are still relatively high, but serial



Xylowatt gasifier in the REGAL 300 kW cogeneration plant at Louvain la Neuve, Belgium (Details at [www.xylowatt.com](http://www.xylowatt.com))

production should bring the ORC to competitive prices within a year or two.

There are only two biomass ORC units manufacturers: the German GET (see [www.international-e-commerce.com](http://www.international-e-commerce.com)) and the Italian Turboden ([www.turboden.com](http://www.turboden.com)).

More technical information about wood-fuelled ORC cogeneration plants can be found at: [www.bios-bioenergy.at](http://www.bios-bioenergy.at).

### **Stirling engines**

A third way to transform direct combustion heat to mechanical energy is by external combustion engines such as the Stirling engine.

The first micro-scale gas-fired cogeneration units based on Stirling engines for domestic use (0.5–6.0 kW) are now commercialized (Whispergen, from New Zealand) and more should reach the market towards the end of 2003 (Solo, from Germany, STM-Power, Sunpower and Enatech, all from the US). However, biomass Stirling cogeneration units are still under pilot or demonstration phase. Some of these companies are working on the adaptation of their technology to wood pellet burners for private homes and plan a first commercialization around the end of 2004. The main obstacle for direct combustion is the clogging of the heat exchanger due to ash deposits, and clinkering and tar accumulation. The efficiency of Stirling engines (from 13–18%) relies on the high temperature of the heat source (over 600°C).

An alternative, which gives higher electrical efficiencies (around 20%), is under beta phase test at the moment in Ansager, Denmark, where producer gas from a wood updraft gasifier is flared directly on the exchanger. A well known, four-cylinder, 35 kW engine designed for wood cogeneration by the Technical University of Denmark has also been announced as ready for commercialization by the end of next year, with a

target price of €50,000. An eight-cylinder version, producing 75 kW, should follow a year later and STM Power has also announced units in the range of 110–200 kW.

Stirling engines, the only biomass cogeneration technology technically and economically viable under 50 kW, are of great interest as they are silent and require little maintenance (once every 5000 operating hours). However, they have a very poor part-load performance.

More information about Stirling engines and manufacturers is at: [www.stirlingengines.org.uk](http://www.stirlingengines.org.uk).

## WOOD GASIFICATION

Although this century-old technology disappeared in Europe immediately after its forced – but short-lived – success (1 million vehicles were running on wood gas during World War II), wood gasification is back today as a growing theme of R&D in many countries. Shell has estimated that, at the end of this decade, biomass gasification could meet 5% of the world energy demand. The US Department of Energy has said that the cost of production of an electrical kWh produced from biomass gasification should fall to as low as 4.5 US cents in the coming years.

It is important to remember here that 80–85% of the energy from wood fuels is liberated in the form of gas, often called producer gas. Composition depends upon the type of wood fuel but the average proportions are summarized in Table 1.

Note that a good producer gas should have less than 2%

methane and no water after condensation in the cooling system, since humidity or moisture in gas will carry carbon through most filtration systems.

In a gasifier, wood goes through four main steps: distillation (transforming water into hydrogen), carbonization, oxidation, followed by reduction (transforming carbon dioxide into carbon monoxide).

There are two different gasification technologies: fluidized and bubbling beds and fixed beds, themselves divided mainly into down- and up-draft gasifiers (sometimes combined in two-stage gasification systems). The producer gas can then be burned in a boiler or in gas turbines or internal combustion engines.

The advantages of gasification over direct combustion are:

- higher overall and electrical efficiency, especially at small scale
- lower emissions, which may enable contaminated wood to be valorized in small gasification units. (Recent tests have suggested that the Belgium Xylowatt 300 kW cogeneration unit had emission levels below the European limits while gasifying creosoted and painted wood wastes)
- lower investment costs
- the opportunity to co-fire biomass in fossil fuel plants (as demonstrated in projects in Austria, Finland and the Netherlands).

For large-scale projects, the objectives are to develop high electrical efficiency 'Integrated Gasification Combined Cycle'

(IGCC), where CFB gasifiers feed producer gas into an adapted version of the successful natural gas combined cycle cogeneration technology. Many large US- and EU-funded biomass gasification cogeneration plants have been built (in Sweden, the UK, the US and Brazil) but all have shut down or produce hardly any biomass electricity. Official reasons are political and financial problems, or prohibitively high wood-fuel costs. But these are the same obstacles that classic steam biomass successful plants have to face too. Though the gasification plants complied with the expected efficiencies at the beginning, no gas turbine has survived a 5000-hour operation: the producer gas, even after gas cleaning, has too much tar and condensates, causing costly deposits on the turbine blades. Large, tar-free producer gas technology has not yet been achieved, and might not be until small-scale gasification has been mastered.

For small-scale projects (under 2 MW) wood gasification cogeneration technology consists of fixed-bed gasifiers feeding lean gas, diesel or dual-fuel internal combustion engines. Several dozen prototypes have been implemented throughout the world but so far, none of them has led to commercial '24-7' (7000-8000 annual production hours) wood cogeneration. The 500 or so working units installed in India and China is not transposable to a western-type market for cost and reliability reasons: cheap engines are used and replaced when worn-out. However, quality wood gasifiers do not belong to the realm of science fiction. Despite some poor performance in wood gasification cogeneration technology, a few less well

known installations are very promising, e.g., a 100 kW project in Londonderry, Northern Ireland that has run for more than 10,000 operating hours in three years.

One important disadvantage of most wood gasification cogeneration plants is the necessity of treating the water from gas cleaning.

Another encouraging solution for low-content tar-gas problems is combustion of producer gas in a burner, producing steam or powering a Stirling engine (some plants in demonstration in Denmark) or a hot-air turbine via a heat exchanger. The Canadian Heuristic Engineering Inc. has sold several 3-5 MW cogeneration plants, combining two stage gasifiers and a gas turbine with external combustors, to British Columbia's large sawmills. Only time will tell what the life expectancy of those highly stressed heat exchangers will be.

The main reasons for the disappointing take-up of wood gasification despite positive R&D results are that:

- Only large organizations can afford the time and the skills to write proposals for financial support.
- The research is often led in too academic a mode, using existing academic knowledge and co-operating too little with small non-academic entities having long-term field experience.
- There is no international database gathering together all available R&D projects and their results, scientific research and the practical know-how.
- There is too much secrecy in the gasification world. It must

be remembered that the extraordinary progress that has been made in wind power is partly due to the co-operative investing system and the important knowledge-sharing policy of the most advanced Danish manufacturers.

Another future technology in wood gasification cogeneration could be hydrogen production to feed fuel cells. At present, research is based on cryogenic extraction or REDOX filters. However, this solution will probably not be available on the market for another five years.

Biomass gasification will play a key role in the development of biomass cogeneration. However, at present the painful experiences of technical mistakes followed by the non-transparent policy of some manufacturers have caused some experts and financiers to lose faith. The success of the first commercialized plants of companies that have overcome the tar and condensates problems should prove the reliability of wood gasification within two years. To finance tar-free wood gas production R&D, manufacturers and governments should focus on the implementation of wood gasifiers for co-firing in existing coal and gas fired cogeneration plants.

For more information on wood gasification technology, visit:

[www.nf-2000.org](http://www.nf-2000.org)

[www.gastechnology.org](http://www.gastechnology.org)

<http://crest.org>

[www.eren.doe.gov](http://www.eren.doe.gov)

[www.woodgas.com](http://www.woodgas.com)

## **FUTURE TECHNOLOGIES**

Other new technologies could also enhance the small-scale biomass cogeneration market. The German Enginion AG has developed a high-efficiency external combustion engine, using steam at 500°C and 500 bar that could be adapted to wood fuels. For more details, visit: [www.enginion.com](http://www.enginion.com).

Some pellet-stove manufacturers are also doing research to make their heating devices independent from the grid. The idea is to generate 100–300 W with a piezzo-electric fixed on the flue, or a high efficiency photovoltaic collector in the hearth.

For more details on the different cogeneration technologies, visit: [www.energytech.at](http://www.energytech.at)

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