



## Forest fire protection and water desalting by means of biomass control

Daniel García Almiñana<sup>1</sup>, Núria Garrido Soriano<sup>2</sup>, Climent Solé Xam-mar<sup>3</sup>

<sup>1</sup>Polytechnic University of Catalonia (UPC) – Engineering Projects Department -  
Colom 11, Building TR5, Room 2.08 - 08022 Terrassa (SPAIN) – daniel.garcia@upc.edu

<sup>2</sup>Polytechnic University of Catalonia (UPC) – Chemical Engineering Department -  
Colom 1, Building TR1, Room 236 - 08022 Terrassa (SPAIN) –

<sup>3</sup> Institut Cerdà, Numància 185 - 08034 Barcelona

### AIM

*The aim of the current study is to define, design, and evaluate a seawater desalination plant capable of producing 10 hm<sup>3</sup>/yr, using a reverse osmosis process. The energy required (electricity) will be produced by burning waste from forestry management or from the woodworking industry.*

### BACKGROUND

The study has had to take into account the negative factors of the coast and a large part of the centre of Catalonia:

- ✓ Significant lack of water, mainly in the Barcelona metropolitan area.
- ✓ Increase in the area ravaged annually by forest fires, despite a decrease in the number of fires, mainly due to the increase in combustible matter in wooded areas and the abandoning of woodlands.

Catalonian woodlands are very much under-managed, giving rise to a high density of combustible material, which, in turn, means easier propagation of fires. Initial estimates as to the possibilities of biomass as a source of energy for Catalonia indicate there is enough waste to provide energy for a reverse osmosis plant of 10hm<sup>3</sup>/yr, which means it is technically feasible to satisfy the present demand for water by improving woodlands and using waste from the woodworking industry. Biomass is considered a renewable energy, and its use presents environmental advantages over traditional fuels, thus making it eligible for direct grants.

This method of water production would benefit from several positive external factors that could affect the financial viability of the plant; including, in some cases, the cost of opportunity:

- ✓ Water shortage compensatory system based on desalination plants.
- ✓ 2015 Energy Plan (increased use of renewable energies, including forestry residues).
- ✓ Technical evolution of methods for collecting forestry residues in geographical relief such as that of Catalonia.
- ✓ Increased social awareness of forest fire hazards after the fires of 2003.
- ✓ Direct economic repercussions of forest fires on the government can be reduced through predictive maintenance rather than the present remedial system.

Many of the measures mentioned are based on cleaning and managing woodlands, which means it is difficult to count on continuity of supply due to the lack of co-operativism in the forestry management sector and little or no previous experience. For this reason, it has been decided to take into consideration other sources, such as waste from the first stage of the woodworking industry as well as gardening as alternative supply lines to complement forestry residues.

The economic evaluation has been carried out separately on both modules – desalination and biomass – so as to assess the profitability of each system and identify the weak points in each.

### DEFINING THE LOCATION

A study of the forestry potential of the different regions of Catalonia and their water shortage as reported by the Catalan Water Agency (*Agència Catalana de l'Aigua*) indicates that the districts which potentially best comply with both requisites are Maresme Nord and Garraf.

As the water requirements are similar in both cases, the final decision was taken based on the availability of biomass for the energy producing plant.

Maresme Nord was found to have a greater wooded area and a better history of forest fires, together with further wooded areas in neighbouring districts.

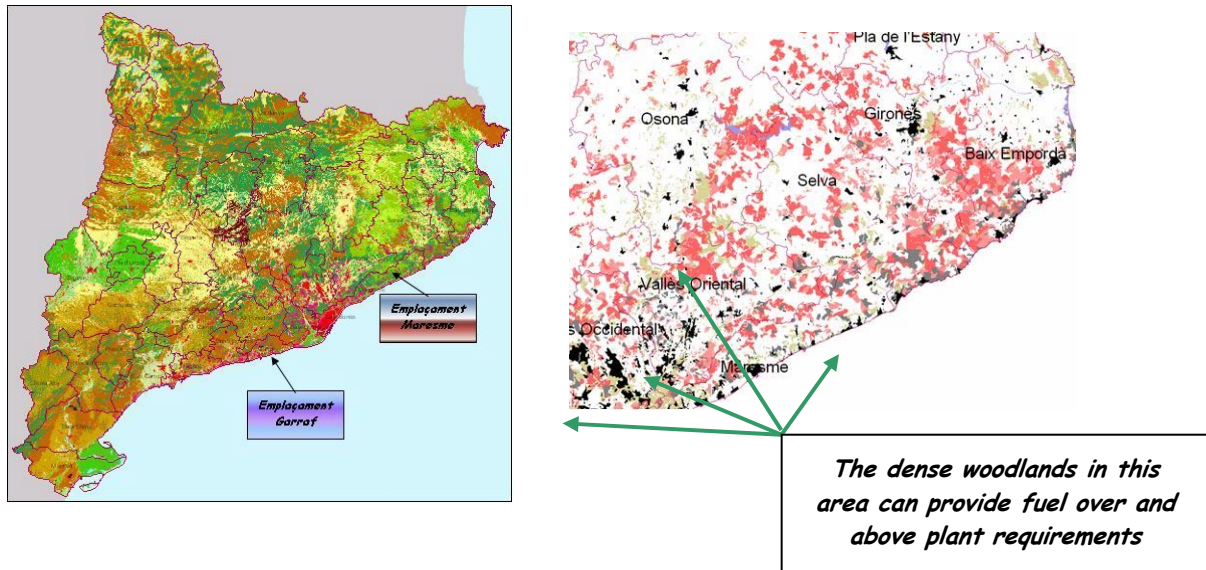


Figure 1 – Possible locations

The location also complies with other predetermined aims in respect of fire prevention, since the plant would be in an area of mostly fuel model 4. The extraction of part of this matter could help reduce the spread of forest fires.

While it is not the best location from the point of view of forest management, the principal requirement is the availability of seawater; an inland location would enable a greater area to be covered. The final decision was taken based on water shortage, since any initial shortage of fuel can be offset by increasing transportation distances.

### BRIEF DESCRIPTION OF THE DESALINATION PROCESS

Seawater is drawn from coastal wells at the rate of 84,788m<sup>3</sup>/day (52,364m<sup>3</sup>/day for the desalination process and 32,464m<sup>3</sup>/day for cooling the energy plant), and pumped at between 3 and 8 bar (depending on distance and geography) through a single pipeline to a pre-treated feedwater cistern where 3ppm of sodium hypochlorite is added. Using four transfer pumps (three, plus one reserve), the percentage of liquid required for reverse osmosis is then piped at a mean pressure of 4 bar to the filter system. In this intermediate stretch, 3ppm ferric chloride and 17.5ppm sulphuric acid are added.

The filter system consists of 10 sand cells (eight plus two reserve) of 6,545m<sup>3</sup>/h each and five cartridge filters (four plus one reserve). In the intermediate stretch 3ppm of scale inhibitor and 15.5ppm of sulphuric acid is added to reduce feedwater pH to 7. After the filtering stage, 4ppm sodium bi-sulphide is added and the treated feedwater goes on to the high-pressure stage in four streams at a pressure of 1.5 bar.

Propulsion in the first stage is provided by five divided-chamber pumps (four plus one reserve) that raise the seawater pressure to 61.6 bar. Pressure at the entrance to the membranes is controlled by four valves – one for each stream.

The first stage of the reverse osmosis system consists of four sequences of 80 pressure chambers, each with six TM820-370 membranes manufactured by TORAY, or of a similar type. This stage provides a permeate flow of 20,945m<sup>3</sup>/h, which leads to a storage tank.

Four booster pumps then propel the liquid at 31,419m<sup>3</sup>/h and 72.8 bar on to the second stage, where 7,855m<sup>3</sup>/h permeate is produced, together with a final residue of 23,563m<sup>3</sup>/h saline water with 82,000ppm.

The concentrate leaves the membrane system at a pressure of 72 bar and, to make the most of this energy, the flow is diverted to Pelton turbines (one per stream) which reduce the energy charge of the first stage pumps.

After leaving the recuperation system, the concentrate is led to a 100m<sup>3</sup> tank to ensure enough water for cleaning the filters.



On leaving the tank, the concentrate is mixed with residual water from the biomass plant condenser and is discharged out at sea through an underwater emission pipe. The reason for mixing is two-fold: to reduce both the salinity of the concentrate and the difference in temperature due to the heating process.

The membrane system in the second stage comprises four trains of 36 pressure tanks with six TORAY TM820-400H membranes.

The product water from the reverse osmosis system is not fit for drinking so it is treated to regulate its pH, hardness and alkalinity. 93ppm of CO<sub>2</sub> and 100ppm of Ca(OH)<sub>2</sub> stabilise the pH at 8.24 and reduce its alkalinity to within official levels.

The CO<sub>2</sub> and lime are added in the membrane chamber itself; although, in practice, they are first added in a bypass or secondary channel which then mixes with the main flow, bringing the mineral content to the required level. This reduces the capital investment in equipment.

Due to its low solubility, the lime is slaked at 8% before it is added to the water by means of a screw conveyor from a silo. The feed screw has a speed control to regulate flow depending on the amount of lime required.

There is an alternative and more economic post-treatment system in which the product water is clean enough for transport (reduced aggressiveness), but it is not potable since it does not comply with official hardness levels (60mg/l). This is the system that is usually used in reverse osmosis plants since it reduces operational costs and allows an ionic balance with other drinking water supplies, which normally have high levels of calcium (very scalent water). The study envisages both methods, but in the latter case, it assumes there will be a mixing of the product water with other sources of drinking water.

## BRIEF DESCRIPTION OF THE POWER PLANT

### Reception

Raw material will arrive at the plant in lorries, and will consist of woodland brash, small stocks, bent or ill stocks rejected by industry, prunings, garden residues and bark. Although the plant was initially expected to use only forestry residues, fuel will ultimately depend on availability of supplies.

Material reception will entail weighing the biomass (a weighing machine will have to be installed) and measuring its humidity. Moisture content on reception is generally between 5% and 55%, and this may mean raw material will have to be paid for according to its calorific value. The best option would be to establish the design conditions (30% and 19,556kJ/kg) as a benchmark.

Once the data has been processed, the lorry goes on to the compacter, the pit, or the chipper, depending on the type of raw material.

### Storage area

The storage area is designed to hold the raw material required for 4½ months of continuous working. This figure is based on the following factors:

- ✓ Forestry work is not allowed during the summer months due to the risk of fire,
- ✓ lack of guaranteed supply,
- ✓ better purchase terms for large stocks,
- ✓ natural drying conditions, which mean drier fuel and better burning,
- ✓ in Catalonian forestry companies it is possible to find up to three years' stocks.

The storage area is divided into three sections:

- ✓ Outdoor: with a capacity for 28,600m<sup>3</sup> (compacted, 110 days) and 4,866m<sup>3</sup> (woodchips, 10 days),
- ✓ under cover: with a total capacity of 7,300m<sup>3</sup> (15 days),
- ✓ feeder silo: with a capacity for of 36m<sup>3</sup> (1.5 hours).

The aim of the covered section is to continue the drying out process and protect the fuel from rain.

Long-term stocks must be used on a FIFO basis to avoid excessive storage times (possible deterioration) and to keep moisture content levels as constant as possible. This means monitoring the "age" of each stockpile, which in turn means dividing the whole section into sectors.

The characteristics of this type of drying process require the installation of a fire control system and the monitoring of other problems, such as pests.

### Compacting and chipping

The compacter compensates anticipated shortfalls in harvesting forestry residues and enables the density of cords to be increased from 100 to 600kg/m<sup>3</sup> as well as higher stacking heights.

The chipper is used to reduce the size of the wood to 5mm-10mm, which benefits air-to-fuel contact and thus improves combustion. Chipping is essential for biomass thermal output while at the same time making internal transport easier, even though it does increase energy consumption (1%-3% of the energy of the raw material).

The plant chipper has to be capable of dealing with all types of incoming residue intended for burning. The fact that chipping is an added cost (energy consumption) means it may be worth considering paying a bonus for chipped material.

### Drying

Drying is a natural process during the storage of both compacted and chipped residue. In a pile of woodchips, natural drying takes place due to a series of reactions caused by fermentation, which raises the temperature of the pile to 60°C. It is expected that a month's storage will reduce the moisture content of woodchips to the levels foreseen in the design; i.e. 30%. That is to say, under normal working conditions, a flow of 6.5 tonnes/h at 30% moisture content will produce 6.1MW of electricity; if the moisture content were 20%, the same rate of flow would produce 7.15MW; and if it were 40%, only 5MW.

The storage time envisaged can reduce the moisture content to below 30%. As there is very little information on this aspect, it is not possible to give precise figures on the real efficiency of the drying process.

The outdoor storage area for woodchips will have canvas covers to stop them absorbing humidity from the rain and so improve the quality of the fuel. Even though a pile may seem homogenous, there will be significant differences in moisture content and other properties. This means it is necessary to turn over or stir the piles using high capacity mechanical shovels.

### Furnace

The biomass furnace is of the movable grid type, working in the range of 20%-30% forced air. Grate systems are appropriate for high moisture and high ash fuels, as well as being capable of dealing with a fairly broad range of fuel types. The fact that the grid is movable facilitates ash withdrawal encouraging better burning conditions than fixed or slanted grates.

The furnace is designed for staged-combustion, burning the smaller particles (30%-50% of fuel intake) in suspension, thus reducing the amount of forced air. The gas burners are sited fairly low down to promote total combustion of unburnt particles on the grate.

In addition, the furnace has a post-combustion section to ensure that undesirable by-products are not formed, by keeping residues at over 850°C for more than 2 seconds as required by regulations.

The furnace heats the water in tubes (water tube boiler), which acts as the heat producer in a Rankine cycle. The normal working ranges for 6.1MW power is 40-60 bar and 400-500°C, which corresponds to a flow of 6.5-9kg/s of biomass.

The burner system has a CO sensor coupled to an oxygen sensor located in the boiler flue in order to monitor the secondary forced air and the return flow, thus optimising the entry of forced air (to control unburnt particles).

### Ash

The combustion process generates solid residues which require managing. The ash is collected at mainly three points:

- ✓ Grid,
- ✓ cyclone,
- ✓ electrostatic precipitator.

The quantity of ash depends on the composition of the woodland residues and will vary according to the origin of the biomass. Bark is the highest ash-forming residue. Under normal conditions, it is expected 2% dry ash will be produced. The ash can then be used for:

- ✓ Soil enrichment (forestry or agricultural),
- ✓ composting,
- ✓ cement factories,
- ✓ road surfacing (asphalt).

For the time being, it must be regarded as a residue until a real analysis has been carried out, and an added cost calculated (transport + unloading).

#### Residual gases

Combustion produces residual gases which will have to be expelled by means of a flue. Although burning biomass is cleaner than most fossil fuels, the expelled gases still require cleansing. The rate of flow will be 33 tonne/h. The main cleansing system entails retaining the particles in suspension by means of a cyclone and an electrostatic precipitator.

#### Cyclone

The cyclone uses gravity and centrifugal forces. The rotation of the drum causes the particles to strike the wall and drop into the ash container.

The main advantages of the cyclone are simplicity of design and maintenance, small size, low cost and low loss of pressure (60-150Pa). The main drawback is its inefficiency in separating small particles, which means a second treatment is usually required.

#### Electrostatic precipitator

The electrostatic precipitator is included to overcome the cyclone's inefficiency in separating small particles. The unit electrically charges the suspended particles and then forces them through an electric field where they are retained. The system is highly efficient, retaining 95%-99% of the particles, but with the disadvantages of initial cost and its large size.

#### Turbine and electrical equipment

The turbine is of the condenser type since there is no need for heat. Its limitation is the pressure, 0.074 bar, required by the coolant (seawater). The turbine is connected to a generator that produces electricity. Systems for the pressure required are compact units including alternator, turbine, control panels and turbine lubrication.

The electricity produced is 6.1MW, of which 10% (based on other plants) will cover the energy requirements of the biomass plant. The excess electricity will be sold to the grid.

The plant will require a transformer and control panels to enable it to deliver energy to the grid as stipulated in current regulations.

#### Condenser

The fluid expelled is sent to a seawater condenser, fed from wells shared with the desalination plant. The expelled water undergoes no change except for an increase in temperature, calculated as 10°C above intake temperature. Once the water has been used in the condenser, it is mixed with the salt-water concentrate from the reverse osmosis process, which reduces the difference in temperatures to 6°C.

Seawater systems have a better heat exchange factor than air systems and allow a lower turbine exit pressure since they work at lower temperatures.

### **SUMMARY OF FINANCIAL STUDY**

The income from the electricity produced by the biomass plant does not cover the operational costs and depreciation, which means these losses must be included in the final cost of the product water. Global costs do not, therefore reflect the real profitability of each module of the plant. It was thought there was no point in increasing the cost per m<sup>3</sup> due to the use of biomass since it would result in a very uncompetitive price (€0.83/m<sup>3</sup>), and simply would not be viable. Taking each module separately, the desalination plant would be profitable to a certain extent.

The dual plant offers little savings in the operational costs of the two modules, although perhaps a slight reduction of personnel costs.



### Cost distribution

Both systems have similar cost structures, with a high initial investment and a high percentage of global costs dedicated to energy (electricity for desalination, and forestry waste biomass).

### Economic viability

With discount rates of 4%-6%, the production costs of water from the desalination plant would be €0.65- €0.70/m<sup>3</sup>. Under these conditions, the plant would begin to be economically viable.

For the power plant, the difference between the required income and the purchase price is too great to be compensated by reducing the price of the raw material; so a new variable must be introduced from among the following:

- Reduce fuel purchase costs

Since fuel purchase costs represent 55.6% of the operational costs of the plant, any reduction in price would mean a significant reduction in annual costs. Although this would seem to be the most logical option, fuel prices are determined by supply and demand, which means it would not be possible to get below €24/tonne, at least not to a degree that would offset losses. Reducing the price would mean being left without raw material.

- Establish an annual subsidy for the ecological benefits

Since the plant has a positive impact on the environment, annual green subsidies could be established. These subsidies would also affect woodland owners since they would not have to reduce their prices. Bearing in mind the annual budget for fire prevention, whether for prevention or compensation, the subsidy required by the plant does not seem to be very significant. It would also improve the country's CO<sub>2</sub> emissions and the percentage of green energy.

- Partial or total subsidy of the initial investment

Reducing part of the depreciation cost means the plant could be profitable in itself, although it would probably never be an attractive investment without some kind of specific help, at least, not with the foreseeable returns.

- Ashes

As has been mentioned above, the ash is a profitable by-product due to its composition (see study on environmental impact). If the cost of the ash could be eliminated, total costs would be reduced by 2.5%, which still does not mean the plant would be viable. Recycling the ash requires a specific analysis for each case due to the variety of sources and the differences in combustion.

- Tax incentives

A reduction in the tax burden would increase the plant's profitability.

These factors led to the conclusion that the most realistic option for a certain level of profitability would be a combination of the systems mentioned, although it would inevitably mean increasing the price per kWh, and an initial subsidy, which was then calculated. The following table shows the results.

Subsidy	Total (€/kWh)
0%	0,0925
10%	0,0881
20%	0,0837
30%	0,0793
40%	0,0749

Table 1: Minimum selling price depending on subsidy and tax incentives

These figures mean that both modules of the plant could be profitable, so the price of the product water would be left untouched at the same price as when considered separately.

## **CONCLUSIONS AND RECOMMENDATIONS**

In the current circumstances the plant cannot be considered profitable. Although the desalination module would be competitive in price initially (the plant in Blanes was priced at €0.64/m<sup>3</sup>), the plant cannot absorb the costs associated with power production, which then becomes the weak link in the process.



Reverse osmosis produces water at reasonable cost and can always be considered when there are no other direct alternatives. Building the proposed desalination plant in Barcelona could change the basis of this study as to whether it would still be required since it would have the Blanes and the Barcelona plants on either side, within a relatively short distance.

The only real option for the power producing module would be to raise the selling price per unit to €0.09- €0.10/kWh, the price set by most European countries.

Market uncertainty is also a factor to be added to the equation of the viability of the plant. It would be necessary to find buyers willing to sign long-term contracts at a higher price.

Finally, the dual plant would have a positive impact not only on the environment generally, it would also produce a significant social effect. It would improve the countryside, increase employment (direct and indirect, since harvesting biomass is labour-intensive), monitor drinking water, as well as other effects which would have to be taken into account when evaluating the plant.

If the environmental effects were valued economically, it is considered they would compensate the operational losses incurred, which would mean the profitability of the power module, that determines the profitability of the entire project, would make the installation viable. From a practical viewpoint, the effects on the Catalanian woodland industry, as well as the social impact at many other levels, more than outweigh the disadvantages. Currently, this point of view is not taken into account, and prices are set by the central government for the country as a whole. This means that, with the odd exception, power plants are operating at a loss (or simply not being built), and in no way adapt to commitments on CO<sub>2</sub> emissions, at least from the standpoint of this type of energy.

Another consideration is the present lack of industrial woodland waste for power production. Slow tree growth, lack of harvesting in summer, and the seasonality of work mean that alternative sources of supply must be found to compensate the fluctuations in woodland residue supply.

In light of recent years' experience, it would be advisable to reconsider our approach to the risk of woodland fires, such an inherent factor in the geography of Catalonia, and introduce the idea of remedial measures to limit their spread, and not focus simply on improvements in fire-fighting techniques.

The setting up of fire-prevention squads at county level to limit the excess of burnable material and draw up contingency plans for those areas most at risk would have a positive effect on the environment that would go beyond just fire prevention. It could also reduce the price of biomass and thus compensate the difference between the income required to make the plant profitable and the present price of water.

From an energy viewpoint, it is considered that the two modules of the dual plant (desalinator and biomass) are similar in that their low exogetic output determines final operating costs. Technological advances in each module would significantly affect final operating costs of the plant, as well as their positive environmental and social effects. Another way to reduce costs would be an increase in the economy of scale, to which both modules are sensitive. Even so, it is considered that in this case, an increase in size would not be without its own costs, due to the lack of availability of biomass for the power module and the possible negative effects of the emission of saline concentrate in very large plants.