Deliverable 8: Report on implementing biomass boiler and co-generator

Action: A.4

Deadline: 31/03/2015

Deliverable Action: A.4

A.4 Analysis of the needs for a co-generator and an innovative biomass application. First Revision

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For: LIFE 13 ENV/ES/1513

Place, Date: Barcelona, 31st of March 2015 (this document is based in a previous version of the 28th of February 2015)

1. SUMMARY

2. INTRODUCTION

According to the original proposal, the main objective of this action was to define the requirements and specifications needed to develop and produce the renewable energy production infrastructure at the central cooperative premises. By means of installing a biomass boiler (thermal energy) and a biomass co-generator (thermal energy and electricity).

Nowadays, the Cooperative Cambrils only eliminates its waste like olive pits (approx. 500 tons/year) and milled olives (approx. 6.000 tons/year) by giving them away or selling them for a really low price.

On the other hand, the current heat consumption of the building is produced with two ten-year-old-350-kW diesel boilers, using approximately 20.000 l of fuel per year.

With the installation of the biomass boiler it is intended to reduce the diesel consumption replacing it for biomass, particularly olive pit, which is currently a waste product and would become the main heating (bio)fuel. This boiler can be a commercial element, knowing that this kind of application is already used in other similar installations.

The idea of the co-generator has a double objective: in one hand, producing electricity to reduce the electricity bill and, in the other, using the exhaust heat for thermal uses, within the same Cooperativa premises.

One of the greatest concerns appears when we are intended to use various types of biofuels in the co-generator (from olive pits, to the results of the bio-crops plantations defined in other actions of this Life Project, or re-using other wastes of the oil production as olive milled waste or mown).

Another difficulty appears knowing that the current heat used is for the oil storage air conditioning and for the olive oil production, both of them in the same yearly time frame, it is necessary to find other uses for the exhaust heat in order to make the investment of the co-generator viable.

The following report was developed by Atres80, but with the important aid of CERTH in the Drying Technologies comparison and the Technical and Economical Study.

3. METHODS DEPLOYED

3.1. Biomass Boiler

In a previous action of this same LIFE projecte (Action A3. Conduction of an Energy Efficiency Study), the thermal needs of the Cooperativa building in Cambrils where detected and listed along with several actions of improvement that could reduce the energy use in the near future, enhancing the performance of the systems.

Taking these data as a starting point, we have defined an optimized consumption scenario and studied the viable ways of replacing the current diesel consumption for a sustainable fuel and defining the new installed heating power.

3.2. Co-generator

The major concern of the data analysis has become the unbalanced requirements of heat and electricity simultaneously in a sustained way during the whole year; using some of the exhaust heat to dry part of the olive oil production waste is an option that is currently being studied. A visit to another Cooperative which are doing a similar action is scheduled for April.

A comparison between the current heat and electricity consumption is shown in the following table:

	Current Heating demand (kWh)	Electric demand (kWh)
January	19.960,00	69.742,00
February	9.980,00	48.282,00
March	4.990,00	43.105,00
April	4.990,00	43.110,00
May	4.990,00	43.708,00
June	0,00	74.688,00
July	0,00	96.296,00
August	0,00	90.703,00
September	4.990,00	80.000,00
October	49.900,00	79.901,00
November	49.900,00	96.586,00
December	49.900,00	74.071,00
	199.600,00	**840.192,00**

The current heating requirements are concentrated in the winter months in coincidence with the olive oil production. If no viable ways of stretching the heat use are found, the viability of the co-generator installation will be in risk as a consequence of the maximum working hours.

4. BOILER SELECTION

4.1. Heating consumption. Current system

As has been explained in the Action A3 deliverable, there are currently the following heating consumptions, taken from the diesel consumption (considering 9,98 kWh/l as diesel's heat of combustion):

	Current consumption (l)	Energy (kWh)
January	2000	19960
February	1000	9980
March	500	4990
April	500	4990
May	500	4990
June	0	0
July	0	0
August	0	0
September	500	4990
October	5000	49900
November	5000	49900
December	5000	49900
	20000	199600

The heating system currently installed consists in two identical boilers of the following characteristics:

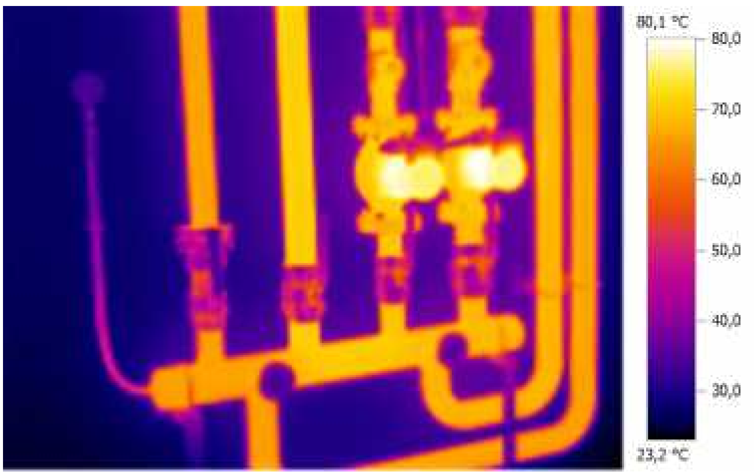
- Multi-Bloc boiler.
- Pressure vessel: Steel.
- Model: BIASI RCA350
- Heating power: 350 kW.
- Fuel consumption: 380 kW.
- Burner: 2 stages (fuel-oil), 30%-100%.
- Factory performance: 91,7% (Stage 1) - 92,1% (Stage 2).
- Year of production: 2.003.
- Expected performance reduction (12 years): - 6%
- Use temperatures: 80ºC out, 60ºC in.
- Maximum temperature: 100ºC.

These boilers are installed within a specific room on the ground floor of the building and are basically used for heating purposes, whether to maintain a 20 ºC temperature in the olive oil storage and bottling areas, or to use it directly in the oil production equipment or for washing.

4.2. Current installation considerations

Auxiliary systems

There were several installation aspects that were pointed in the Action A3 deliverable regarding the heating system installation that were pointed out to be necessarily improved, like the absence of insulation for heating pipes (as can be seen in the following thermal image taken in the Cooperativa building in December 2014) or individual control devises or the need of a buffering tank to avoid a great number of starts and stops of the boiler burner.



We assume, from this point, that the corrective measures will take place, so the global system performance will improve globally as follows:

- Losses for piping insulation (yearly improvement: 5,67%):

Pérdidas mensuales por radiación en tubería

	Caldera partida	Caldera comparar
Enero	0,36 %	0,01 %
Febrero	0,41 %	0,02 %
Marzo	0,48 %	0,05 %
Abril	0,66 %	0,12 %
Mayo	1,17 %	0,34 %
Junio	0,00 %	0,00 %
Julio	0,00 %	0,00 %
Agosto	0,00 %	0,00 %
Septiembre	5,00 %	3,72 %
Octubre	1,44 %	0,46 %
Noviembre	0,58 %	0,07 %
Diciembre	0,38 %	0,02 %

- Installation of a hot water buffering tank (yearly improvement: 2,20%)

Pérdidas mensuales por arrancadas y paradas del quemador

	Caldera partida	Caldera comparar
Enero	0,59 %	0,25 %
Febrero	0,59 %	0,27 %
Marzo	0,59 %	0,28 %
Abril	0,59 %	0,32 %
Mayo	0,59 %	0,41 %
Junio	0,00 %	0,00 %
Julio	0,00 %	0,00 %
Agosto	0,00 %	0,00 %
Septiembre	0,59 %	0,46 %
Octubre	0,59 %	0,44 %
Noviembre	0,59 %	0,32 %
Diciembre	0,59 %	0,26 %

If these improvements are carried out, the new consumption scenario will be something like the following table (a global reduction of 15.518 kWh/year, a 7,77% reduction):

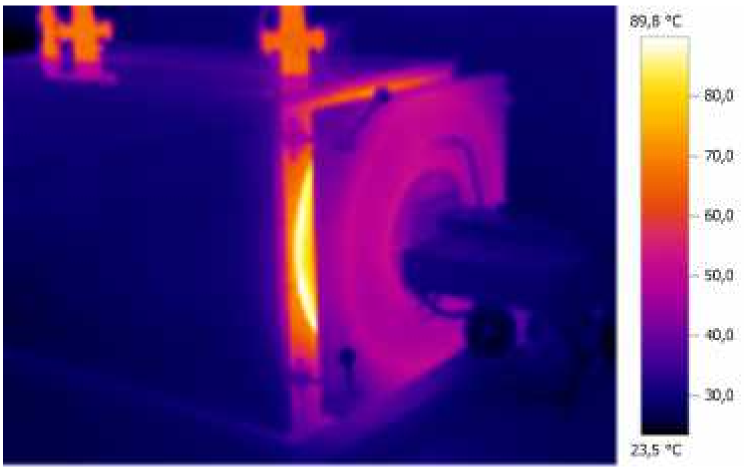
	Current consumption (l)	Energy (kWh)	Piping Insulation (-5,67%)	Buffering tank (-2,20%)
January	2000	19960	18822,28	18408,19
February	1000	9980	9411,14	9204,09
March	500	4990	4705,57	4602,05
April	500	4990	4705,57	4602,05
May	500	4990	4705,57	4602,05
June	0	0	0,00	0,00
July	0	0	0,00	0,00
August	0	0	0,00	0,00
September	500	4990	4705,57	4602,05
October	5000	49900	47055,70	46020,47
November	5000	49900	47055,70	46020,47
December	5000	49900	47055,70	46020,47
	20000	199600	188222,80	184081,90

<u>Boilers</u>

Combustion efficiency is the effectiveness of the burner only and relates to its ability to completely burn the fuel. The boiler has little bearing on combustion efficiency. A well-designed burner will operate with as little as 15% to 20% excess air, while converting all combustibles in the fuel to thermal energy. In our case, having a two-stage burner, the range of performance is clearly limited.

Thermal efficiency is the effectiveness of the heat transfer in a boiler. It does not take into account boiler radiation and convection losses - for example, from the boiler shell, water column piping, etc.

It is called In-Service efficiency, the one that takes into account cycling and purge losses, operating levels (boiler radiation, convection losses, etc.), and other variables. More importantly, in-service efficiency—the amount of fuel you have to use to get the needed output, may be a truer measurement of the value of a system. Following these lines there is a current thermal picture of the boiler in winter time.



Replacing the current boiler for a new one with better in-service efficiency (better design combined with advanced controls to provide a lower operating cost), the greatest performance improvements are to be expected (yearly improvement 25,89%):

Pérdidas mensuales por radiación en cuerpo de caldera

	Caldera partida	Caldera comparar
Enero	0,96 %	0,01 %
Febrero	1,10 %	0,02 %
Marzo	1,30 %	0,04 %
Abril	1,78 %	0,09 %
Mayo	3,16 %	0,27 %
Junio	0,00 %	0,00 %
Julio	0,00 %	0,00 %
Agosto	0,00 %	0,00 %
Septiembre	15,00 %	3,02 %
Octubre	3,90 %	0,38 %
Noviembre	1,56 %	0,06 %
Diciembre	1,03 %	0,01 %

4.3. New boiler fuel choice

This project was originally decided to use biomass energy as the source of power, knowing that the biomass fuel products are harvested and mass-produced and used in everything from engines to power plants.

- No Harmful Emissions: Biomass energy, for the most part, creates no harmful carbon dioxide emissions. Many energy sources used today struggle to control their carbon dioxide emissions, as these can cause harm to the ozone layer and increase the effects of greenhouse gases, potentially warming the planet. It is completely natural, has no such carbon dioxide side effects in its use.
- Clean Energy: Biomass energy does release carbon dioxide but captures carbon dioxide for its own growth. Carbon dioxide released by fossil fuel are released into the atmosphere and are harmful to the environment.
- Abundant and Renewable: Biomass products are abundant and renewable. Since they come from living sources, and life is cyclical, these products potentially never run out, so long as there is something living on earth and there is someone there to turn that living things components and waste products into energy.

- Reduce Dependency on Fossil Fuels: It has developed as an alternate source of fuel for many homeowners and have helped them to reduce their dependency on fossil fuels.

One of the most important considerations to be made regarding the choice of a biomass fuel (typically pellets or wood chips for this range of heating power) is to obtain a constant and reliable supply in the mid-term.

A key point in the current project is the availability of dried olive pits as a waste product of the olive oil production that makes it the ideal fuel for the new boiler to be installed.

However, there are several technical characteristics regarding the quality of the olive pits, prior to be used in the process as followed:

	Propiedad /Método de análisis		Unidad	A	B
Normativa	Origen y fuente EN 14961-1			3.1.2.3 Huesos / cáscaras (no tratados químicamente) 3.2.2.2 Huesos / cáscaras (tratados químicamente)	3.1.2.3 Huesos / cáscaras (no tratados químicamente) 3.2.2.2 Huesos / cáscaras (tratados químicamente)
	Contenido de aceite, por método Soxhlet		%	≤ 1.0	≤ 2.0
	Humedad, M, EN 14774-1, EN 14774-2		b.h., p-%	M12 ≤ 12	M16 ≤ 16
	Cenizas, A, EN14775		p-% b.s	A1.3≤ 1.3	A2.6 ≤ 2,6
	Poder calorífico neto, Q EN 14918		b.h., MJ/kg o kWh/kg	Q18.0 Q ≥ 18,0 o Q ≥ 4.4	Q15.1 Q ≥ 15,1 o Q ≥ 4.2
	Densidad aparente, BD, EN 15103		kg/m³	BD650 ≥ 650	BD600 ≥ 600
	Nitrógeno, N, prEN 15104		p-% b.s	N0.4 ≤ 0,4	N0.8 ≤ 0.8
	Azufre, S, prEN 15289		p-% b.s	S0.03 ≤ 0.03	S0.06 ≤ 0.06
	Cloro, Cl, prEN 15289		p-% b.s	Cl0.04 ≤ 0.04	Cl0.08 ≤ 0,08
	Arsénico, As, prEN 15297		mg/kg b.s	≤ 0,5	≤ 1
	Cadmio, Cd, prEN 15297		mg/kg b.s	≤ 1.5	≤ 3
	Cromo, Cr, prEN 15297		mg/kg b.s	≤ 10	≤ 20
	Cobre, Cu, prEN 15297		mg/kg b.s	≤ 10	≤ 20
	Plomo, Pb, prEN 15297		mg/kg b.s	≤ 5	≤ 10
	Mercurio, Hg, prEN 15297		mg/kg b.s	≤ 0.01	≤ 0,02
	Níquel, Ni, prEN 15297		mg/kg b.s	≤ 10	≤ 20
	Zinc, Zn, prEN 15297		mg/kg b.s	≤ 10	≤ 20
Inf.	Fusibilidad de las cenizas [a], prEN15370		°C	DT ≥ 750	DT ≥ 750
				FT ≥ 1375	FT ≥ 1300
Norm.	Tamaño de partícula, EN 15149-1	Finos < 1 mm.	%	< 3	< 8
		Finos < 2 mm.	%	< 20	< 50
		Tamaño máximo	mm.	Todas< 16 mm	Todas< 18 mm

[a] La fusibilidad de las cenizas es informativa pero es obligatorio un análisis de DT y FT. El límite DT es recomendable

Tabla 1. Límites de acuerdo a los estudios Biomasud

The most important considerations are the following:

- Humidity (gross %): < 12%
- Density (kg/m^3): 650 – 700
- Heat of Combustion (kWh/kg): 5,00-5,28

The greatest advantage of this fuel is its availability and low cost, being as it is a current waste of the process; the Cooperativa de Cambrils are currently selling the dried olive pits but its production is exceeding the sales.

The greatest inconveniences are related to the fact that it is not a certified fuel, so a quality control will be needed (a minimum humidity and density control process) before using it in the boiler, or it may cause problems because of an excess of ashes or a chemical corrosion of the pressure vessel.

4.4. New boiler selection

Once analyzed the fuel consumptions and considering that the various system improvements mentioned in the previous chapters will be carried out, obtaining a far better performance globally.

This situation will lead to a new scenario where the power installed will be able to be reduced, and as a consequence, the new biomass boiler that will replace one of the existing ones, can be reduced in size more than a 20% (counting both the system and the boiler performance enhancements).

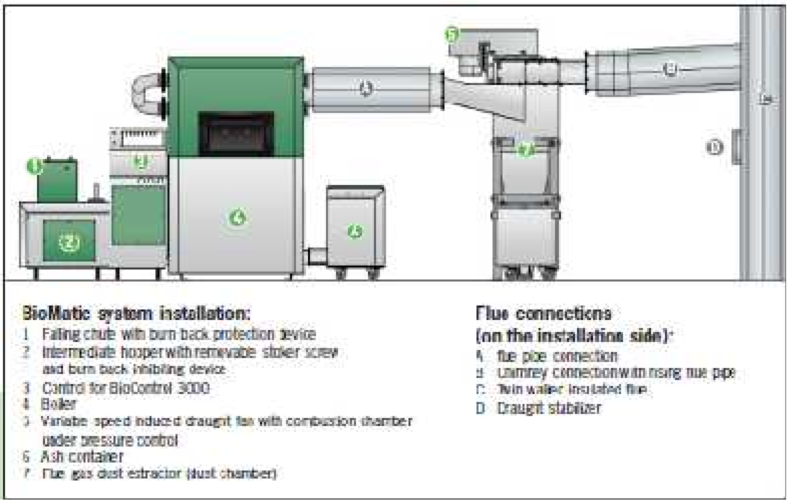
Consequently, the power installed can be reduced from the current 700 kW to approximately 560 kW. It leads to a new biomass boiler of around 210 kW.

<u>Boiler characteristics</u>

Not all the biomass boilers can use dried olive pits as fuel, the new equipment to install will require a certification from the supplier that can allow specifiably the use of this biomass fuel.

The new boiler must have a devise which continuously monitors the exhaust values and reacts to different fuel qualities, to make it possible to always obtain perfect combustion and the lowest emission values, due to the permanent correction of the necessary fuel quantity and secondary air, thereby guaranteeing the cleanest combustion, for both total and partial load operation.

The surfaces of the standing pipe heat exchanger need to be automatically cleaned during boiler operation. This needs to be carried out using some mechanism which guarantees a continued high level of efficiency between services by minimizing heat lost to the exhaust.
Ash and clinker build-up on the combustion grate must be automatically removed and conveyed to external ash boxes via independent augers.



The space requirements for this kind of boilers are similar to a diesel one and the current room will be enough to locate the new one.

As it has been mentioned Buffer storage is recommended, particularly for larger systems, because it reduces the number of boiler start-ups, guarantees a continuous heat leak, and allows the boiler to optimize when it turns on.

Using a buffer store, continuous power generation can be sustained for a longer period. Thus frequent cycling of the boiler can be avoided and the level of efficiency improved.

The minimum buffering volume would be between 4.400 to 6.600 l. We recommend to install at least a 5.000 l buffering hot water tank.

Fuel storage and extraction

Automatic feed boilers burning wood pellets or chips or dried olive pits can also be classified by type, and range in size from 10 kW to the very largest boilers. It is important to understand the variations in fuel supply systems, starting with the fuel store and ending with the delivery of fuel into the boiler.

Fuel can be stored in a range of ways, including silos, hoppers, containerized stores, flexible fabric silos, and in sheds above fuel extractor systems in large installations.

Fuel silos, containerised fuel storage or flexible silos are options that can be studied for this application and will depend on the definitive boiler supplier.

Apart from the well-understood issues of working in confined spaces and in silos containing materials which flow, there are specific and separate issues relating to the delivery and storage of biomass fuel. Due that the Cooperativa de Cambrils, currently has dried olive pit as a waste product of the Olive oil production, they have the knowledge and the equipment to handle it correctly.

Supplying the boiler

Many physical system layouts are possible using combinations of the fuel store and fuel extractor systems. The fuel store and boiler do not have to be on the same level, nor do they have to be contiguous (although this is preferable as long feed augers increase the risk of blockages and jams, reducing reliability). Fuel is fed by the fuel extractor mechanism to the boiler feed mechanism via at least two physical safety devices to prevent the fire in the boiler burning-back to the fuel store.

Regarding Boiler feed mechanisms, Fuel is usually fed into the boiler by either a rotary auger or a hydraulic ram-stoker. Auger feed mechanisms are the most common feed systems in use on automatic feed biomass boilers. Although generally made of steel, flexible plastic augers may be found on small pellet fired installations, and can minimize costs and weight.

All biomass boilers have a number of fuel feed safety devices to prevent the fire on the grate burning back up the feed mechanism in the event of fuel delivery failure or incorrect set-up of fuel air ratios: this is often known as burn-back. It is normal for a minimum of two devices to be installed between the combustion grate and the main fuel store or silo.

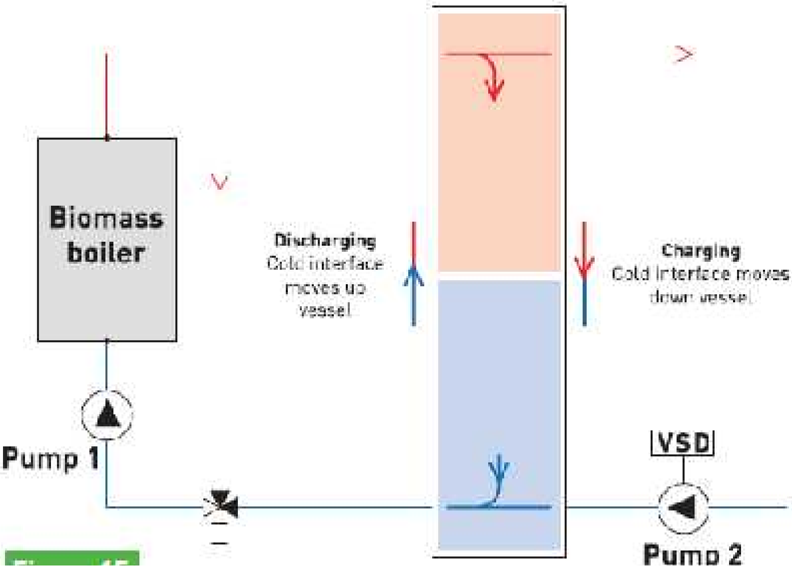
Fuel from the extractor auger is dropped onto the top of a rotary valve which meters fuel onto the boiler feed auger below. The segmented design of the rotary valve enables it to provide a positive seal between the two augers every time it rotates, physically preventing the fire from traveling to the fuel silo. The inclined stoker also provides a degree of burn-back protection. A burn-back flap valve may be used as an alternative to a rotary valve.

Buffer vessel operation

A buffer vessel is more than just a hot water cylinder. In a typical domestic hot water cylinder, or commercial hot water calorifier, the intention is to produce hot water by creating convection currents within the cylinder. When drawing hot water the mixing action continues such that the water temperature gradually reduces as the cylinder is discharged.

However, this situation is of no use in a buffer vessel where a constant hot water temperature is required from the top of the store as it discharges.

Buffer vessels are fitted with sparge pipes on their return inlets which introduce the cooler return water at very low velocity to minimize mixing and allow stratification. When charging, the hot interface moves down the buffer vessel, while discharging causes the cold interface to move up.



The boiler is usually fitted with a constant speed pump (pump 1) whereas the connection to the load circuits must have a variable speed pump or variable speed drive (VSD; pump 2) installed if the system is configured for thermal storage operation as opposed to a simple buffer vessel.

When charging, the heat produced by the boiler is greater than the heat demand from the load circuit and the flow rate through pump 2 is less than that of pump 1. When discharging, the output from the boiler is insufficient to meet the load, and the speed of pump 2 is greater than that of pump 1. The speed of pump 2 is often determined by setting a constant temperature difference across the load circuit, allowing the pump flow to be varied to meet the power demanded by the load.

4.5. System optimization

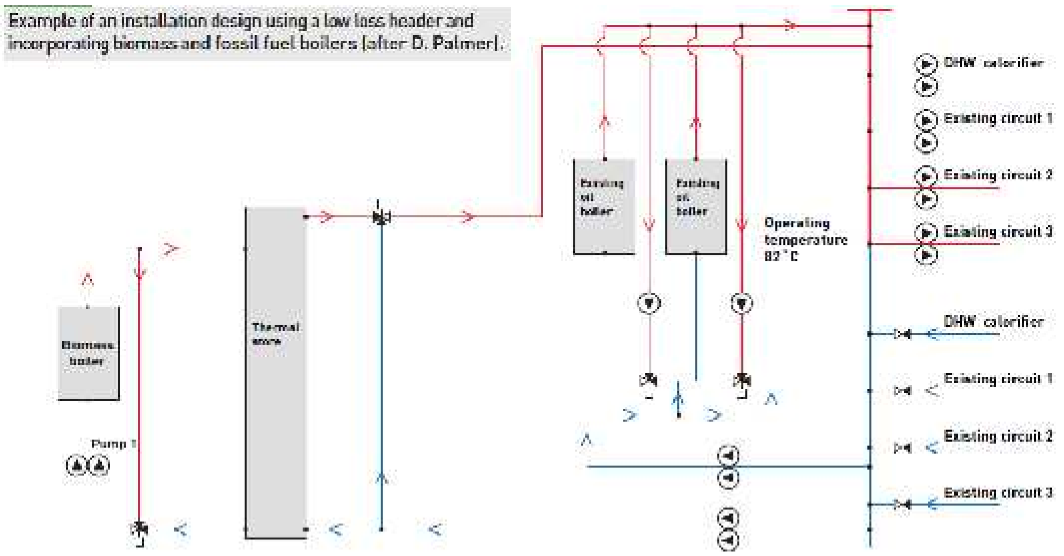
A biomass boiler can be connected directly to a system operating at 82 °C flow providing the temperature in the buffer vessel does not exceed this temperature by more than a few degrees. With a typical mean circuit return temperature greater than 60 °C, the temperature difference across the buffer vessel is only 20 °C. Since the energy storage capacity of a buffer is directly proportional to the temperature difference across it, a low temperature difference means a larger buffer vessel is needed to store the required heat. If only variable temperature (external temperature compensated) load circuits are present, the associated control system will allow the buffer vessel to operate at a higher temperature together with low return temperatures to optimize the energy storage capacity.

This means that it is not uncommon to operate biomass boilers at a temperature of up to 95 °C,
and sometimes as high as 110 °C on larger boilers. Unfortunately, if a boiler and buffer vessel operating at above 85 °C are directly connected to a system operating at 82 °C (like would be in our case, when we connect the new biomass boiler to the diesel existing one), the system pressure may need to be increased to accommodate the higher operating temperature (to prevent flash steam formation).

Depending on the nature of the lower temperature heating system it may not be possible to increase pressure sufficiently to provide an adequate flash margin. In this case it may be necessary to isolate the biomass boiler from the heating system and auxiliary boiler by using a plate heat exchanger, to allow an increase in the system pressure accordingly.

When connecting to an existing heating system, if it is not possible to reconfigure the system to a low loss header system, the simplest way to ensure the existing system remains hydraulically balanced is to replace one of the existing boilers with a plate heat exchanger.

Providing the pressure loss on the secondary of the plate heat exchanger at full load is equal to that of the boiler it replaces, the existing heating system should continue to operate as before without the need for a circuit rebalancing exercise.



Example of an installation design using a low loss header and incorporating biomass and fossil fuel boilers (after D. Palmer).

Boiler performance improvements

The new boiler performance it is expected to match the following results:

Rendimiento estacional mensual

	Caldera partida	Caldera comparar
Enero	77,75 %	96,98 %
Febrero	77,61 %	97,12 %
Marzo	77,40 %	97,40 %
Abril	76,88 %	97,71 %
Mayo	75,34 %	98,13 %
Junio	0,00 %	0,00 %
Julio	0,00 %	0,00 %
Agosto	0,00 %	0,00 %
Septiembre	62,25 %	94,39 %
Octubre	74,50 %	98,14 %
Noviembre	77,12 %	97,43 %
Diciembre	77,68 %	97,02 %

4.6. Expected results

Energy results

Once the existing boiler is replaced by a new high-efficiency biomass boiler and the other technical requirements of the system performance have already been solved, the current Stationary In-Service performance of the system is calculated as 75,17% and the expected new one would be of 97,15%.

The energy consumption comparison between the current and the expected should be as follows:

	Current Heating demand (kWh)	Optimized Heating demand (kWh)
January	19.960,00	14.910,63
February	9.980,00	7.455,32
March	4.990,00	3.727,66
April	4.990,00	3.727,66
May	4.990,00	3.727,66
June	0,00	0,00
July	0,00	0,00
August	0,00	0,00
September	4.990,00	3.727,66
October	49.900,00	37.276,58
November	49.900,00	37.276,58
December	49.900,00	37.276,58
	199.600,00	**149.106,34**

The expected energy savings would be of 50.494 kWh/year.

Carbon dioxide reduction results

The current dioxide carbon emissions are 62.076 kg CO_2/year (considering 0,311 kg CO_2/kWh for diesel according to IDAE) and the new scenario would be of 2.684 kg CO_2/year (considering 0,018 kg CO_2/kWh for biomass according to IDAE). Then, the expected carbon emissions yearly savings would be of 59.392 kg CO_2.

The equivalence of 4.396,2 pine trees (*Pinus pinea*), according to the "Informe Cambio Climático y Planteamiento Territorial y Urbanístico en la CAPV".

This will also be accompanied by other savings in pollutants as SO_x, NO_x or CO.

Fuel storage needed

Knowing that the availability of fuel is constant in the Cooperativa building and that the transport equipment is existing, the minimum size of the olive pit storage must be able to cover the demand of fuel for a period of two weeks during the less favorable month (approximately 20.000 kWh), which is the minimum amount determined by the Spanish HVAC codes (Reglamento Instalaciones Térmicas en los Edificios).

This storage which would be a volume of 12 m^3 considering a silo efficiency of 50%, a density of olive pit 650 kg/m^3 and a calorific value of 5 kWh/kg and it can be used a textile silo, a containerized storage or other options, depending on the boiler supplier, but it will need to be located out of the building, attached to the boiler room.

5. SELECTION OF THE COGENERATOR

5.1. Introduction

Although generally, it is said that cogeneration is the combined production of heat and electricity, that is a simplification of what can really be considered. Cogeneration could be defined as the combined production of heat or useful cold with justifiable economic value, and electrical or mechanical energy.

It is called cogenerator to the person or company that generates thermal useful energy simultaneously to mechanical and/or electrical through cogeneration for direct use or for partial or total sale.

Useful thermal energy is understood as the one produced in a cogeneration process to satisfy, but not overcoming, an economically justifiable demand of heat and/or cooling and therefore would have to be satisfied, at market conditions, by other energy processes, not resorted to cogeneration. That is, that useful thermal energy is that which, if not produced by the cogenerator should be produced otherwise (consuming fuel as a consequence), to meet an existing demand of heat or cold, whether it is needed in an industrial process, or as HVAC demands in any type of building.

The performance of cogeneration installations is given by the formula: R = (E + V) / Q, where:

- Q = primary energy consumption, as measured by the lower heating value of the fuel used.
- V = useful heat or useful thermal energy defined in the previous section. In the event that the demand is cooling, the useful thermal energy would take the same value corresponding to the final cooling demand satisfied by cogeneration. It is considered a primary energy attributable to the production of useful heat (V) required by high efficiency boilers in commercial operation, and a performance is established for useful heat output equal to Ref H, which may be revised depending on the technological evolution of these processes.
- E = electric power generated measured in alternator terminals and expressed as thermal energy, with an equivalent of 1 kWh = 860 kcal. The equivalent electrical efficiency (EEE) of the system shall be determined by the formula:
  - REE = E / [Q- (V / Ref H)], where: Ref H: performance reference value for separate heat production in accordance with the provisions of Directive 2004/8/CE of the European Parliament and Council or regulation that transposes it. To determine the equivalent electrical performance at the time of extending the act of a plant commissioning, Q, V and E parameters are counted during an uninterrupted period of two hours of operation at rated load.

For the purposes of justifying compliance with the equivalent electrical performance in the annual declaration, the parameters Q, V and E accumulated during this period will be used.
The values of minimum equivalent electrical efficiency for biomass co-generation plants are:

- Biomass included in b.6 and b.8 types: 30%.
- Biomass included in the b.72 group: 50%
- For plants of less than 1 MW, the requirement is reduced by 10%, it means, 27% and 45% respectively.

This would be the case for the COOP2020 project.

5.2. Applications of co-generation

In general, any simultaneous consumer of thermal and electrical energy:

- Industrial sector.
- Agricultural and livestock industry (bio-gas from waste).
- Residential or tertiary sector (housing, hospitals, sport facilities, shopping centres, office buildings, etc.).

Heat utilization:

- Steam production.
- Direct use of gas (Dryers, ovens, purines, etc.).
- Hot water (heating + DHW).
- Cold production (thermally activated cooling cycles)

Prerequisites:

- Consumption of large quantities of heat.
- Reliable fuel supply.
- High utilization factor.

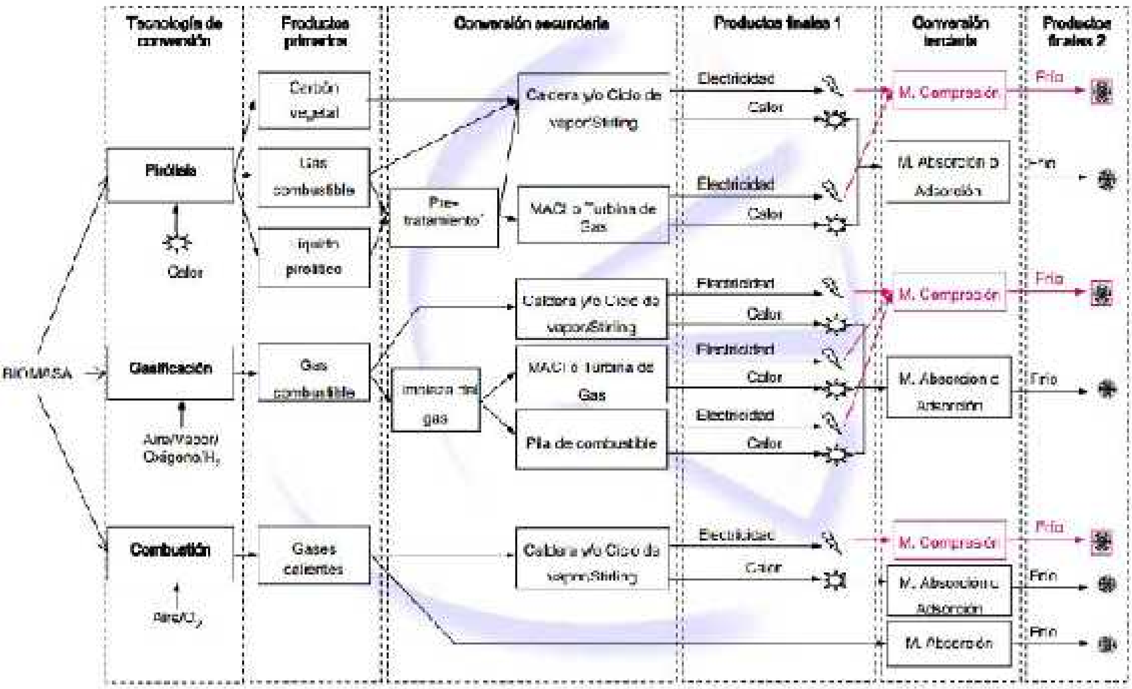
In the case of the Cooperative of Cambrils (COOP2020), the second and third conditions are met, but it will be difficult to meet the first of the essential requirements as previously discussed in a previous chapter.

5.3. Applicable technologies

According to the literature, the most suitable technologies for micro-cogeneration by using biomass as fuel are: (S. B., Ana):

- Alternative Internal Combustion Engine (AICE).
- Gas micro-turbine.
- Organic Rankine Cycle (ORC).
- Stirling engine.

- Fuel cell.



Below, there is a table featuring a comparison between the typical micro-cogeneration systems suitable for biomass, according to the literature:

	Efficiency	Application range	W/Q ratio	Cost €/kWh	Part load	Maintenance	Availability	Pros	Cons
AICE	25-45%	5kWe-15MWe	0,5-2,0	400-1.000	OK	High	High	Initial cost	Weight
Micro-turbine	15-30%	25kWe-250kWe	0,4-1,0	800-2.000	NO	Low	Medium	Weight	Efficiency
ORC	8-15%	3,5kWe-200kWe	0,1-0,4	2.000-5.000	OK	Low	Medium	Low Tª	Efficiency
Stirling	17-30%	3kWe-150kWe	0,2-0,6	3.500-5.600	OK	Medium	Low	Efficiency	High Tª
Fuel cell	30-55%	1kWe-10MWe	1,0-2,0	5.000-10.000	OK	Low	Low	Noise	Lifespan

After studying all the available options with these technologies, and the aspects described, in addition it was also considered the possibility of finding equipment and technical services within close distance and assessing the costs and difficulty of maintenance, initially, the co-generation system that could meet both the technical requirements of the project, and the Life Project planned budget for this item was found.

5.4. Definitive studied option

In a second course of study of technological options we discovered an alternative that was not present in the explanatory texts of COGEN Spain (Spanish Manufacturers of Cogeneration Association) and that technical and initial investment level could fit the criteria of heat demand of the Cooperative of Cambrils.

A Spanish manufacturer produces co-generation equipment based on heat recovery between a cold source and a hot through a cooling circuit. The HRU-25 model is a thermal machine capable of converting thermal waste energy, from 85 °C in electric power, with an output power up to 25 KWelec. The product has been tested under Aircraft Protocols, being subjected to extreme operating conditions and is currently industrialized. In the case of the Cooperative of Cambrils a prototype for a power output of 15 kWe would be developed.

In our case, the hot spot would be the new biomass boiler with conditions of thermal output of 150 kW with 85°C water and a cooling system of the condensation circuit through an evaporative condenser with air exchange should be installed.

The equipment could be installed within the same existing boiler room and the evaporator on the top mezzanine above it and connected to the front windows.

The technical characteristics of the equipment, according to the manufacturer studies are as follows:

Hot Water Inlet Temperature: 90ºC

Hot Water Outlet Temperature: 82ºC
Hot Water Flow: 16 m3/h
Thermal Power Recovered (Evaporator): 158 KWt
Cold Water Inlet Temperature: 16 ºC
Cold Water Outlet Temperature: 24,4 ºC
Cold Water Flow: 15 m3/h
Thermal Power Exchanged (Condenser): 146 KWt
Gross Electric Power: 11,3 KWe
Shelf-Power Consumption: 1,4 KWe
Net Electric Power: 9,9 KWe
Gross Efficiency: 7,1%
Final (Net) Efficiency: 6,3%

Compared to the systems described in the table in the previous chapter, we would obtain low yields compared to other systems, but instead both the initial cost and maintenance costs, the Heat Exchanger has the system best ratio of those studied.

Once found the best technology for the COOP2020 project, from these facts and features, a technical and economic study was conducted to assess the investment and anticipate their possible repayment and, therefore, if it could become an example that could be replicated in other similar projects.

6. TECHNO-ECONOMIC INVESTIGATION STUDY OF A BIOMASS BOILER AND CO-GENERATOR

6.1. Introduction

This aim of this study is to find the techno-economic feasibility of the biomass installation and the co-generator installation at the Coop Cambrils facilities.
Hence the scenarios of the installation of biomass and co-generator are compared with the current status, where diesel boiler are used for the heating demands of the Cambrils Cooperativa.

The following cases are investigated:

- The installation of the biomass boiler for the covering of the heating demands
- The additional installation of the co-generator for the covering of the electrical demands

Data from other activities are used in order to simulate the current case of the Cooperativa Cambrils. More specifically, linked to the action A3, the annual heating (kWh) and electrical demands (kWh) are equal to 149.106.34 and 840.192 respectively.

In what concerns the biomass type used in the boiler, the olive pits have been selected to be used. According to the physicochemical analysis conducted by CERTH during the activities in the A5 action, the Lower Heating Value of the olive pits found 19.5 MJ/kg approximately. The comparison was carried out with the use of the diesel fuel (current status in the Cooperativa Cambrils) with Lower Heating Value equal to 42.5 MJ/kg.

6.2. Technical issues

The capacity of the biomass boiler is 150 kW. The operating hours for the case of the biomass boiler is estimated at 6500h annually, since there are no heating demands on the summer months. Taking into consideration, the heating demands, as well the operating hours, the partial load for the boiler is estimated at 27 kW.

Regarding the case of the cogenerator, the boiler has the same properties as given in the previous case. The technical specifications are given in the Chapter 6.4. The operating hours are considered 4000h. This happens, because during the period from October to December the heating demand are too high, so it is more technical feasible to cover only the heating demands, in order to not put on danger the smooth operation of the olive mill. According to the technical specifications, the electrical output is estimated at 15 kW, while the net electrical output is at 13 kW

Investment cost

Regarding the case of the installation of the biomass boiler, the investment cost consists of the biomass boiler and the feeding system/silo and Regarding the case of the installation of the co-generator, the investment cost consists of the biomass boiler, the feeding system/silo and co-generator. The indicative costs are given in the following table:

Table 1: Investment cost of the cases

Cost investment (€)	Biomass boiler case	Biomass cogenerator case
Biomass boiler	40,000	40,000
Feeding system/silo	5,000	5,000
Biomass co-generator	-	65,000
Total	**45,000**	**110,000**

Operation costs and revenues

In what concerns the determination of the cash flows, the avoided costs and revenues in comparison with the current operation with the diesel boilers were taken into consideration. These correspond to the following categories:

- ***Avoided fuel cost***: This category corresponds to the replacement of the diesel fuel by biomass (olive pits). The diesel fuel has been received equal to 0.94 €/l. It is mentioned that the biomass is produced at the Cambrils Cooperative, so no cost is considered for its supply.
- ***Avoided cost of the electrical consumptions:*** This category corresponds to the avoidance of the payment for the electrical consumptions according to the electrical grid pricing, since the electricity production by the co-generator. The price ranges from 0.135 €/KWh to 0.15 €/kWh according to the Spanish legislative framework.
- ***Avoided biomass revenues:*** In contrast of the previous two categories, this category corresponds to the avoided revenues concerning the sale of the biomass (olive pits). In specific, the sale price of the olive pits is estimated at 150 €/t
- As it is obvious, the avoided cost categories correspond to revenues for the examined business plan, while the avoided biomass revenues corresponds to the cost expenditures.
- Moreover, in what concerns the OPEX cost, the indicative values per examined case are given in the following table. The OPEX cost corresponds mainly to the maintenance costs. The biomass boiler perform higher OPEX comparing to the diesel boiler.

Table 2: OPEX for the examined cases

	Diesel Boiler	Biomass Boiler	Co-generation system
Maintenance	2000	3000	4000

Additional	1000	1000	1000
Total	3000	4000	5000

6.3. Evaluation of the project's techno-economic feasibility

The results of the business plans for the two cases prove that the case of **the biomass boiler installation is a sustainable solution for the Cambrlis Cooperativa, while the co-generator system is not a viable solution**.

More specifically the IRR indicator (lifetime: 10 years) for the two cases is estimated:

- 21% for the case of the biomass boiler
- -18% for the case of the co-generator

See the next chapter to review all the figures.

6.4. Basic calculations

The following table contents all the information gathered in our cases:

	Current Case	Biomass Boiler	Cogenerator (electricity)	Cogenerator (heat)
Availability (hours)	6500.00	6500.00	4000.00	2190
Installed capacity of the boiler (kW)	150.00	150.00	158.00	
Partial load	26.99	26.99		60.07506849
Electrical output (kWe)	0.00	0.00	15.00	
Net Electrical output (kWe)	0.00	0.00	13.00	
Electricity price (€/kWh)	0.15	0.15	0.15	
Diesel price (€/l)	0.94	0.94	0.94	0.94
Olive pits sales (€/tn)		150.00	150.00	150.00
Produced El. Energy (kWhel)	0.00	0.00	52000.00	
Heating demands (kWh)	149106.34	149106.34	149106.34	111829.74
Electrical demands (kWh)	840192.00	840192.00	840192.00	
LHV diesel (MJ/kg)	42.50	42.50	42.50	42.50
LHV biomass (MJ/kg)	19.50	19.50	19.50	19.50
Diesel consumption (kg)	14859.04			877.0964706
Biomass consumption (kg)	0.00	32385.09	116676.92	5734.858462
Investment cost (incl. installation)	0.00	45000.00	110000.00	
Biomass boiler	0.00	40000.00	40000.00	
Feeding system/silo	0.00	5000.00	5000.00	
Biomass cogenerator	0.00	0.00	65000.00	
OPEX	3000.00	4000.00	5000.00	
Maintenance	2000.00	3000.00	4000.00	
Additional	1000.00	1000.00	1000.00	
Other cash flows (revenues, cost)				
Fuel cost (diesel)	16828.31	0.00	0.00	993.34
Energy consumptions cost (electricity)	126028.80	126028.80	118228.80	0
Avoided Biomass cost	0.00	4857.76	17501.54	860.23
Avoided fuel cost (diesel)		-16828.31	-15834.97	
Avoided energy consumptions		0.00	-7800.00	
Avoided biomass revenues		4857.76	18361.77	
Net cash flow		10970.55	3273.21	

7. COMPARISON OF INDUSTRIAL DRYING PROCESSES

7.1. Introduction

During the process of study of a biomass co-generation application we encountered the problem of how to use the exhaust heat of the thermal process and it was decided to study different technologies of industrial drying processes to see the feasibility of using them in the Cooperativa de Cambrils olive oil production process and that could improve the ratio of energy use of the co-generation.

The greatest problem found in the Cooperativa de Cambrils project was the quality (temperature) and flow of water at the disposal of the drying system. It has been proved to be a too low temperature and not enough flow to allow the drying system to be used in any of the processes of revaluing the organic wastes of the olive oil production process.

7.2. Drying process

There is a number of dryers' types globally, many of which are suitable for biomass drying. Selecting the appropriate dryer depends on many factors including the size and characteristics of the feedstock, capital cost, operation and maintenance requirements, electricity cost, environmental emissions, energy efficiency, available waste heat sources, available space and potential fire hazard.

If a sample of the material to be dried is exposed to the drying medium at controlled constant conditions, and the rate of moisture loss from the sample is plotted against time, the resultant curve takes the general form shown in **Figure** 1. There is an initial period A-B during which the material heats up and the drying rate increases. This is followed by a period of constant drying rate B-C, the constant rate period, during which movement of water through the solid is sufficiently rapid to maintain saturated conditions at the surface, and evaporation is equivalent to that from a body of water. Finally, internal movement of water can no longer maintain saturated conditions at the surface and a period of falling drying rate C-D is entered, the falling rate period. This period is often divided into two, a period where the material surface is partially wet and neither mechanism dominates fully, followed by a period where the material surface is completely dry and movement of water through the solid is fully rate limiting.

It is obvious that the requirement of the low moisture levels has as consequence longer drying time and therefore greater dryer capital cost.
In what concerns the determination of the drying rates, experimental methods are applied under certain conditions. The crucial requested moisture depends on several parameters, such as the material structure, material thickness and the initial moisture content.

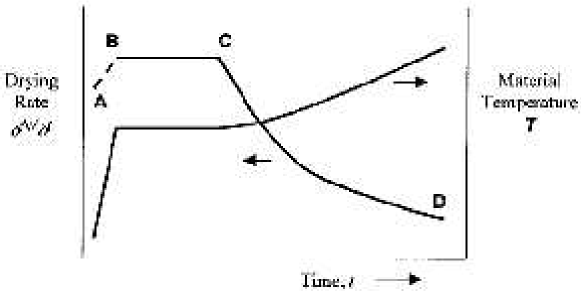


Figure 1: Drying periods

7.3. Dryer classification

Dryers can be classified into several categories according to different parameters. More specifically:

- Heat transfer mechanism: Direct or indirect fired
- Media required for drying: Flue gas, hot air or superheated steam
- Heat transfer media: Flue gas, hot air, steam or hot water
- Pressure: Atmospheric, vacuum or high pressure
- Heat source: Dryer burners, boiler (flue gas or steam), recovered waste heat from facility processes

Heat transfer mechanism (Direct-Indirect)

In terms of heat and mass transfer, the available dryers can be classified into: (a) direct drying systems; (b) indirect drying systems.

- Direct fired dryers are one type of drying equipment, in which heat is transferred to the material by direct contact with the heating medium. Usually, the heating medium, which is also the drying medium, is hot gas and the heat transfer mechanism is convection. It can be found in two different variants, with the material and the heating medium in parallel flow and in counter-current flow. (**Figure** 2)
- Indirect fired dryers are one type of drying equipment, in which heat is transferred primarily by conduction and radiation, and the heating medium is physically wall-separated from the drying material (**Figure** 3).
- Direct fired dryers are generally more efficient than indirect-fired dryers, which have the disadvantage of transferring heat from the steam tubes to the material. An indirect-fired dryer is also efficient, when no air is injected, and the moisture vented from the dryer as steam is recovered to serve process heating needs.

Figure 2: Direct fired dryers: a) Parallel flow, b) counter current flow

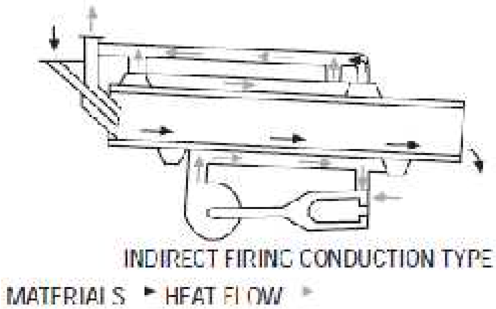


Figure 3: Indirect firing

There are also efficient combined systems, with characteristics and advantages from both direct and indirect drying methods (**Figure** 4), such as a fluidized bed dryer for drying of heat-sensitive polymer or resin pellets with immersed heating tubes or coils. This dryer can be only one third the size of a purely convective fluidized bed dryer for the same duty.

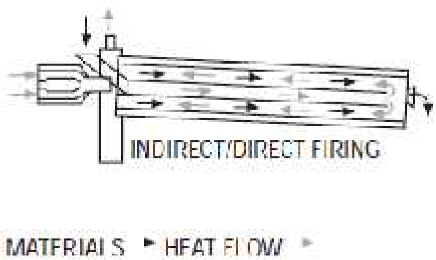


Figure 4: Indirect/direct firing

A comparison of the main characteristics between the two types of heat transfer mechanism is presented below.

Table 3: Characteristics of direct and indirect dryer

Dryer type	Capital & Operating Cost	O&M Requirements	Environmental Emissions	Energy Efficiency & Heat Recovery	Fire Hazard
Direct Dryer	Low	Low	Heating medium treatment required	High efficiency Less opportunity to recover waste heat.	High
Indirect tube Dryer	High	High	No flue gas emissions	Low efficiency in general Equally efficient with direct dryers when heat recovery option from steam is available	Less fire hazard – Absence of oxygen

Heating medium (air – flue gases – steam)

The heating medium which can be used in the dryers can vary according to the process demands and the available medium. The heating medium can be a) flue gas, b) air or c) steam. In direct drying systems, the heating medium is also the drying medium.

Flue gas dryer

A flue gas dryer has the advantage of using waste heat which improves the energy efficiency. However, a large flow of flue gas is required due to the low flue gas temperature. Hence, this impacts to a large scale biomass dryer with high electricity consumptions.

Air dryer

Recently, low temperature air dryers have received significant interest for biomass drying system because of low grade heat and low gas emissions. The heat demand for a low temperature air dryer is about 2700 KJ/Kg H_2O• .

Steam dryer

As steam dryers have the potential to recover a large amount of input heat through moisture condensation, considerable attention has been shown for heat integration. Due to energy recovery, the net heat demand for a steam dryer is about 600 KJ/kg H_2O.

Dryer types

The main types of the dryers are the following: belt conveyor, rotary/drum, cascade/fluidized bed, Pneumatic/Flash, Superheated steam, Bed/Grate, Open air drying, Perforated floor bin, Electromagnetic radiation (microwave), Disk (Porcupine), Screw Heat Exchanger, Tray, Spray, Hot Air-Stenter, Contact Drying-Steam Cylinders/Cans, Infra-red drying, Radio frequency drying
In the following paragraphs some additional data for the main dryer types are given.

Belt dryer

Belt dryer is a continuous through-circulation dryer type suitable for biomass feedstock. The operating principle is based on blowing the drying medium upward or downward through a thin static layer of material on a horizontal permeable conveyor belt. Two main classifications are distinguished according to the stages and pass design. Multi-stage dryers use more than one stages of drying, horizontally laid out, following one another. (**Figure** 5)

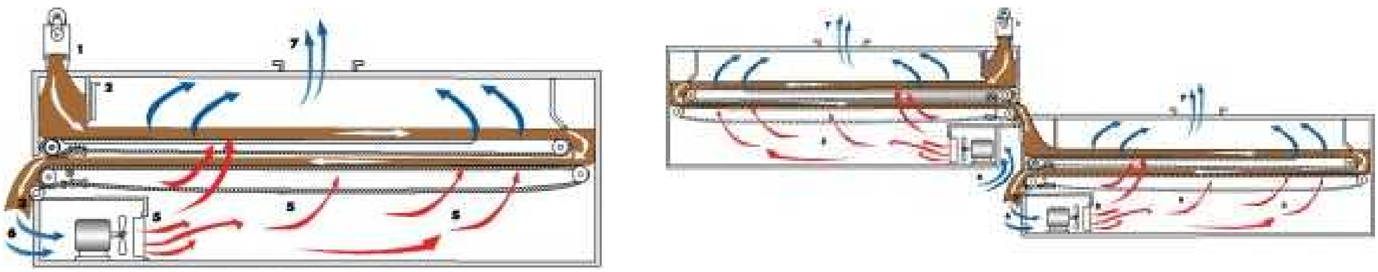


Figure 5**: A)Single-stage multi-pass design dryer** **B) Multi-stage multi-pass design dryer**

The drying medium is usually either flue gas from combustion or hot air. The air provided by fans through the dryer is heated by means of hot water or low pressure steam with heat exchangers. During the process, the moisture content, the residence time and the maximum temperature are the main monitoring parameters. In general belt dryers occupy a large space and area and present large footprint.

Rotary dryer

The rotary dryer is the most common existing dryer type. The rotary dryers can be found in both direct and indirect type. The biomass is passed through a large, inclined, slowly rotating cylindrical shell (drum). The biomass enters the drum from above, passes through where it is heated and dried and exits from below, at the other side of the drum. Affixed to the interior and along the rotary drum, there are flights which lift the material and cascade it through the drying medium stream as the drum rotates. This cascade creates a uniform curtain of material spanning the width of the rotary dryer, maximizing the efficiency of heat transfer

Direct-Fired Rotary Dryers

Continuous-feed, direct-fired rotary dryers (**Figure** 6) are the most common type of dryer for hog fuel, sawdust and bark, and many other materials. In general, the highest possible temperature without scorching the fuel results in greater dryer efficiency.

Compared to rotary steam-tube indirect-fired dryers, direct-fired dryers have lower operation and maintenance costs. Their availability is higher. The direct-fired rotary dryers produce higher VOCs emissions and particulates, perform lower waste heat recovery options, and increased fire hazard especially during shutdown process and located after the dryer. A gas cleaning systems is required consist of cyclone, baghouse filter, scrubber or electrostatic filter in order to remove the PMs

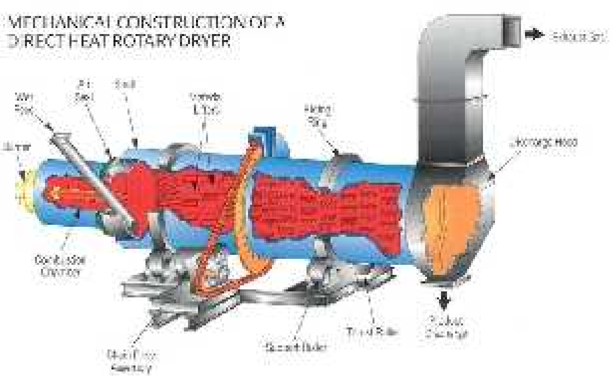


Figure 6**: Direct-fired rotary dryer**

Indirect-Fired Rotary Dryers (Steam-tube dryers)

The indirect fired rotary dryers perform a number of characteristics, which make them more preferable than the direct rotary dryers. More specifically, the drying material cannot be exposed to combustion products, the direct heating will lead to excessive entrainment and carry over of fines or dust, as well as the low cost of the low or medium pressure stream.

There are three main reasons for applying indirect (conductive) rather than direct (convective) heating in a rotary dryer:

- the drying material cannot be exposed to combustion products;
- direct heating will lead to excessive entrainment and carry-over of fines or dust;
- low or medium pressure steam is available at low cost.

A number of designs exist for bringing the heating medium into indirect contact with the material. Single-pass concentric outer shells or double-pass arrangements with an outer shell and an inner tube are used for this purpose.

The most usual type of the rotary indirect type is known as a steam-tube rotary dryer. Its structure is shown in the **Figure** 7. Steam-tube dryers may use steam from an existing power

boiler to dry the fuel, passing the steam through tubes or other heat exchanger type located inside the drum. This operation corresponds to energy costs, since the steam can be used for electricity generation.
In general, as it is obvious the indirect dryer are considered less efficient compared to the direct fired dryers.

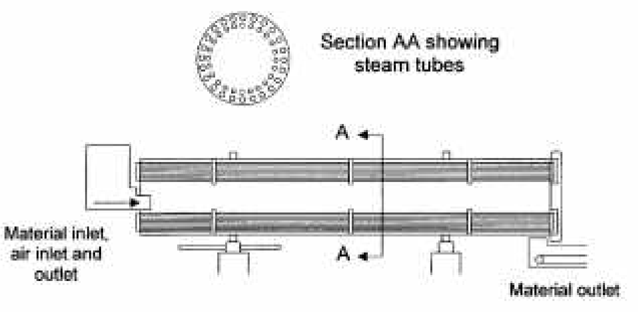


Figure 7: Indirect-Fired Rotary Dryer

Fluidised bed Dryers
Conventional fluid bed dryers using hot air or exhaust gases could be suitable for biomass feedstock. The speed of such processes is high, while they are characterized high efficient.The size of the dryer is quite smaller comparing to the other drying methods. More specifically this drying method combines the advantages of steam drying and the excellent heat and mass transfer characteristics of a fluidised bed. In what concerns the operation of the fluidized bed, the recycled moisture evaporated evaporated from the feed can be used as a drying and fluidizing medium. The continuously discharged flow of excess evaporated steam may be used as process steam elsewhere, resulting in reduced heat loss and higher energy efficiency.

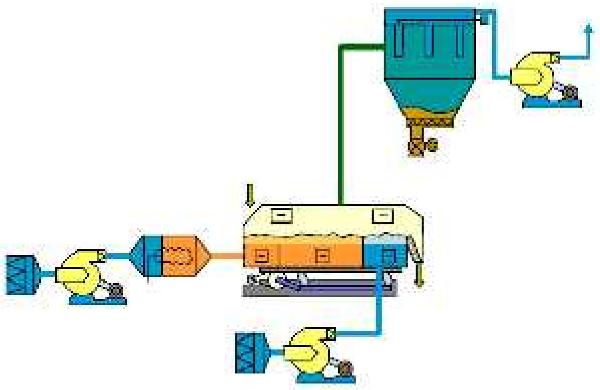


Figure 8: Flow scheme of a sub-fluidized bed dryer with cooling

Cascade (spouted bed) dryers
The cascade dryers are considered fluidized bed dryers.The material is introduced into a flowing stream of hot air in an enclosed chamber. It is carried upward by the air and then cascades back to the bottom to be lifted again. Material is drawn out through openings in the side of the chamber (**Figure 9**). The operation temperature ranges between 160-280 °C.

Although they have a smaller footprint than rotary and conveyor dryers, they are more easily affective by corrosion and erosion phenomenon. Hence the maintenance costs are too high.

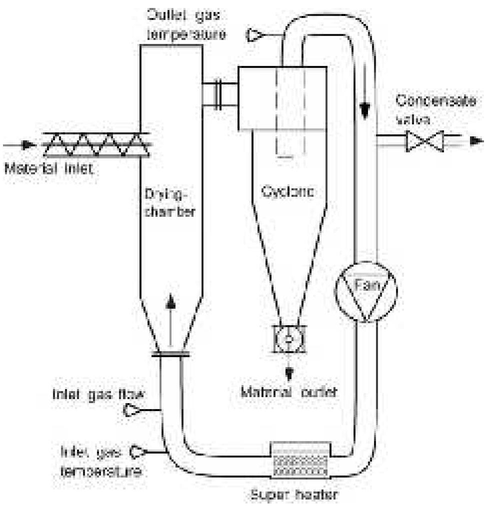


Figure 9a: Cascade dryer

Flash dryer

The pneumatic or 'flash' dryer dries biomass rapidly, as free moisture is easily removed or where any required diffusion to the surface occurs readily; short time (few seconds) is required for the drying procedure to be accomplished. Wet material is mixed with a stream of heated air (or other gas), which conveys it through a drying duct where high heat and mass transfer rates rapidly dry the product. Flash or pneumatic dryers are followed by a cyclone. The gas passes through a scrubber to remove entrained particulate material. A simplified process of a flash dryer is shown in **Figure** 10. Their size is quite small, while their operation temperature is lower than rotary dryers (150-280^{o}C). Heat recovery is difficult due to the fact that the air is mixed with the water steam. Flash dryers have a lower risk than rotary dryers due to shorter retention time and lower operating temperature.

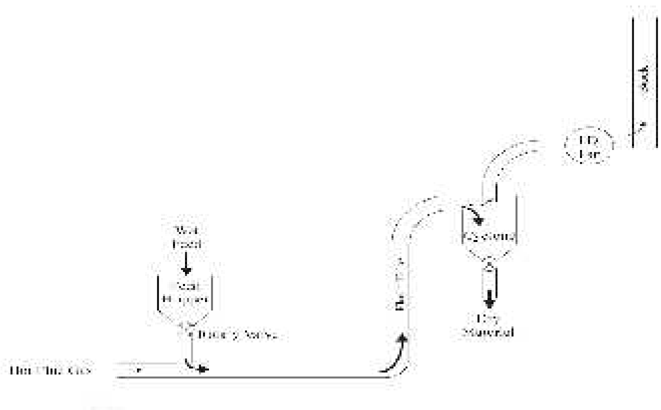


Figure 10**: Typical Flash Dryer configuration**

Microwave drying

Unlike the conventional dryers, where heat is applied externally to the surface of the material, microwave simultaneously heats the bulk of the material. When properly designed, microwave drying systems have several advantages over conventional methods including a reduction in the drying time, high energy efficiency, improvements in product quality for various industrial applications, a reduction in fire hazards and lower air emission. Microwave drying of wood products, however, has not been used to a larger extent in wood industries mainly due to the insufficient knowledge of the complex interaction between wood and process parameters during drying as well as the higher investment expenses.

Infrared Drying

One of the increasingly popular, but not yet common, methods of supplying heat to the product for drying is infrared (IR) radiation. The IR dryer are batch or continuous type. The continuous dryers are the most often met dryers of such a type of dryers. It is mentioned that the air flow is required in IR ovens, because of the air movement to cool and to protect oven walls and terminals, as well as the oven exhaust to remove smoke, moisture, solvents, hazardous vapours etc.

7.4. References

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