Politecnico di Torino

CLIK CONNECTION LAB AND INNOVATION KITCHEN

FINAL REPORT

Challenge@PoliTo_by Firms – Wastescapes_By Azzurra S.r.l.

Team LEOS

1. SECTION: PERSONAL DATA

1.1. TEAM NAME: LEOS

1.2. PERSONAL TEAM DATA

Name	Surname	Matricola	Mail *(PoliTo and Private)*
Eugenia	Bertolino	320318	S320318@studenti.polito.it
Davide	Forte	319380	S319380@studenti.polito.it
Negar	Nazari	290060	S290060@studenti.polito.it
Alessandro	Vilardi	334423	S334423@studenti.polito.it
Atakan	Yilmazer	318681	S318681@studenti.polito.it

2. SECTION: DESCRIPTION OF THE PROBLEM

2.1. THE PROBLEM THAT YOUR SOLUTION WANTS TO SOLVE

The problem that our solution aims to solve is the complex and multifaceted challenge of expanding an existing industrial waste treatment plant (in particular, the solid waste and the sludge treatment lines) in a way that harmonizes with environmental, spatial, and socio-economic contexts. Specifically, our solution addresses issues such as: environmental impact, spatial integration (to seamlessly integrate the new process with the existing landscape and infrastructural network), community relations, and safe waste management.
By doing so, we aim to set a new standard for how industrial waste treatment plants can operate harmoniously within their local contexts and contribute to a sustainable future.

2.2. HOW THE PROBLEM PROPOSED IS RESOLVED CURRENTLY

SOLID WASTE LINE:
Regarding solid waste management, Azzurra receives a diverse array of waste materials, including organic waste, paper and cardboard, textiles and textile bags, plastic bins and cans (both full and empty), rubber, glass, metals and metal cans

(both full and empty), inert materials, rubber gloves, batteries, wood, electronic waste (RAEE), filters, sandpaper, and others. Given the heterogeneous nature of these inputs, designing an effective treatment line is complex.
Some of the solid wastes undergo a shredding process within a counter-rotating roller shredder.
This shredder operates at a limited rotation speed to prevent significant heating of the moving parts. It is equipped with thermal cameras to monitor the temperature of the material being processed, water spray nozzles on the loading hopper to manage dust and heat, and a fire extinguishing system to ensure safety during operation.
Waste with high odor impact, a flash point below 35°C, a pH lower than 2, or that is dusty, oxidizing, or reducing cannot undergo volume reduction.
Some of the solid wastes undergo chemical and physical operations, for instance inertization.
The inertization treatment is allowed for waste with a predominantly inorganic matrix, except for those with a flash point below 55°C, a molybdenum concentration exceeding the acceptance limits of the specific facility intended for the treated waste, or a maximum organic content, expressed as Total Organic Carbon (TOC), equal to or greater than 6% by weight. The treatment takes place in a depressurized environment, and the effectiveness of the treatment must be verified through analytical tests.

SLUDGE LINE:
Azzurra treats both internally produced sludges and those received from external sources. According to the AIA documentation, the treatment process for pumpable sludges involves the following steps:

1. Acceptance and Storage: Sludges are accepted, sampled, and stored in tanks.
2. Treatment Operations:

- Conditioning, Coagulation, and Chemical Flocculation: Enhancing sludge properties for further processing.
- Stabilization: Reducing the putrescibility of the sludge.
- Dehydration: Using filter presses to remove water from the sludge.

The outputs are:

- Solid Material: Stored in containers and sent to external facilities for disposal or recovery.
- Liquid Residue: Directed to the water treatment line via an equalization tank.

Shovelable sludges, on the other hand, already have a water content between 20% and 70%, and they undergo various operations based on their specific characteristics:

- Mixing with Additives and Reagents: Enhancing properties for processing.
- Iron Removal.
- Mixing and Crushing: Using a rotary drum.

Additionally, there is a plant for emptying drums and big bags, which allows for mixing shovelable sludges with ashes and powders.

3. Section: Solution proposed by the team

3.1. Short description of the solution

We plan to receive incoming solid waste in a pit and process it through several stages.
Initially, we'll employ an eddy-current separator to extract metals, followed by an air separator to remove heavier fractions like glass. Shredding will then take place, strategically positioned after the initial separators to avoid unnecessary remixing of distinct objects such as metal cans.
A dryer will then reduce the humidity content to levels suitable for gasification.
The obtained syngas is purified to be sent to an ICE unit for electricity and heat production to be used in the plant and ashes are sent to a geopolymers production unit.
As for sludge treatment, we'll continue to utilize the existing filter press for sludges with a solid residue content below 20%. Subsequently, we'll mix civil and industrial sludges and dry them until they reach a solid residue content of 90%. This operation will be powered by heat generated from other units within the plant.

The architectural proposal for the waste management plant extension incorporates sustainable solutions such as, bamboo cladding, solar panels, glass facades for natural light, and dedicates 36,000 square meters to tree planting, showcasing a commitment to eco-friendly and efficient practices.

3.2. TYPE OF SOLUTION

A product/device ☐ A system ☐ A processing method ☐

An algorithm ☐ Other ☐ (explain)

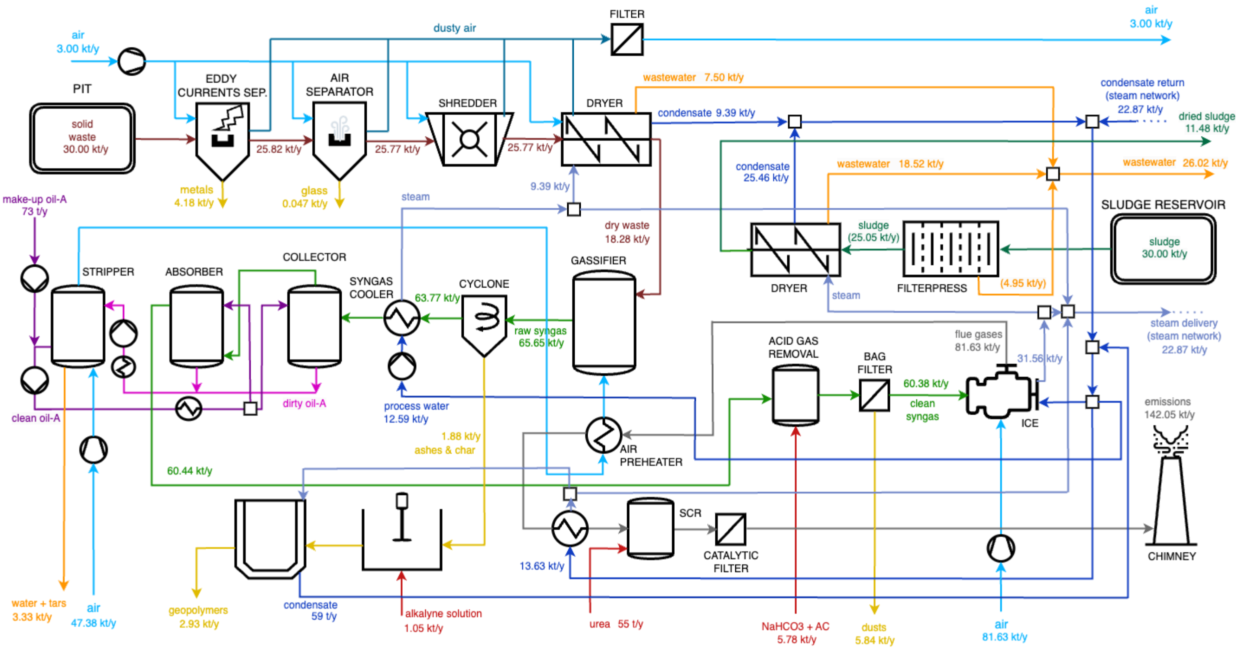
Comment and short motivation:

Our solution is not just a processing method, but a comprehensive approach aimed at achieving process goals, specifically the treatment of solid waste and sludge, while also addressing a wide range of other critical aspects.
We maintain a broad vision by incorporating an integrated strategy that includes thermal integration, energy self-sufficiency, and the production of secondary products, such as geopolymers. This ensures not only environmental sustainability but also economic viability for the enterprise.
Additionally, we have considered architectural redesign to enhance the plant's logistics while respecting local communities. The plant is meticulously designed with environmental impact considerations, such as advanced syngas and air treatment systems, to minimize negative effects.

3.3. APPLICATION AREAS OF THE SOLUTION

The solution presented in this work can be applied in companies that treats solid waste and industrial sludge to decrease their hazardousness and obtain valuable product like power, steam and geopolymers. This solution embraces the modern philosophy of waste to energy and waste to chemicals in the optic of the development of society based on circular economy.

3.4. ACCURATE DESCRIPTION OF THE SOLUTION

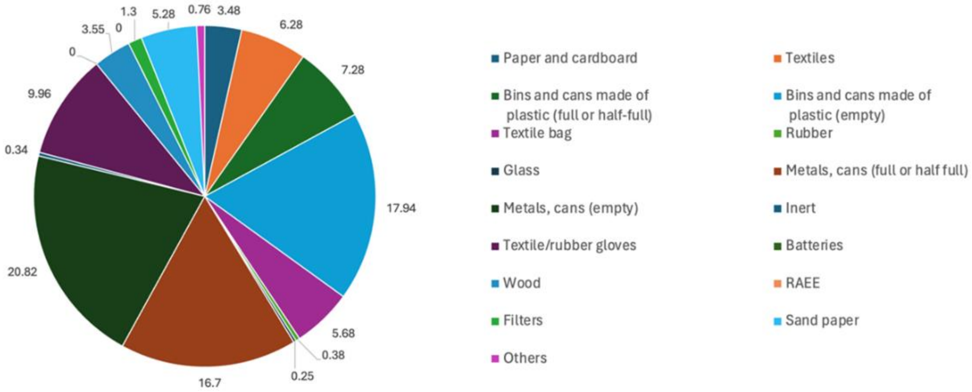


Full process schematic

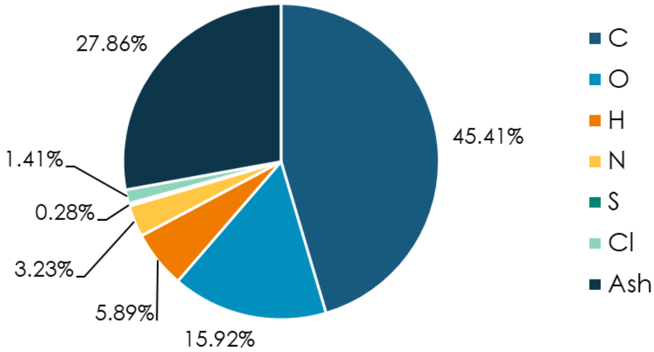
Above is shown our plant scheme proposal. We will now go into more detail about how we plan to implement our solution, including numerical data and architectural considerations.
For a better clarity, the various plant section will be analysed separately.

SOLID WASTE LINE:

The plant receives 30000 t/y of solid waste of heterogeneous and variable composition. The average solid residue of such waste is approximately 63%, indicating that the water content of the solid waste is about 11150 t/y.
By combining the data provided by Azzurra with our literature analysis, it was possible to estimate the characterization of the waste. This includes not only the type of objects constituting the waste but also its elemental composition.
Below is reported the result of such analysis, which was commented in much detail in the previous reports and presentations.



Solid waste composition obtained from product analysis



Solid waste elemental composition

This detailed composition study was crucial in determining both the selection and sequence of equipment for the plant.

Eddy-current separator:
As previously mentioned, the first piece of equipment is an eddy-current separator, which isolates all metallic objects from the rest of the waste. Given that the solid waste contains distinct metallic items like cans, it is more efficient to separate them before any shredding operation.
The working principle of this equipment is the following: the separator works by using a rotating magnetic field to induce electric currents (eddy currents) in conductive materials. These eddy currents create their own magnetic fields that oppose the original magnetic field, causing the conductive materials to be repelled and separated from non-conductive materials.
From the mass balances, it was possible to estimate that the separated metals flow rate is around 4181 t/y, while the rest of solid waste is 25819 t/y with a solid residue of 56.82%.

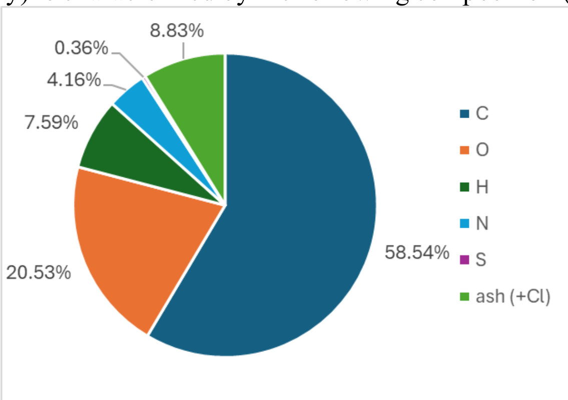
Wind separator:
The second equipment is a wind separator, which works by using a stream of air to separate materials based on their density and aerodynamic properties. Heavy fractions like glass are not carried by the air stream and fall out of the waste stream, while lighter materials are carried away and separated.
As for the eddy-current separator, this equipment was put before the shredding operation to easily remove objects such as bottles.
This equipment separates around 47 t/y of glass, while the remaining 25772 t/y of solid waste (with solid residue 56.74%) continue through the process.

Shredding:

The next step is a shredding operation, whose usage is very common in the context of solid waste treatment. It works by using rotating blades to cut and break down the waste into smaller, more manageable pieces. It is normally used to reduce the size of waste materials, making them easier to handle, transport, and process. Shredding is useful because it increases the surface area of the waste, improving the efficiency of subsequent sorting, recycling, or disposal processes. The outlet flow rate is the same as the inlet one, 25772 t/y, and so it the solid residue, as this equipment only reduces the size of the waste without performing any separation.

Drying:
It is necessary to have a drier to reduce the water content of the solid waste to a suitable level for gasification. The feed of such equipment is 25772 t/y of solid waste with a solid residue of 56.74%, namely a humidity content of around 43.26%. The target is to reach a solid residue of 80%, as the water content for gasification should not be greater than 20%. Around 7494 t/y of water is removed, and the final output to send to the gasification unit is 18278 t/y of solid waste with a solid residue of 80%.

Gasifier:
The reactor chosen for the gasification is a rotary kiln gasifier. After the previous mentioned pre-treatments, the fed of the rotary kiln gasifier (18278 t/y) is characterized by the following composition (on mass basis):

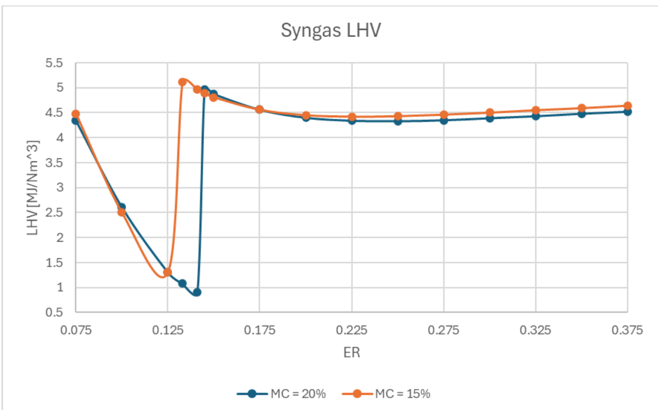


Composition of the feed to rotary-kiln gasifier

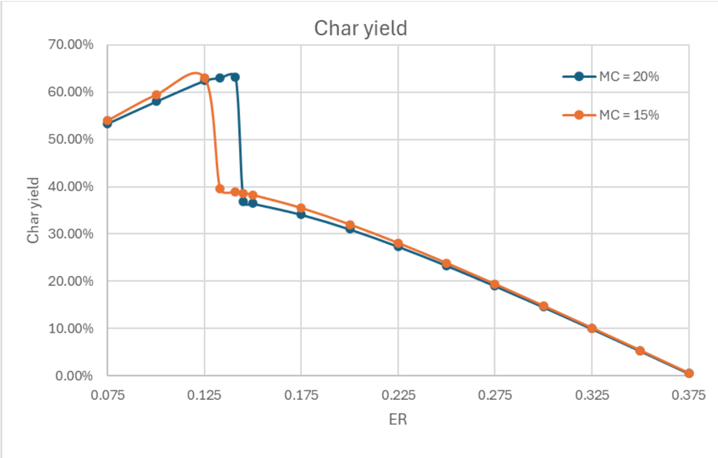
The composition of the syngas exiting the gasifier has been estimated using a Matlab script from literature, presented and well validated by *Ibrahim et al*. The inputs needed are the elemental analysis of the feed, the equivalence ratio (ER) of air (that fixes the flowrate of air fed to the reactor) and the moisture content of the waste. The software considers a gasification pseudo-reaction (see the reference for more detail) and solves a system of equations composed of:

- Mass balance of elements C, H, O, N, S;
- Equilibrium reactions of methanation, water gas shift, Boudouard reaction and ammonia synthesis.

Thanks to this set of equations the script is able to evaluate the syngas composition and its LHV, the char yield and the adiabatic temperature of the gasifier. The value of the ER has been evaluated through a sensitivity analysis whose objective was the minimization of the char yield. This analysis led to the following plot:



Syngas LHV vs. Equivalence ratio



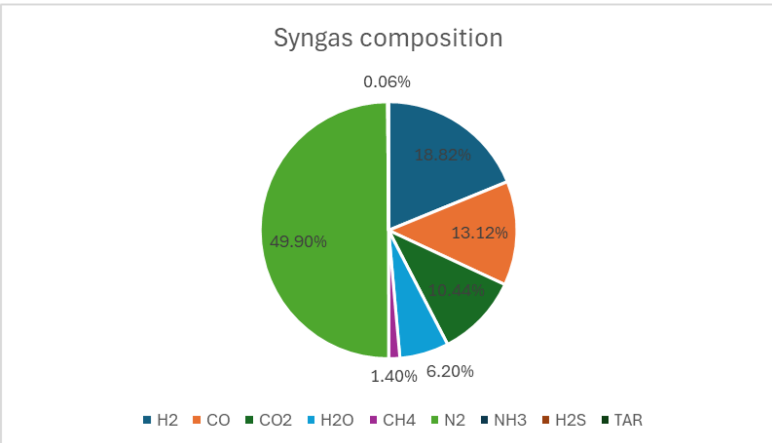
Char yield vs. Equivalence ratio

To minimize the char yield (expressed as the ratio between the moles of char produced, modelled as graphite, and the moles of the entering carbon C) we imposed an ER of 0.375, close to the results found on literature, which result in an air flow rate of 47.38 kt/y. Other results and operating parameters were reported in the following table:

Parameter	Value
ER	0.375
LHV of the syngas [MJ/Nm^3]	4.19
Amount of syngas produced [t/y]	65653
Char yield [wt%]	0.118
Adiabatic temperature of the reactor [°C]	808
Ash produced [t/y]	1290

Gasifier operating parameters

The syngas composition, on molar basis, is reported in the following pie chart:



Raw syngas output composition

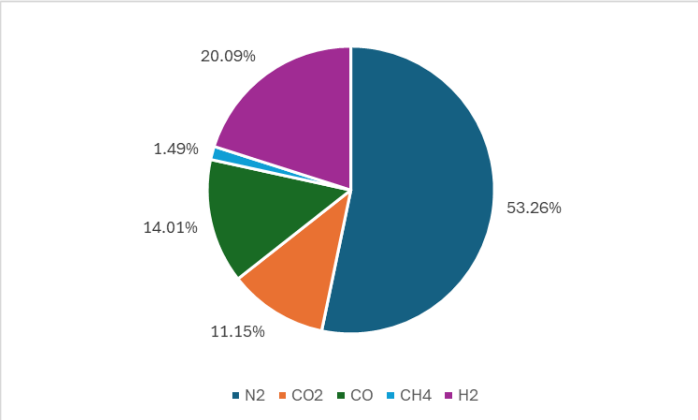
Syngas purification section:

After the gasification step, the syngas, before entering the ICE for the power production, must be cleaned. To clean the syngas the following equipment are used:

- Cyclone: used to remove char and ashes entrained in the outlet syngas (1.88 kt/y). The removed part is sent to the geopolymer synthesis department.
- Syngas cooler: the syngas is cooled from the gasifier outlet temperature (800°C) down to around 350°C, in the working range for tar and acid gas removal, producing superheated steam (12.6 kt/y) at 120°C and 2 bar.

- OLGA unit: it is composed by a collector, an absorber and a stripper. The OLGA unit is used for TAR removal. It is performed via scrubbing with mineral oil**;** tars are removed in a collector while lighter tars in an absorber, using methyl-oleate as solvent. The "dirty" solvent is then regenerated in a stripper; the stripping medium is the air needed by the gasifier (this allows a full recirculation of tars and a more efficient abatement). Considering a unitary efficiency for OLGA scrubber, the wastewater exiting the stripper, composed of the tars generated and the condensed water is 3.325 kt/y.
- Acid gas removal unit: is performed using a mixture of sodium bicarbonate and activated carbon. Sodium bicarbonate (166 t/y) is over-stoichiometric (1.2) with respect to the H_2S while for the activated carbon (5.61 kt/y) a ratio of 20 kg H_2S/m^3 of carbon, drawn from literature, was used.
- Bag filter: traps the remaining PM and the dusts generated during the acid gas removal (5.75 kt/y).

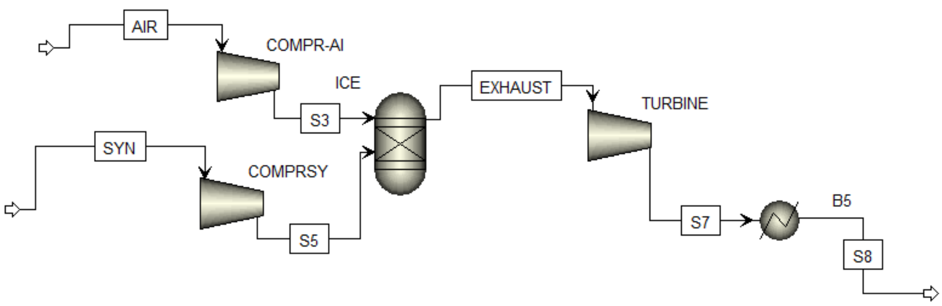
At the end the final composition of the cleaned syngas that will be sent to the ICE can be represented in the following pie chart:



Clean syngas composition

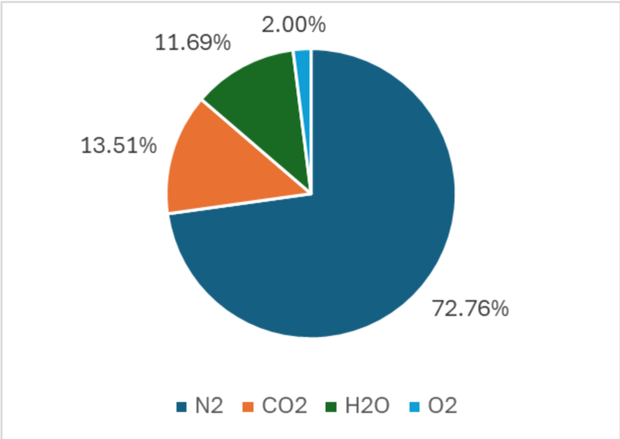
Internal combustion engine

The clean syngas (60.38 kt/y) before entering in the ICE is preheated using the hot flue gasses exiting the ICE itself. The flue gases are also used to preheat the air entering the ICE (81.63 kt/y) and the rotary-kiln gasifier (47.38 kt/y). The combustion reaction has been modelled using Aspen Plus software as showed in the following scheme:



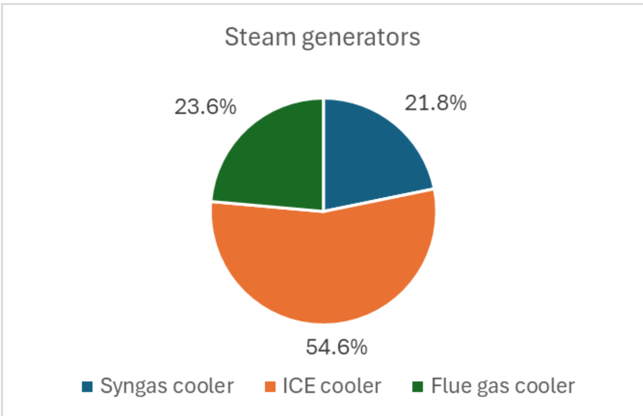
Aspen model of the ICE

The compression and the expansion of the syngas in the combustion chambers is simulated with two compressors (one for air one for the syngas) and a turbine; the combustion is simulated through an equilibrium reactor. Compressors and turbines have been considered to have an isentropic efficiency of 90%. The air fed allows to have a 2% of O_2 (molar basis) in the exhausts. This led to an air excess of 20%. The overall performance of the ICE can be evaluated by calculating its mechanical efficiency as the ratio between the net mechanical work obtained divided by the chemical energy of the reactants. This results in a 13.83% of net efficiency with a useful work of 1.10 MW. The efficiency value found for this scenario is low compared to typical value of mechanical efficiency of an ICE found in literature that are around 30-40%. This big difference depends mainly on the low quality of the compressed syngas. In fact, more than 50% of the clean syngas (in molar basis) is N_2. This percentage further increases to 70% after the addition of air for combustion. This means that a big part of the mechanical work produced by the engine is exploited to compress an inert gas like nitrogen. The composition of the exhausts (142 kt/y) at the exit of the ICE (on molar basis) is reported in the following pie chart:

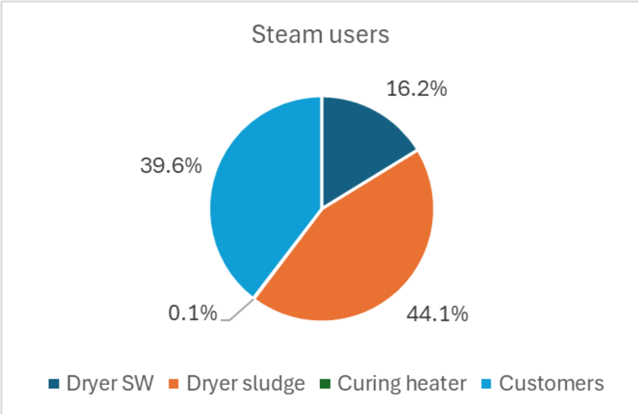


ICE flue gases composition

Despite the low mechanical efficiency of the engines, their high thermal efficiency (41.60%) indicates that a significant portion of the combustion enthalpy is being converted into heat. This heat is then recovered by the engine cooling systems to produce steam. The steam produced by the ICE cooling system, the syngas cooler and the flue gases cooler (a total of 57.78 kt/y) exceeds the steam consumed by the solid waste and sludge driers and the geopolymers curing unit (which will be described later) by 22.87 kt/y. The surplus steam is sold to the nearby industries at a convenient price and delivered through an industrial steam network. The steam is sent at a temperature of 120°C and pressure of 1.2 bar, and it is collected back as liquid water at a temperature of 60°C. The following pie charts show the steam distribution in the plant among generators and consumers:



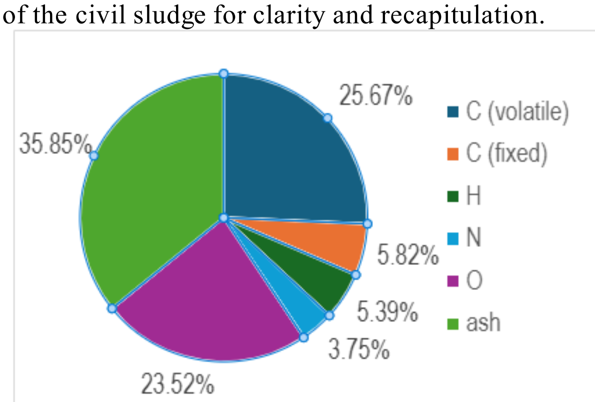
Steam distribution among steam generators



Steam distribution among steam consumers

Exhausts treatment and emission:
After the thermal integration, the cooled exhausts are sent to a SCR (selective catalytic reduction) unit. In this unit we fed 55 t/y of urea to remove the NO_x formed during the syngas combustion process (46 t/y). Once removed, the NOx the exhausts are sent to a chimney and released to the atmosphere (142 t/y).

SLUDGE LINE:
The plant receives a total of 30000 tons of sludge per year, comprising 15000 tons of civil sludge and 15000 tons of industrial sludge with variable CER codes.
For solid waste, we conducted a composition analysis of the sludge by integrating data provided by Azzurra with findings from literature research to make informed assumptions when data was missing.
While the detailed analysis methodology has been extensively covered in previous reports, we now present a pie chart summarizing the composition of the civil sludge for clarity and recapitulation.



Civil sludges input composition

For the industrial sludge, on the other hand, a statistical characterization was determined:

Equivalent sludge (t/y)	Lower calorific value (kJ/kg)	Total solid residue (105°C)	Fixed residue (600°C)
15000	2000	38.9%	23.7%

Industrial sludges composition

After discussing many alternatives with our mentors, we decided to mix the civil and industrial sludge to perform the same treatment, so the final assumed ultimate composition of the mixture is:

Element/Fraction	% db.
C	25.37%
H	4.38%
N	3.06%

O	19.14%
Ash	48.05%

Mixed sludges composition

As evident from the characterization, the sludge contains a substantial amount of ash, rendering it unsuitable for gasification, which was our initial concept.
We decided to keep the filterpress already present in the plant to dewater the sludge, and then analysed three possible scenarios for the subsequent operations.
The scenarios, already detailed in the previous reports, are here summarized:

1st SCENARIO: SLUDGE THERMAL DRYING TO 80% + GASIFICATION

The initial approach involved a thermal dryer to reduce sludge water content to 80% solid residue, followed by gasification.
However, analysis using methods applied to solid waste showed the sludge's unsuitability for gasification due to its high ash content of approximately 48% on a dry basis. This high ash content makes sustaining autothermal gasification impractical. The estimated thermal power required for gasification at 800°C is approximately 622 kWth, but only 360 kWth can be recovered from gas outlet temperatures of 500°C.
Therefore, additional electricity from the grid would be necessary, requiring a methane flow rate of 240546 Nm3/year if produced by burning methane, which is economically disadvantageous given the low-quality nature of the sludge.

2nd SCENARIO: SLUDGE THERMAL DRYING TO 75% + PLASMA GASIFICATION

Another possible scenario considered was plasma gasification instead of an ordinary one.
With an analogue approach as used for the 1st scenario, it was verified that also this option is not feasible because the additional syngas obtained through plasma gasification process does not energetically repays the electricity needed to sustain the plasma torch.

3rd SCENARIO: SLUDGE THERMAL DRYING TO 90%

As an alternative, thermal drying to achieve 90% solid residue was explored. This approach utilizes residual heat from the cooling water of the syngas production unit, avoiding the need for additional heat generation, in a sustainable and integrated view.
To size the thermal drier, we estimated the thermal energy demand starting from data such as water and sludge specific heat, supposing a temperature variation and thus calculating both sensible and latent heat required to evaporate and remove water from the sludge.
The supposed temperature variation intervals are the following:

- Water: inlet 120 °C - outlet 65 °C
- Sludge: inlet 20 °C - outlet 60 °C

Other relevant quantities are:

- Drier efficiency: 75% (supposed)
- Outlet solid residue percentage: 90%
- Drier energy demand: 1487 kW. This value was compared to the energy demand of other real similar applications, such as the drier of the Castiglione Torinese plant, and it was found that they were coherent.

Finally, we also estimated the required flow rate of water (steam) coming from the ICE to perform the drying, which is equal to 25814 tons/year. This value was obtained by considering the equipment efficiency and the enthalpy of the streams.
The values are summarized in the following table:

Parameter	Value
Water ΔT [°C]	120 – 65
Sludge ΔT [°C]	20 - 60
Solid residue in the outlet sludge [%]	90
Drier efficiency [%]	75
Thermal energy demand [kW]	1487

Inlet sludge [t/y]	30000
Outlet dried sludge [t/y]	11476
Inlet water (present in the sludge) [t/y]	19671
Removed water [t/y]	18524
Inlet steam (from the ICE) [t/y]	25814

Sludge drier operating conditions

This was the chosen scenario.

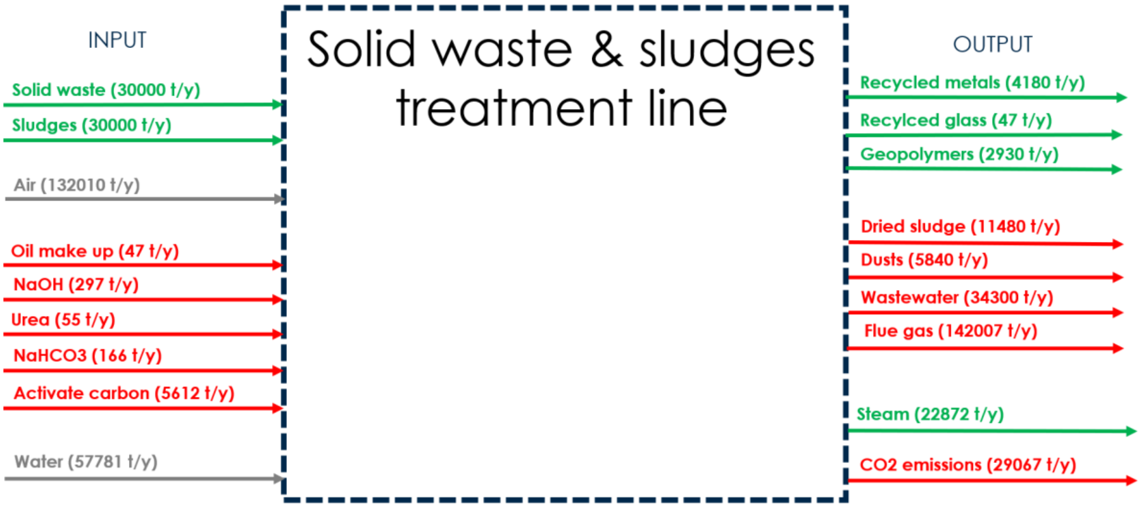
DETAILED EQUIPMENT SIZING AND CONSUMPTION:
All equipment previously mentioned has been sized, and their consumption (electric or thermal) has been evaluated. The results are reported in the following table:

	Type	Electricity cons. (kW)	Thermal cons. (kW)	Volume (mm x mm x mm)	Fixed cost (k€)
Crane		7	-	/	104.8
Eddy curr. separator	Double drum	6	-	4000x1800x1400	52.4
Wind separator		6	-	8000x2500x4000	18.6
Shredder	Drum, double, atmospheric	81	-	5870x2450x3890	139.7
Dryer (sw)	Drum dryer, double, atmospheric	5	(steam)	1070(D)x10800(L)	1707.2
Pollutant blower	Centrifugal, 1psi	37	-	2450x1640x1900	17.4
Pollutant filter	Leaf filter	-	-	520x520x520	85.0
Gasifier	Rotary kiln, hazardous material	9	(waste)	1150(D)x20500(L)	19437.9
Gasifier compressor	Centrifugal, air, 125psi	167	-	4100x1950x2000	608.8
Cyclone	Cyclone, large	-	-	1600(D)x7000(L)	44.2
Syngas cooler	Shell and tube, in Hastelloy	-	(steam)	2000x2000x5000	24.8
Syngas cool. pump	Horizontal, ANSI, 1stage	0	-	/	30.0
Collector	Vertical vessel	-	-	1250(D)x13500(H)	8803.9
Absorber	Vertical vessel	-	-	1250(D)x13500(H)	
Stripper	Vertical vessel	-	-	595(D)x3400(H)	
Oil-A pump	Gear, chemical injection	0	-	/	10.9
Acid gas removal	Column, no internals	-	-	1120(D)x2400(L)	71.8
Bag filter	Baghouse, large	-	-	1050x1050x1050	387.2
ICE	Syngas ICE, 12 cylinders	-	(syngas)	5750×2650×2500	1550.1
ICE compressor	Air, centrifugal, 125psi	288	-	5200x2300x2800	825.7
Air preheater	Shell and tube hx., U type, fixed head, SS304 inside - CS outside	-	(flue gases)	2500x2500x6000	16.1
Recuperator	Shell and tube hx., U type, fixed head, SS304 inside - CS outside	-	(flue gases)	2000x2000x5000	29.8

SCR	Column, no internals	-	-	3400x10200	329.1
Catalytic filter	Baghouse, large	-	-	1350x1350x1350	562.3
Conveyor belts	Belt, closed, w/ walkway	2	-	1500(W)x12000(L)	211.2
ICE pump	Horizontal, ANSI, 1stage	0	-	/	39.3
Filterpress	Plate sludge press	62	-	(already existing)	(already existing)
Dryer (sludge)	Drum dryer, double, atmospheric	8	(steam)	1350(D)x13400(L)	3136.1
Conveyor belts	Belt, open	2	-	1500(W)x10000(L)	118.3
Pump filterpress	Horizontal, ANSI, 1stage	0	-	/	16.2
Pump dryer	Horizontal, ANSI, 1stage	0	-	/	18.0
Geopolymer reactor	Mixed vessel	2	-	1300(D)x2600(L)	425.3
Curing furnace	Hot air curing tunnel	-	(steam)	650(D)x1300(L)	63.9
PV modules	Monocrystalline silicon	680	0	/	230.1

Equipment level design results

OVERALL MASS BALANCE:
Looking at our process as a black box we can distinguish the following inputs/outputs:



Plant black box model

The inputs are:

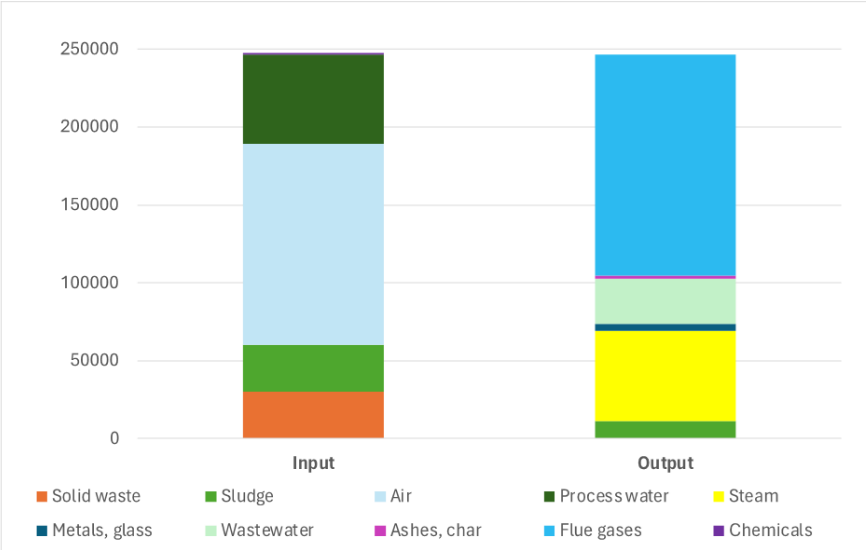
- Solid waste and sludges: input streams of the process to be treated.
- Air: used in the gasification of the solid waste and for syngas combustion in the ICE (internal combustion engine).
- Oil make-up: used in the OLGA unit for TAR's removal.
- Sodium hydroxide: used for geopolymer synthesis.
- Urea: used for NO_x abatement in the SCR unit.
- Sodium bicarbonate and activate carbon: used for acid gas removal.
- Water: used in a closed loop, exploited for thermal integration in various part of the pant. Demi water streams are used to cool down the syngas at the outlet of the gasifier and the ICE's exhaust. Thanks to that heat removal we can produce overheated steam at 130°C and 1.2 bar. This steam can be used partially in our plant for different purposes (dryer, curing heater) and partially can be sold to nearby industrial facilities.

The outputs are:

- Recycled metals and glass: obtained from the pre-treatment of the solid waste. In particular, metals are obtained from the eddy current separator, while glass from air separator.

- Geopolymers: obtained from the geopolimerization reactor and the curing heater that exploit the ashes and chars produced in the gasification unit and separated from the syngas at the outlet of the reactor thanks to a cyclone.
- Dried sludge: obtained from the dewatering of the input sludge through mechanical (filter press) and thermal (dryer) treatments.
- Dusts: coming from air filters.
- Wastewaters: coming from solid waste and sludges drying unit. This additional amount of wastewater will be treated in the existing liquid department of Azzurra.
- Flue gas: coming from the exhausts of the ICE. Exhausts contain 29067 t/y of carbon dioxide.
- Steam surplus: portion of steam produced not used in the plant that can be sold.

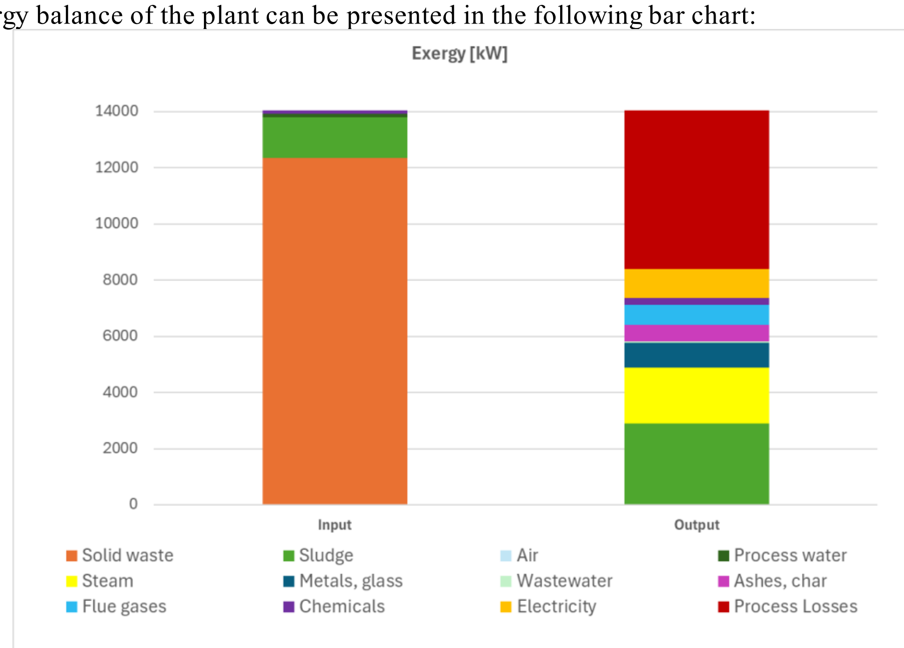
All the input and output mass flow of the plant can be reported in a summarized way in the following bar chart:



Mass balances results

OVERALL ENERGY BALANCE:

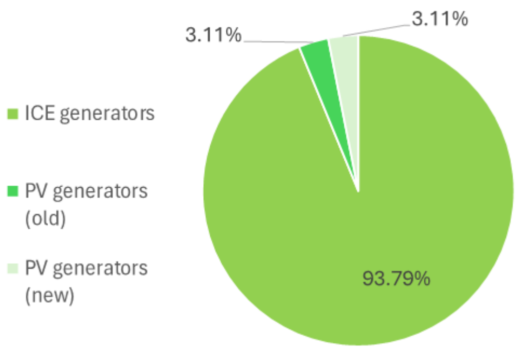
The overall exergy balance of the plant can be presented in the following bar chart:



Exergy balance results

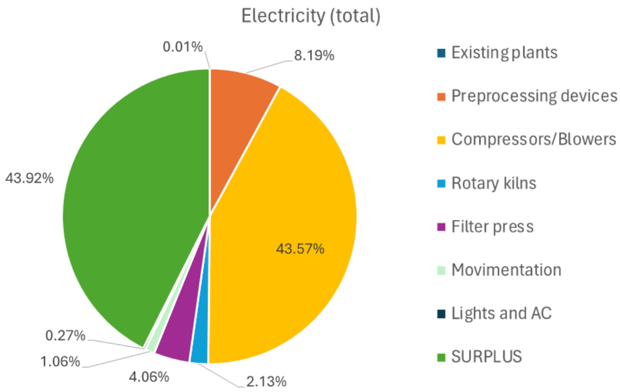
Exergy is the fraction of total energy that can be converted into useful mechanical work. One thing that can be observed is that in the input the biggest part of exergy is contained by solid waste. This happens because of their high calorific value. At the output of the process, we can notice that 40% of input exergy is destroyed. Another interesting thing we can notice is that the exergy content of the sludge increases. This can be explained considering that, thanks to the drying of the sludge, their calorific value increases and, consequently, also their exergetic content.

Coming to electricity production, the following pie chart clarifies how the power is produced in our plant:



Electricity generators power distribution

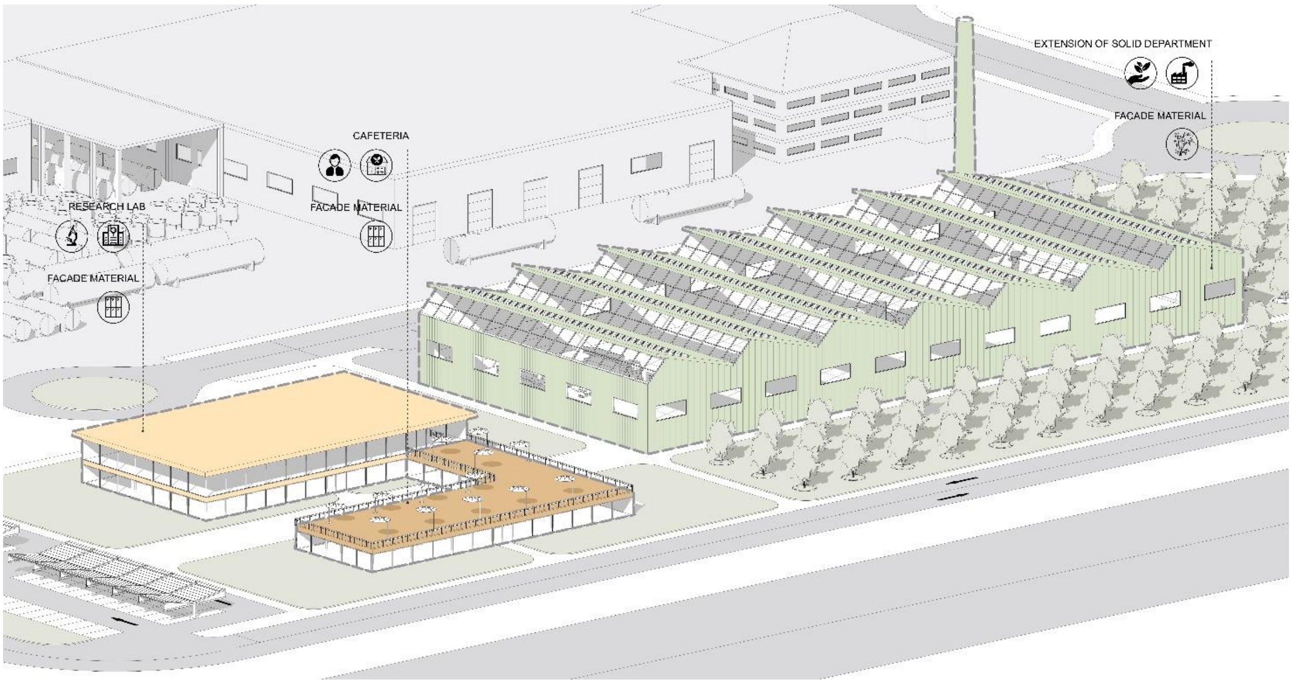
The total power production is 9.2 GWh/year. It can be noticed that most of the power production comes from the ICE, while a lower amount from the renewables (PV generators placed on the roof of the plant). The power produced is partially used in our plant to drive different equipment and partly (surplus) can be injected into the grid. The following pie chart, instead, clarifies the power utilization in our plant:



Electricity plant balance

The power surplus is 44% of total power production. The biggest amount of power is consumed by compressors and blowers.

ARCHITECTURAL PROPOSAL:

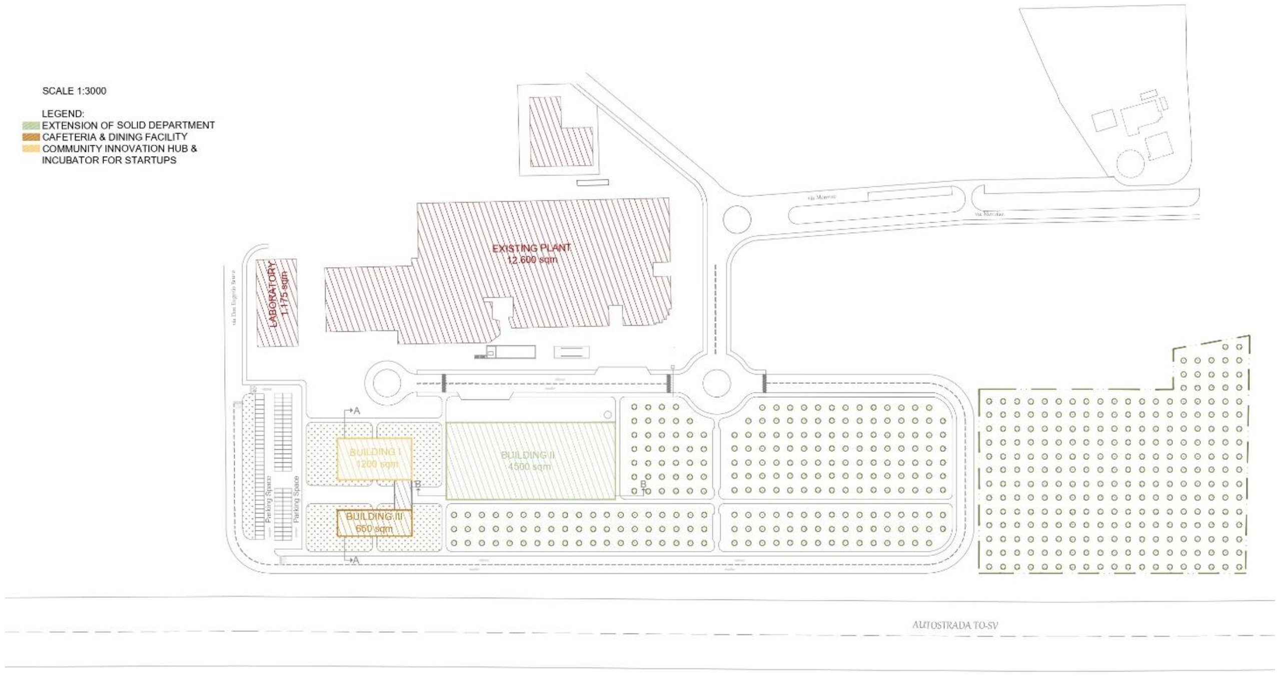


Plant expansion 3D representation

The newly constructed waste management plant, designed as an extension to the existing facility, incorporates several sustainable solutions and modern architectural elements. This extension features bamboo cladding, which not only provides an aesthetically pleasing and natural look but also contributes to the building's sustainability through its renewable nature. Photovoltaic panels are strategically installed on the roof to harness sunlight, generating electricity to power the facility and reduce its carbon footprint.

The extension includes two distinct new constructions: a research lab and a cafeteria. Both buildings are designed with a focus on transparency, utilizing extensive glass facades to allow natural sunlight to flood the interiors. This design choice not only creates a bright and inviting atmosphere but also reduces the need for artificial lighting, thereby conserving energy.

In addition to these sustainable architectural features, a significant portion of the surrounding area, totalling 36,000 square meters, is dedicated to planting trees. This green initiative enhances the mitigates impact of the industrial zone, promoting biodiversity and contributing to the overall sustainability of the area. The integration of these elements showcases a commitment to creating an eco-friendly and efficient waste management facility that aligns with modern sustainable practices.



Masterplan proposal

The proposed master plan for the expansion of the waste management plant is thoughtfully designed to enhance functionality and sustainability while integrating seamlessly with the existing infrastructure. The plan is morphologically divided into three key parts:

1. Extension of the Solid Waste Department:
   This segment includes the construction of a 4,500 sqm extension dedicated to the solid waste department. The new extension is designed to operate as a cohesive unit with the existing plant, ensuring streamlined processes and efficient land use. The existing road network will be preserved and repurposed for internal circulation, facilitating truck traffic and maintaining operational efficiency.

2. Research Lab:
   A new two-storey research lab will be constructed, occupying a built-up space of 1,200 sqm. This facility is intended to support innovative waste management solutions and environmental research, enhancing the plant's capacity for technological advancement and sustainability.

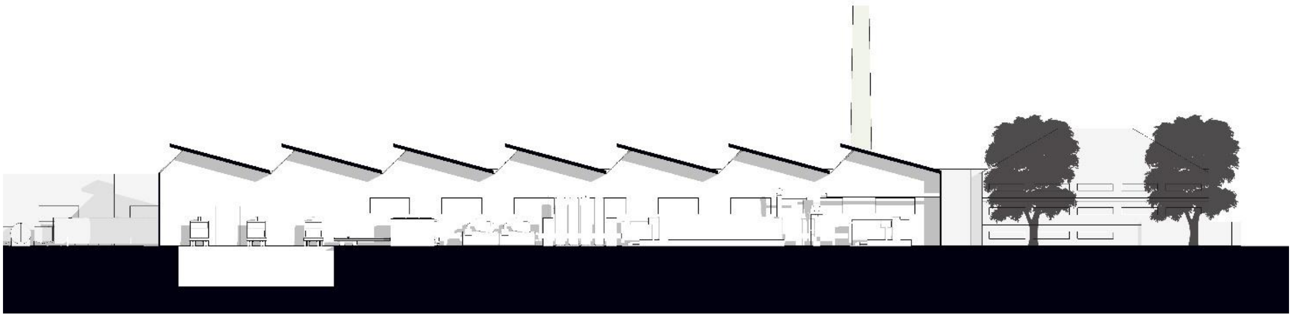
   Cafeteria:
   Adjacent to the research lab, a cafeteria covering 650 sqm will be constructed. The cafeteria includes a rooftop area designed as a relaxing space for users, promoting well-being and offering a comfortable environment for employees and visitors. The research lab and cafeteria are interconnected internally, facilitating smooth service operations and enhancing the user experience.

3. Parking Spaces:
   A new parking area comprising 96 spaces will be developed to accommodate both employees and visitors. This parking zone is strategically located to ensure easy access from the research lab and cafeteria, improving convenience and functionality. The design of the parking spaces ensures they are easily accessible from all new constructions and the existing plant, promoting seamless integration and efficient use of space.

All new constructions are designed with accessibility in mind, ensuring that they are easily reachable from the existing plant. The master plan emphasizes maintaining a cohesive and efficient circulation system, utilizing the existing infrastructure while introducing new elements to support the expansion.

This master plan not only increases the operational capacity of the waste management plant but also integrates sustainable practices and modern architectural elements to create a functional, efficient, and environmentally conscious facility.

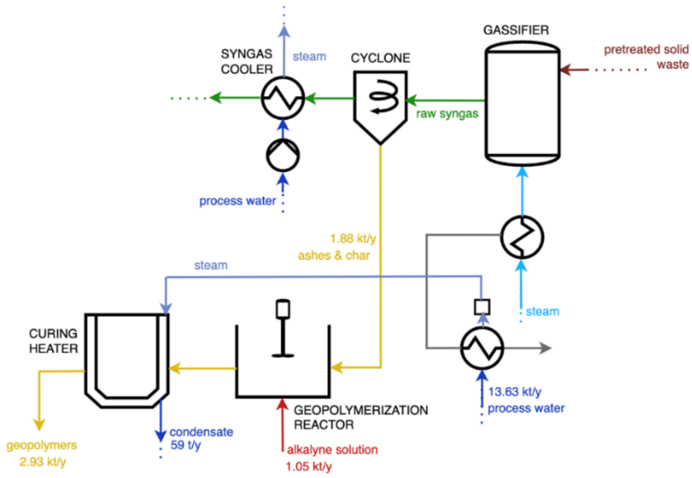
Cafeteria and Research Lab, Section A-A, Scale:1:500



Extension of the Solid Department, Section B-B, Scale:1:500

3.5. ADDITIONAL DESCRIPTION OF POSSIBLE PARTICULARLY INNOVATIVE ASPECTS OF THE SOLUTION

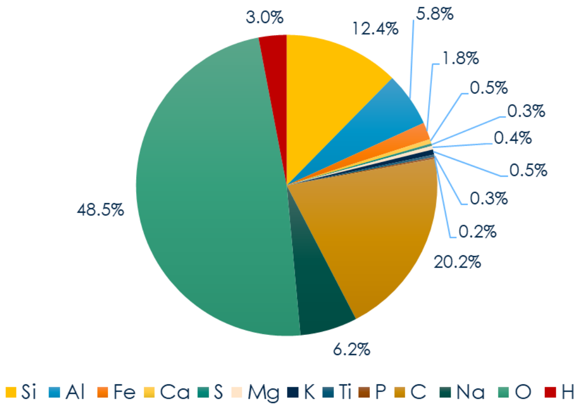
One of the most innovative aspects of our solution regards the geopolymer production section (showed in the figure below) that exploits the ashes coming from the solid waste gasification to produce geopolymers.



Geopolymer department schematic

The geopolymer production section is composed mainly of two devices:

- The <u>geopolymer reactor</u>: it is a rotary kiln working at ambient temperature in which the gasification ashes, that have pozzolanic properties, react with an alkaline solution of water and caustic soda to induce geopolymerization reactions. The ashes have been characterized using an ultimate analysis taken from literature, typical of gasification ashes:



Ashes ultimate analysis

Then, the added water and NaOH have been dosed according to the following optimal ratios (derived from literature): Na/Al ratio of 1 and water to solid ratio of 0.4. The process lasts around 30 hours.

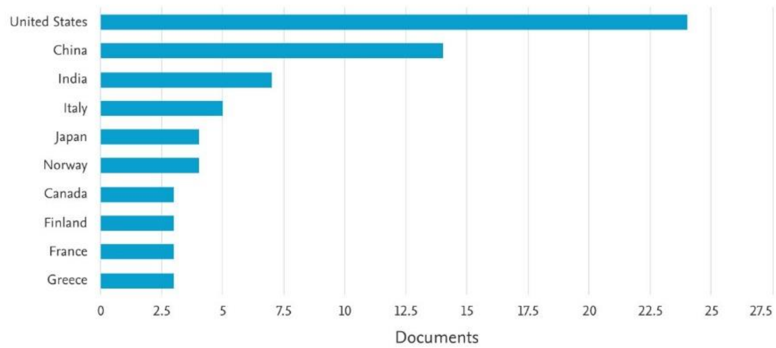
- The curing heater: it heats the slurry up to 80°C inducing its solidification in the final product. The heat needed is provided by the process steam with indirect heat transfer. The process lasts around 3.5 hours.

As final remarks, even if curing processes above 60°C are known to induce good tensile strength, the geopolymers produced will not be characterized by exceptionally good properties because of two reasons. The former is that there is a significative fraction of char between the ashes that is known to reduce the mechanical properties (at least for concrete); the latter is that gasification ashes have a Si/Al ratio > 2, while the best mechanical properties are obtained for Si/Al < 1.7.

3.6. Development status of the Solution

The solution proposed exploits almost exclusively well-affirmed technologies adopted at industrial full scale since many years. The exceptions are the rotary kiln gasifier for hazardous waste gasification and the OLGA tar removal for syngas purification. Therefore, the Technology Readiness Level (TRL) of the proposed solution entirely depends on them.

Rotary kiln gasification, the technology has already reached a TRL of 9 for the process of coal gassification and hazardous solid waste incineration. For what concern waste gassification, the interest in the scientific literature has steadily increased in the last years, as demonstrated by the following literature analysis, conducted using *Scopus*, that shows as Italy is the 4th nation for number of publications on rotary kiln gasifier after US, China and India:



Number of publications on rotary kiln gasification, *Scopus* database

Furthermore, as it will be show in section 4, there are already companies that are commercialising the technology at full scale, a commercial 1.1MWe setup in Moissannes (France) for processing wood and wine residues and a significant number of patents (often integrating rotary kilns with plasma torches).

OLGA tar scrubbing is a well-known technology since the first years of the 2000s. Nowadays, there are two plants employing this technology in Europe: MILENA gasifier (Netherlands) since 2005, with a TRL of 5, and CoBiGas (Sweden) with a TRL of 8, and some patents on oil scrubbers for gassification.

For what concerns geopolymers, several companies as already commercialising geopolymer concrete (Wagners, Zeobond, Ecocem, Geopolymer Solutions LLC, PyroGenesis Canada Inc, Solidia Technologies, ...) and have developed full scale plants to produce them. The limiting factor, however, is related to the penetration in the market as a concrete competitor.

4. Section: State of the Art

This section is devoted to the description of the state of art of the technologies deployed in the plant that have a TRL lower than 9 (full scale, commercial) and that may be problematic for the entire process development. These technologies are the rotary kiln gasifier, the geopolymer synthesis line and the OLGA tar removal.

4.1. Description of the known solutions present in Literature/ Papers

Paper Title	Authors	Brief description of the Paper	Differences with the Proposed Solution
Rotary Kiln Gasification of Solid Waste for Base Camps.	Cosper, S. D.	Design and construction of a WtE system based on rotary kiln gasification. The system is capable of processing 1 to 3 tons per day of mixed municipal waste, converting it into energy with minimal pre-processing	The scale of the gasifier is smaller compared to our plant, but still relevant. The tar removal is based on water quench.
Cleaning of producer gas from hazelnut shells gasification in a bench-scale rotary kiln gasifier by a thermal cleaning unit.	Tarquini, C., Gallucci, F., Kersten, S.R.A., & De Jong, W.	Gasification of hazelnut shells in a bench-scale rotary kiln using air at 800°C, integrated with a thermal cleaning unit operating at 800-1100°C. The gas cleaning unit significantly reduces benzene.	The feed is a biomass and not a solid waste. The cleaning process is a hot process (while OLGA is performed at moderate temperatures); however, it could be used as a tar pre-treating step.
The potential of sewage sludge gasification: A bench-scale investigation of experimental parameters.	Vercruysse, K., Dewil, R., Smets, K., & Appels, L.	Energetic recovery potential of sewage sludge gasification using a bench-scale rotary kiln. Experimental tests were conducted at temperatures between 750°C and 850°C, with an equivalence ratio up to 0.24, producing a gas yield of about 1 Nm^3/kg of dry sewage sludge and achieving a maximum cold gas efficiency of 67%.	The feed is sewage sludge and not solid waste. Lab-scale setup.
"OLGA" TAR REMOVAL TECHNOLOGY Proof-of-Concept (PoC) for application in integrated biomass gasification combined heat and power (CHP) systems.	Boerrigter, H., van Paasen, S. V. B., Bergman, P. C. A., Könemann, J. W., Emmen, R., Wijnands, A., Veringa, H. J., & Biomass, E.	Lab-scale experiments demonstrated OLGA's capability to remove tars to very low levels, with tar dewpoints below -15°C. This makes the product gas suitable for high-demand applications such as gas engines and synthetic natural gas synthesis. The technology is scalable and suitable for pressurized operations.	

Oil-based gas washing - flexible tar removal for high-efficient production of clean heat and power as well as sustainable fuels and chemicals.	Zwart, R.W.R., van der Drift, A., Bos, A., Visser, H.J.M., Cieplik, M.K., & Könemann, H.W.J.	The OLGA system was demonstrated through a 675-hour duration test with a 500 kWth circulating fluidized bed gasifier using crushed wood pellets. Commercial Project in Moissannes France for processing wood and wine distillery residue, resulting in 1.1 MWe.	Different feed (biomass), different scale (but still commercial).

4.2. Prior Art - Existing Patents

Patent Number	Brief Patent description	Differences with the Proposed Solution
CN104976622B	Waste classification gasification system using a rotary kiln and plasma melting, which includes devices for garbage feeding, pyrolytic gasification, metal sorting, crushing, and a plasma melting stove. This system effectively combines low-temperature rotary kiln gasification with high-temperature plasma melting; the ashes are vitrified. Secondary pollution from dioxins and heavy metals.	No integration with plasma torches.
CN106642159A	Hazardous waste treatment system combining a rotary kiln and plasma gasification. The system sorts hazardous wastes, feeding easily handled wastes into a rotary kiln incinerator and difficult wastes into a plasma gasification furnace, utilizing the advantages of both technologies to safely treat hazardous waste, prevent dioxin and heavy metal pollution.	No integration with plasma. The kiln performs incineration.
CN110255996B	Fly ash geopolymer concrete made from fly ash, metakaolin, and an alkali activator, along with modified ceramic microspheres, polymer fibers, coarse and fine aggregates, and water. This concrete exhibits excellent mechanical properties, durability, and corrosion resistance.	No ceramic microspheres and polymer fibers
ES2895661T3	Process for producing a geopolymer: mixing aluminate and silicate precursors in an alkaline solution to form a sol-gel, optionally adding additives, and diluting the sol-gel with water. The mixture is then processed to form a geopolymer, with steps to reduce alkali metal cation content and achieve a sodium content of less than 200 ppm, including techniques such as high shear mixing, ultrasound-induced cavitation, acid addition, decanting, membrane filtering, or emulsifying with an organic phase and steam stripping.	No ultrasound-induced cavitation or acid addition.
CN110759655A	Easy-to-prepare geopolymer made from industrial waste, consisting of 35-45% aluminum ash, 10-15% blast furnace slag, 35-40% steel slag, and 8-15% metakaolin, with an alkaline activator added. This geopolymer, formed by grinding, mixing, molding, and curing at room temperature, utilizes abundant industrial byproducts, promoting resource conservation and environmental protection.	Even if similar, the feed is not the same of our process (gasification fly ashes)
CA2774700C	Treatment of tar-loaded gas with two fluids: aromatic hydrocarbons and linear hydrocarbons. The tars absorbed by the aromatic fluid are separated based on evaporation temperature, with the lighter fraction returned to the process and the heavier fractions either discharged or recycled back to the biomass reactor.	The two scrubbers use different fluids.

4.3. Known Product

Product Name	Manufacturing Company	Brief description and features of the Product	Differences with the Proposed Solution
Kiln gasification system	Tsukishima Kankyo Engineering Ltd	Rotary kiln gasification system including a stoker for complete combustion of solids, and a secondary combustion chamber for gas combustion. Its key features include a specialized sealing configuration to minimize air leakage and a prong for improved waste material agitation in the kiln, and a nozzle for waste liquid treatment in the secondary combustion chamber.	No direct gas combustion.
Haiqui gasification	Haiqui Environ Ltd	Two-stage treatment garbage pyrolisis and gasification with direct gas combustion. The combustion temperature is 850-1100°C. It can process domestic waste, industrial waste and hazardous waste with high LHV.	Grate gasifier (no rotary kiln). Higher working temperatures.

5. Section: Business

5.1. Definition of Value Proposition

Azzurra presents a transformative solution to the challenges of waste management, cantered around the principles of sustainability and innovation. By embracing gasification, we not only minimize environmental impact but also maximize resource recovery and energy efficiency. Unlike incineration, gasification converts waste into clean syngas, red ucing our carbon footprint and contributing to a healthier environment.

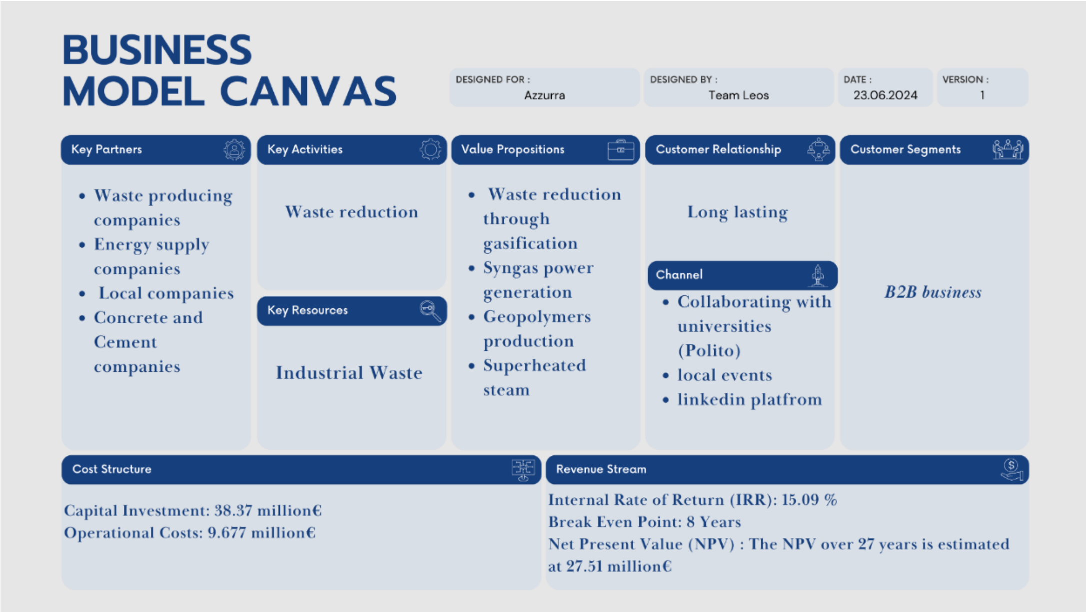
Through meticulous waste characterization and thermal integration, we optimize processing efficiency while ensuring energy self-sufficiency. This allows us to not only treat solid waste but also extract valuable resources and produce secondary products such as geopolymers, further enhancing the sustainability of our operations.

Additionally, our plant design incorporates architectural redesign to enhance logistics and minimize environmental impact, demonstrating our commitment to responsible operations and community welfare. By prioritizing environmental stewardship and technological advancement, Azzurra sets a new standard for waste management practices, paving the way for a cleaner, greener, and more prosperous future.

5.2. Definition of one, or more, "Use Case" for the use of the solution

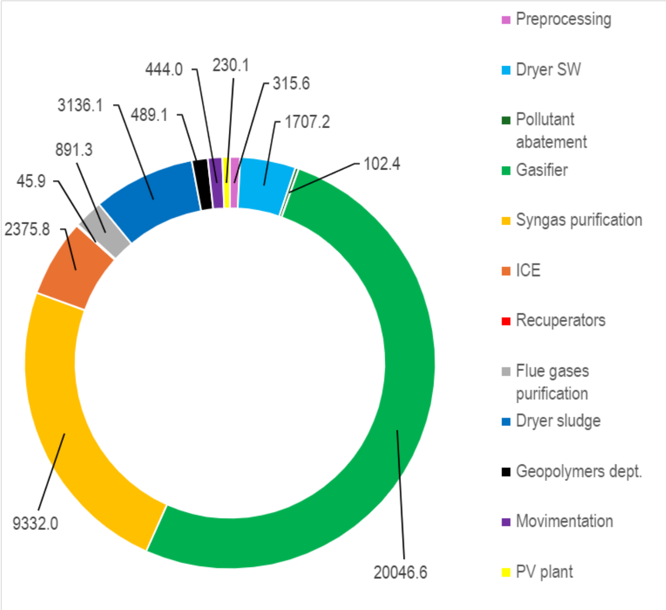
The proposed expansion of the Azzurra plant showcases how a thermally and electrically integrated self-sustainable gasification technology can be applied to other contexts to manage hazardous and non-hazardous waste efficiently. This solution could find integration into waste management systems of urban areas, manufacturing plants, and other industrial settings to convert waste into clean syn gas for cogeneration purposes.

5.3. Business Model Canvas



1- **Key Partners:** Municipality of Villastellone, waste producing copanies, concrete industries (for geopolymers sale).
2- **Key Activities:** Hazardous waste gasification, syngas cogeneration in ICEs, sludge drying, geopolymer synthesis.
3- **Key Resources:** Hazardous solid waste (30 kton/y) and civil & industrial sludges (3 kton/y).
4- **Value Proposition:** Advanced and modern solid waste and sludge treatment solutions with low environmental impact, high social acceptance and focused on circular economy.
5- **Customer Relationship:** Collaboration with nerby companies for the construction of an industrial steam network (possible partners: Pneumatic IndTech, Powerpol, G&B Edilizia, RGB Vision LED, Campari Roberto Serramenti in Legno, Mabert Srl, Accossato, Ecopallets srl, Co.Ge.Car)
6- **Channels:** Avertising through promotonial activities and local events, collaboration with Politecnico di Torino to share knowledge and raise awareness about clean & integrated waste processing.
7- **Customer Segments:** Business to Business.
8- **Cost Structure:**

Investment cost: considers the bare cost of equipment and their installation labour, instrumentation & control, piping, electrical installations, building cost and infrastructures, yard improvements, service facilities, la nd cost, engineering & supervision, construction expenses and contingency. The bare price of equipment has been estimated using techno-economic cost functions (Turton & Towler cost functions, actualised with CEPCI index, if needed) or by taking their market price. All the other costs have been calculated as percentage of the bare cost using fixed cost estimation methods (Guthrie method and Peters & Timmerhaus methods). The total investment cost is 39166 k€, distributed between the different equipment as shown in the following pie chart (costs are reported in k€):



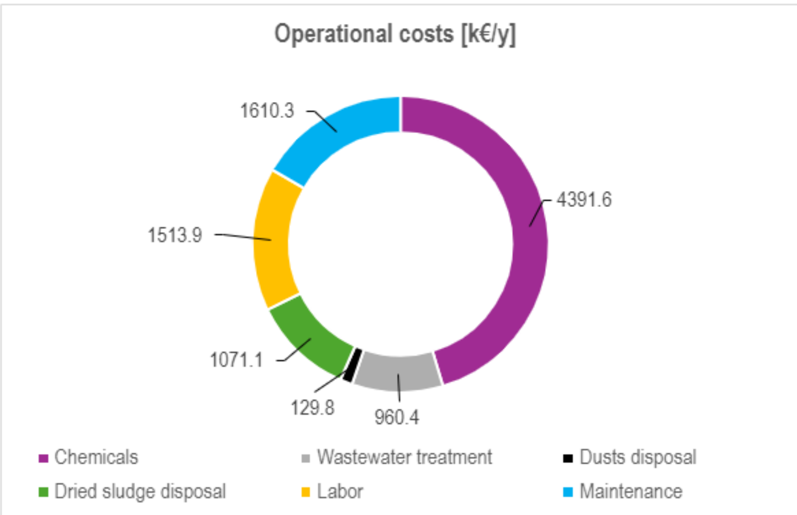
Plant Investment cost

The most impacting cost (more than 50%) is the rotary kiln gasifier cost, followed by the syngas purification section cost (related to the complexity of OLGA tar removal). The remaining cost is distributed among proprocessing devices, driers, pollutants abatement systems, ICEs, movimentation, PV plant and geopolymers department.

<u>Operational costs:</u> involving

- chemicals and reactants costs 4392 k€/y (OLGA makeup oil, NaOH, urea, sodium bicarbonate, active carbon), estimated using market prices
- disposal costs of byproducts 2161 k€/y (wastewater from sludge treatment, dusts from acid gas abatement and dry sludges from filterpress), estimated based on prices from similar companies
- maintenance cost 1610 k€/y, assumed 10% of other operational costs
- labour cost 1514 k€/y, estimated using both Turton method for human resources estimation and a re-scaling of current Azzurra labour cost: this resulted in a total number of people between 30 to 35 and a cost per worker of 50820 €/y (INPS+IRPEF of 34.19%).

Results are visualized in the following pie chart (costs are reported in k€)/y:



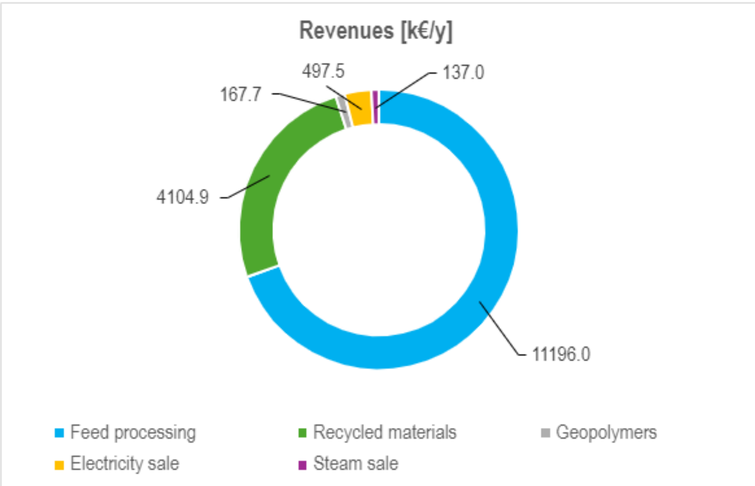
Plant Operational costs

Capital Investment: The total capital investment required for the plant is estimated at 39.116 M€.
Operational Costs: Annual operational costs are projected to be 9.677 M€/y.

9- **Revenues:** Azzurra produces revenues in the following ways:

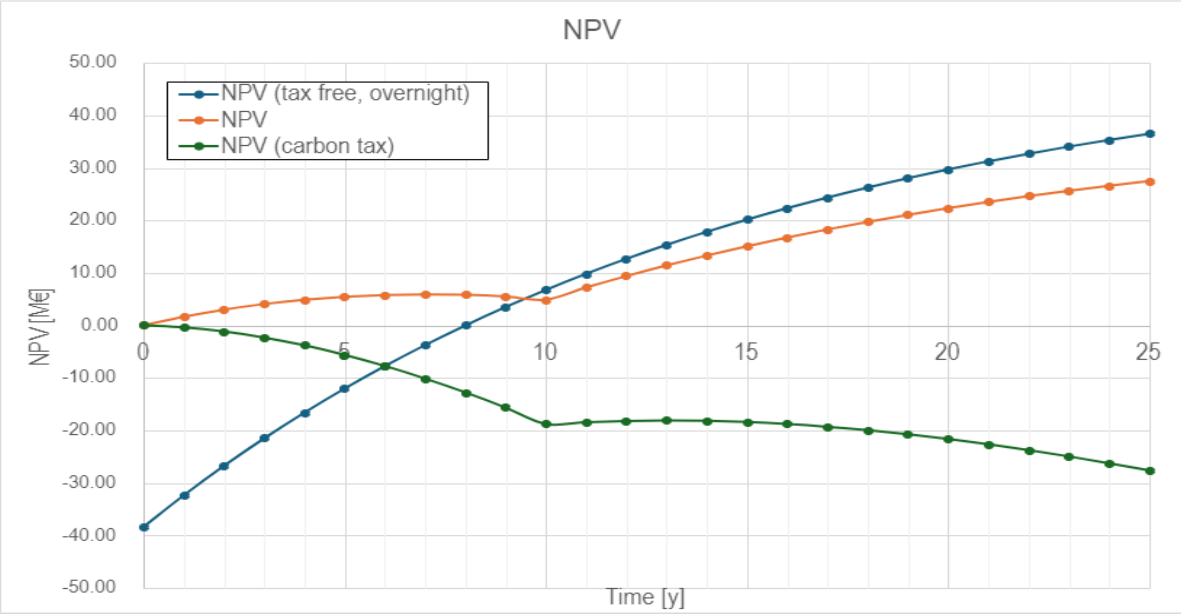
- Feed processing: Azzurra is paid to treat the waste (sludge and solid waste) produced by other facilities for a total revenue of 11196 k€/y. The specific feed revenue has been estimated equal to 186.6 €/ton through a sensitivity analysis aimed at obtaining an investment payback time of 8 years.
- Metals and glass sale: with an average selling price of, respectively, 4096 €/ton and 8.5 €/ton, metals and glass are separated in the preprocessing section and sold to third parties equipped with the facilities to recycle them for a total revenue of 4105 k€/y.
- Electricity sale: Azzurra produces an electricity surplus of 689.3 kW, which will be sold to the grid, generating an estimated revenue of 497.5 k€/y (estimated using Italian average 2023 PUN).
- Steam sale: Azzurra produces a steam surplus of 13.97 GWh/y (as superheated steam at 130°C and 1.2 bar) that can be sold, through an industrial steam network, to nearby companies at a convenient price (assumed 10% lower compared to natural gas price in €/kWh). This generates an annual revenue of 137.0 k€/y.
- Geopolymers sale: Azzurra produces geopolymers at a rate of 2930 ton/y, with each ton priced at 57.22€. This generates an estimated revenue of 167.7 k€/y. The Geopolymer Market size is estimated at USD 14.76 billion in 2024, and is expected to reach USD 53.36 billion by 2029, growing at a CAGR of 29.32% during the forecast period (2024-2029).

The results are visualized in the following pie chart:



Plant Revenues

The total profitability analysis of the investment has led to the following Net Present Value (NPV) curve:



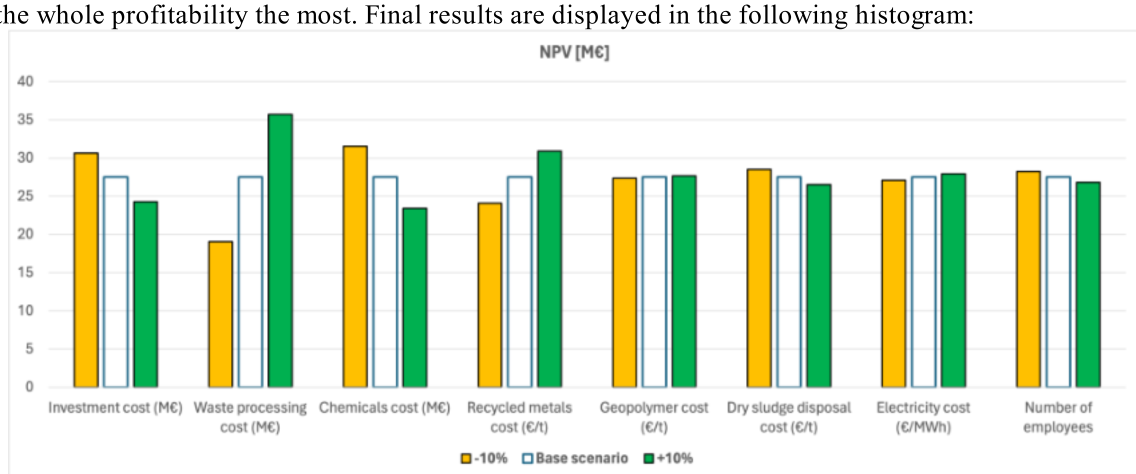
Investment NPV curve

Considering the investment cost as an overnight cost generates a curve (blue line) with a PBT of 8 years and a final NPV of 36.52 M€. If the investment cost is spread over a depreciation time of 10 years and taxes are considered (IRES at 24% and IRAP at 3,9%) the NPV curve (orange line) yields a final NPV of 27.51 M€. Since the in-atmosphere carbon dioxide emissions are generated from waste gasification no carbon tax is applied to them; furthermore, if European carbon taxation is applied the total investment would be economically unfeasible (green line), yielding a final NPV of –27.65 M€. NPV curves have been calculated with a Weighted Average Cost of Capital of 7%.
The following values for the main financial indicators were obtained:

Pay-Back Time (PBT)	8 years
Internal Rate of Retutn (IRR)	15.09%
Return Over Investment (ROI)	0.717

Investment financial indicators

In conclusion, a sensitivity analysis was performed to determine what are the costs or the sources of revenues that impact the whole profitability the most. Final results are displayed in the following histogram:



Results of sensitivity analysis on NPV

The sensitivity analysis suggests how the waste processing cost yields the highest impact on NPV, followed by the investment cost. Chemicals cost and Recycled metals sale cost hold a moderate impact; geopolymer sale cost, dry sludge disposal cost, electricity cost and number of employees, instead, hold an almost negligible impact.

5.4. S.W.O.T. Analysis

Azzurra, operating under the umbrella of the Marazzato Group, is pioneering sustainable solutions in industrial waste management throughout Italy, specifically in the region of Piemonte. Specializing in the treatment of both hazardous and non-hazardous industrial waste, Azzurra integrates gasification technology to minimize the waste in an efficient way and reduce environmental impact.

5.4.1. Strengths

- Plant self-sustainability (electrical and thermal)
- Advanced Gasification Technology for energy generation could attract funds and investments
- High social acceptance (seamless integration with landscape, external garden, no large chimneys, new jobs for local inhabitants created)
- Strategic Partnerships with local companies

5.4.2. Weaknesses

- High Initial Capital Investment (building a facility able to process hazardous waste requires large investments, to impose security and abate all pollutants in emissions and effluents to acceptable levels. Also, navigating the challenging market for geopolymers, which is a relatively new sector in Italy, requires substantial initial capital investment. This includes the cost of research and development, specialized equipment, infrastructure, and setting up manufacturing processes)
- Use of some technologies that are not at full industrial scale yet (geopolymers synthesis, OLGA scrubber)
- The wastewaters generated, in order to be treated, may require the expansion of the existing liquid department

5.4.3. Opportunities

- Geopolymer: The Geopolymers market is forecasted to expand significantly, with a projected compound annual growth rate (CAGR) of 29.32% during the forecast period (2024-2029).
- According to ISPRA (Rapporto Rifiuti Speciali Edizione), industrial waste has increased by 12% compared to the previous year.
- Artificial Intelligence (AI) is increasingly becoming a transformative technology in every industry, particularly within upcoming startups. AI's capability in analysis-based optimization empowers waste management companies to streamline operations, improve sustainability practices, and achieve significant cost efficiencies through data-driven decision-making and continuous improvement initiatives.

5.4.4. Threats

- Larger competing companies in the same area: by investing in advanced technologies and process optimization, large companies can achieve higher efficiency in waste-to-energy conversion by benefitting from economies of scale.

5.5. Competitors

The total number of Waste Management Companies in Italy is 5,212. Milan is the largest province with a 6% market share (298 Waste Management Companies). Second is Rome with 238 Waste Management Companies (5%). Turin also has a large number of Waste Management Companies: 215. These three provinces combined have an 14% market share in the total Italian Waste Management Companies industry.
Waste treatment market has grown at a CAGR of 2.1 % between 2019 and 2024 fuelled by the need for sustainable waste disposal methods. The market size of the Waste Management industry in Italy is €2.4bn in 2024.

Large waste management companies are the main competitors in the industry. These companies often have established reputations and long-standing relationships with commercial, industrial, and municipal clients. Their brand recognition and market presence can make it challenging for Azzurra to penetrate the market or attract large-scale contracts. On the other hand, some local startups can become significant competitors in the waste management and renewable energy sectors. By specializing needs or offering personalized services, startups can carve out a competitive advantage and attract customers who value unique solutions.

Here there is a list of possible competitors;

- Blue Wings Composting (Torino-Piemonte) provides services and tools for the sustainable management, bio-control and bio-transformation of organic waste sources coming from urban, farm and industrial processes.
- Termovalorizzatore TRM di Torino: by employing stringent emissions control measures and ensuring minimal environmental impact and adherence to strict regulatory standards it may look a more solid solution for potential customers.
- A2A AMBIENTE S.p.A. Waste-to-Energy plant in Milan, in operation since 2001. The plant is located in the North West of Milan and is a precious energy source (electricity and heating) for the city. The plant produces electrical and thermal energy from municipal solid waste, downstream of selective waste collection

6. Section: Future Developments

6.1. Possible Future Developments

Future developments in Azzurra's plant include enhancing the integration of renewable energy sources, such as expanding photovoltaic panel installations on the roof and possibly adding PV panels on the covered car parks, to increase energy self-sufficiency. Also, a few electric charging stations should be added to the park to accommodate the needs of employees or customers possessing electric vehicles.

There will be a focus on optimizing gasification processes and valorising other byproducts like sulphur salts from acid gas removal, following the idea of circularity. More established tar removal methods could be incorporated to improve the quality of syngas and reduce maintenance costs.

The facility aims to expand its industrial steam network, fostering partnerships with nearby companies for shared energy resources. An internal air conditioning system, exploiting a small part of the heat generated (also in winter, through adsorption chillers) could be employed, to further reduce the expenses for building thermal management.
Enhanced monitoring and automation systems (also based on AI) will be introduced to ensure operational excellence. In particular, advanced monitoring technologies will be positioned at the chimney and in other locations to monitor the quality of flue-gases and ensure emissions levels always in line with the norms.

In conclusion, further collaborations with academic institutions and industry partners will be explored to drive innovation and technological advancements. A renewing of the company communication channels (e.g. social media) could attract new customers and increase social acceptance.

6.2. Interests of the Team in Continuing Development

Due to our advanced university studies, none of our team members are interested in internships or collaborations with the company currently.

Politecnico di Torino

CONNECTION LAB AND INNOVATION KITCHEN

DATA PROCESSING

Data processing is authorized according to General Data Protection Regulation (EU) 2016/679 (GDPR) for the purposes contained in this application.

Date

SIGNATURE OF THE TEAM MEMBERS

(Name, Surname and relative signature)

Eugenia Bertolino……………………………………………………

Davide Forte……………………………………………………

Negar Nazari……………………………………………………

Atakan Yilmazer……………………………………………………

Alessandro Vilardi……………………………………………………