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Pau Case Study: From a Wastewater Treatment Plant to a Biofactory †

Damien Lebonnois [1,*], Eric Judenne [2], Loïc Perroy [3], Hugues Vanden Bossche [2] and Guillem Grau [4]

1 SUEZ Italy SpA, Via Benigno Crespi 57, 20159 Milan, Italy
2 SUEZ Treatment Infrastructure Water, Tour CB21, 16 Place de l'Iris, 92040 Paris, France
3 SUEZ Traitement de l'Eau, 91 Rue Paulin, 33000 Bordeaux, France
4 SUEZ Eau France, 91 Rue Paulin, 33000 Bordeaux, France
* Correspondence: damien.lebonnois@suez.com
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Abstract: A wastewater treatment facility in Pau, France, will soon be modified to become a so-called "Biofactory" able to produce different resources or energy through a series of state-of-the art and innovative technologies. SUEZ will lead the consortium responsible for the design and construction of the biofactory, with commissioning planned for the beginning of 2023, and they will then operate the plant after its completion. First, the sludge treatment line will include classic and mature anaerobic digestion producing biogas, which will then be purified to biomethane before grid injection. Two innovative technologies will then be used to optimize both sludge volume reduction and energy management: (1) a hydrothermal carbonization reactor will allow for sludge volume reduction with minimal energy consumption and for additional biogas production thanks to filtrate methanisation; (2) a catalytic methanation reactor will convert the CO_2 coming from the biogas purification to CH4, thanks to hydrogen coming from an electrolysis plant fed with renewable electricity produced on site; this methanation process will also supply heat for the digestion process. Additional resources will also be produced by the biofactory, with the recovery of nitrogen through the production of ammonium sulphate to be used as fertilizer. The expected performance of the Pau plant, in terms of energy, resource preservation, avoided and CO_2 emissions, is a tangible indicator of the multiple benefits given by this biofactory approach.

Keywords: biofactory; biomethane; methanation; hydrothermal carbonization; nutrient recovery; electrolysis

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1. Introduction and Biofactory Concept

In the last decades, the design and functionalities of the Wastewater Treatment Plants (WWTP) have evolved substantially. Initially, wastewater treatment plants were built on their primary function, i.e., clearly to "treat wastewater", especially removing organic contamination from the water before discharging it into a receiving body. From a resource point of view, this process was purely linear: wastewater came in, resources (energy, reagents, etc.) were consumed, and treated water came out, in addition to residues, such as sludge disposed of as waste, as shown in Figure 1 ([1]).

The biofactory evolution is the move from this linear/mono-function model towards a system covering several functions among the following ones ([2,3], Figure 2):

- Wastewater treatment
- Water reuse
- Energy recovery
- Biosolid recovery
- Nutrient recovery

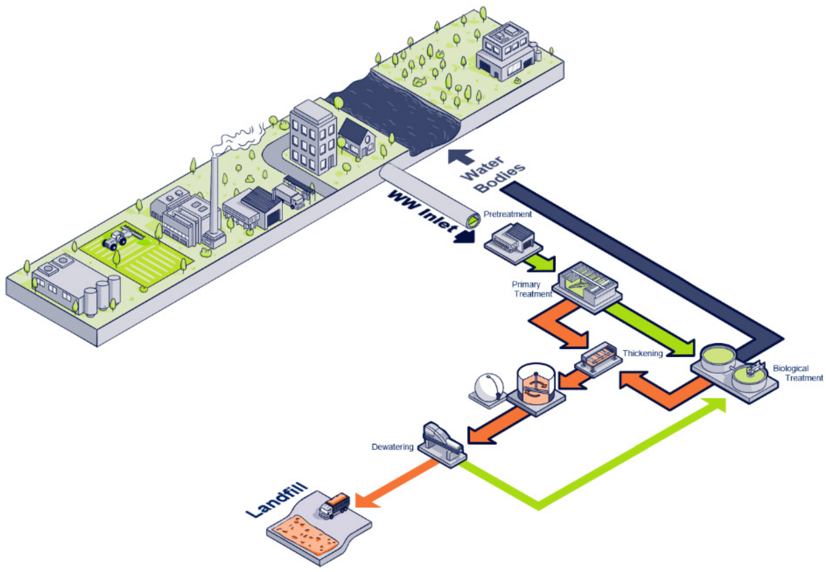

Figure 1. Linear model of a wastewater treatment facility without energy or resource recovery.

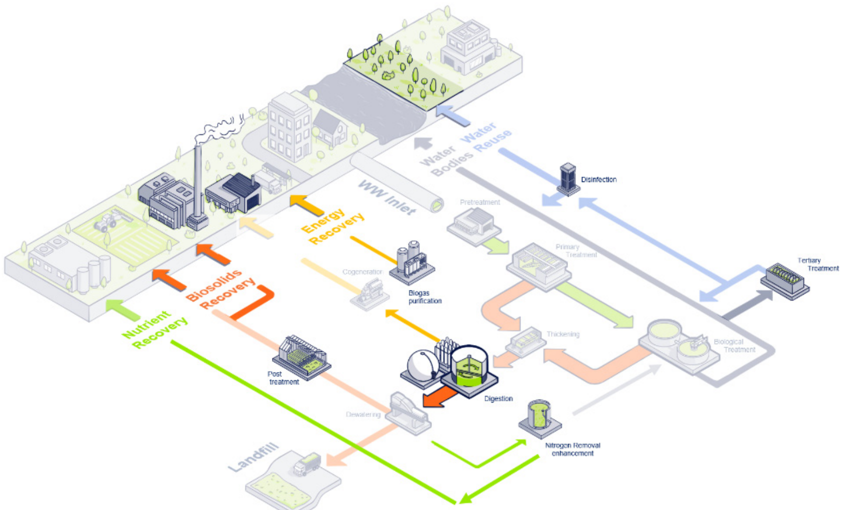

Figure 2. Example of biofactory configuration with energy, biosolid, nutrient recovery and water reuse.

The biofactory concept is about innovating to always improve the performance of those different functions, resulting in increased resource preservation (nutrient recovery for instance) and an improved carbon footprint (especially thanks to energy recovery).

For instance, in Naples (Figure 3), the plant includes energy recovery (sludge anaerobic digestion with biogas production) and biosolid post-treatment (drying) allowing for a possible off-site recovery (such as combustion in cement kilns to replace fossil fuel).

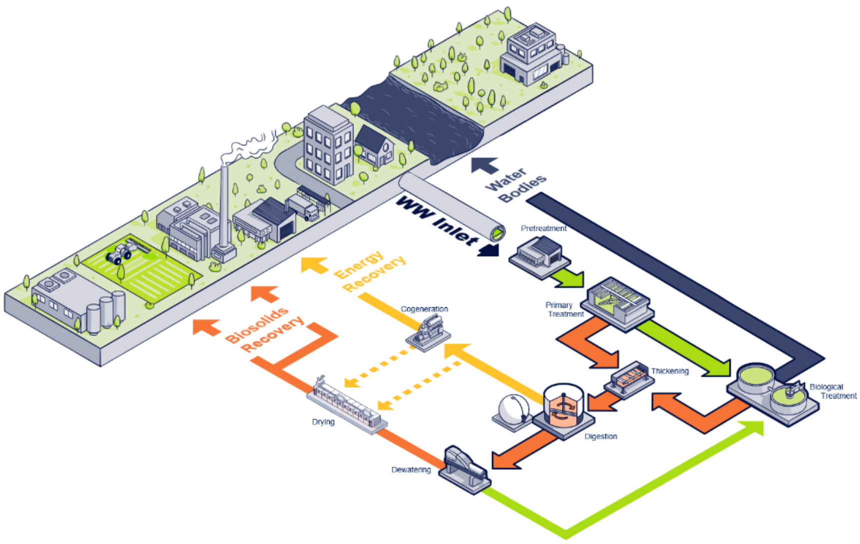

Figure 3. Example of energy recovery and biosolid recovery in Naples (Cuma and Naples North) WWTP.

2. The Pau Biofactory

The Pau project in France is an example of a biofactory which integrates additional innovations to improve the performance of several of the abovementioned functions. Figure 4 gives an overview of the process steps related to the various functions: in green for the nutrient recovery, in dark orange for biosolid recovery and in light orange for energy recovery.

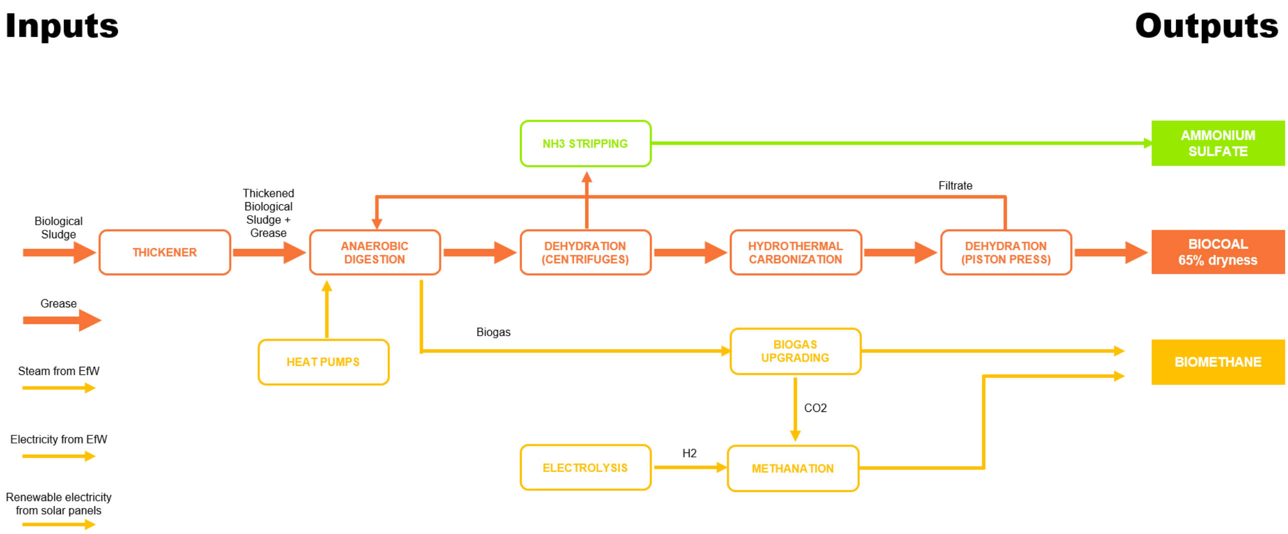

Figure 4. Simplified process flow of the Pau sludge treatment line.

2.1. Energy Recovery

In terms of energy recovery, the Pau plant includes:

- Anaerobic digestion (mesophilic) of greases and sludge to convert part of the sludge into biogas;
- This biogas is then cleaned (removal of H_2S, water, siloxanes, etc.) and CO_2 is removed (thanks to membranes) to produce a biomethane with a CH_4 content above 98% suitable for grid injection;
- A heat pump is used to supply heat to the digester.

In addition to this on-site energy recovery, the plant is directly connected to local energy producers:

- Solar panels are installed just on the neighboring land plot;
- Electricity and heat (steam) arrive from the nearby energy-from-waste facility to supply heat to the sludge conditioning system and nutrient recovery system.

The renewable energy produced by the solar panels will then be converted to hydrogen through electrolysis, while the hydrogen will be used to convert the CO_2 removed from biogas to additional biomethane, thanks to a catalytic methanation reactor.

2.2. Biosolid Prodution and Recovery

The sludge produced in the Pau wastewater treatment plant is dehydrated after its digestion by a standard centrifuge to reach 20% dryness. It is then sent to a Hydrothermal Carbonization unit (HTC), which is a pressurized reactor (about 16 bar) heated up with steam (about 200 °C), conditioning the sludge in two different ways:

- Solubilisation of part of the sludge volatile matter. This solubilized organic matter is then sent to the anaerobic digester to produce additional biogas, improving even further the plant energy recovery.
- The remaining sludge (non-solubilized volatile matter and mineral matter) is dehydrated in a piston press to reach a final dryness above 65%.

This sludge (called biocoal) presents characteristics which make it suitable for both recovery in:

- Agriculture (through composting): no pathogens, and no remaining polymers.
- Energy recovery: given its low moisture content, the sludge has a physical shape (behaviour similar to a soil) and a lower heating value (above 7 MJ/kg) close to the LHV of residual municipal waste (usually between 9 and 10 MJ/kg in Europe (like in [4]), which eases its use in an energy-from-waste facility.

2.3. Nutrient Recovery

From the anaerobic digestion, some ammoniac is present in the water phase: an ammoniac stripper will be installed to recover NH_3 from the centrates (in the form of ammonium sulfate), which will then be used as a fertilizer after product certification. This nutrient recovery is thus an example of enhanced resource recovery, replacing a linear treatment (i.e., treatment in the biological basins with air and carbon consumption) by the recovery of a valuable product.

3. Expected Performance

3.1. Energy Recovery

Table 1 reports the expected energy recovery of the Pau biofactory in comparison to two other WWTP configurations with: (2) anaerobic digestion for biomethane production and with (3) anerobic digestion and sludge drying. In this last configuration, it is assumed that the thermal energy needed for the drying is supplied by the biogas (burnt in a boiler), implying that a low quantity of remaining biogas (using thermal energy needs for drying given by [5]) will be available for biomethane injection in the grid: in such a case, the investment for biomethane upgrade and injection would not be justified and the biomethane production is assumed to be zero. Furthermore, in cases 2 and 3, part of the biogas is assumed to be burnt to supply heat for the digesters, which is not the case in Pau, where the heat will be supplied by a heat pump and heat recovery from the carbonization and methanation unit. As a whole, the expected biomethane injection in Pau without methanation is expected to be about 50% higher than in a standard Anaerobic Digestion (AD, derived from [6]), mainly because of the additional biogas production thanks to the carbonization filtrates. With the addition of the methanation, the biomethane injection will be more than twice the standard AD case.

Table 1. Key performance indicators of Pau WWTP in terms of energy recovery and comparison with other WWTP configurations.

Key Performance Indicator		Pau WWTP (Expected)	Standard AD	Standard AD with Sludge Drying
Raw biogas production without grease	$Nm^3/h/1000$ PE	1	0.8	0.8
Biomethane injection without methanation	$Nm^3/h/1000$ PE	0.7	0.45	0
Biomethane injection with methanation	$Nm^3/h/1000$ PE	1.2		
Avoided Greenhouse Gas emissions thanks to biomethane *	$kgCO_2/yr/PE$	23	9	0
	tCO_2/yr for 150,000 PE	3500	1300	0

* Emission factors for natural gas substitution are taken from [7].

3.2. Biosolid Prodution and Recovery

As far as sludge production is concerned, the Pau plant presents several process steps aiming at sludge volume reduction:

- Anaerobic digestion, which converts part of the volatile matter into biogas;
- Hydrothermal carbonization, which will further impact the volatile matter by converting part of it into off-gas (minor part) and by solubilizing part of it in the liquid phase. This solubilized volatile matter will then be partially converted to biogas in the digester.
- Thanks to the piston press, the final dryness of the sludge is about 65%.

All those contributions allow for a total mass reduction of about 85% compared with a plant without AD and with standard dehydration (Table 2). Compared with a dried sludge, the mass reduction is slightly lower (about 3% less), but is obtained with a lower energy consumption, compatible with biomethane injection in the grid (while the dryer sludge will consume almost all the biogas).

Table 2. Key performance indicators of Pau WWTP in terms of biosolid production and comparison with other WWTP configurations.

Key Performance Indicator		Pau WWTP (Expected)	No AD, No Drying	Standard AD with Sludge Drying
Dehydrated sludge production	t/yr/1000 PE	52	98	54
Final sludge/residue production	t/yr/1000 PE	16	98	15.5
	t/yr for 150,000 PE	2400	14,700	2300
Final sludge dryness	% (as received)	65%	23%	90%

3.3. Nutrient Recovery

The ammoniac stripping unit, installed on the centrates, is planned to produce ammonium sulfate, usable as a fertilizer. The expected quantities of nitrogen to be recovered are given in Table 3, as well as the avoided GHG emissions corresponding to the substitution of a chemical nitrogen fertilizer. The reference emission factor used for the chemical nitrogen fertilizer is 5.66 $kgCO_2/kgN$ ([8]).

Table 3. Key performance indicators of Pau WWTP in terms of nutrient recovery and comparison with another WWTP configuration.

Key Performance Indicator		Pau WWTP (Expected)	Standard Plant without N Recovery
Recovered nitrogen	kgN/yr/1000 PE	276	0
Avoided GHG emissions thanks to nitrogen recovery	$kgCO_2/yr/PE$	1.5	0
	tCO_2/yr for 150,000 PE	234	0

4. Conclusions

Wastewater treatment plants are progressively moving from a linear mono-functional model (i.e., "treating the wastewater) to the more complex and sophisticated concept of a "biofactory" which will integrate additional functions such as: water reuse, energy recovery, biosolid recovery, and nutrient recovery. The Pau wastewater treatment plant is an example of such an evolution, with outstanding performance indicators in the field of: (1) energy recovery/biomethane production (more than 50% compared with standard AD, without methanation); (2) sludge volume reduction: hydrothermal carbonization will lead to about an 85% volume reduction compared with a plant without AD or drying and a similar volume reduction to a configuration with AD + drying, but with much lower heat consumption, allowing for biomethane injection; (3) nutrient recovery: nitrogen will be recovered in the form of ammonium sulfate for use as a fertilizer. Those indicators are key to quantify the impact of the biofactory implementation in terms of energy, GHG emissions, and resource preservation.

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