DRIVING COMPANIES TO PURSUE ECOLOGICAL GOALS: THE CASE FOR ANAEROBIC DIGESTION

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WHITEPAPER

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Introduction

In recent years, pressure on companies to pursue sustainable management has been steadily increasing. Goal 12 of the United Nations' Sustainable Development Plan aims to ensure sustainable consumption and production patterns by "doing more and better with less". [1] Economic activities should reduce the exploitation of natural resources, along with degradation and pollution along the entire lifecycle. This boost towards sustainable economic growth also relates to companies' internal need to reduce costs. The prices of energy and water play a large role in how companies are managed, and they are looking for solutions to reduce their water footprint and improve energy efficiency. In this framework, renewable sources of energy represent a crucial opportunity to match sustainability with economic growth.

In this whitepaper, we analyze the use of anaerobic digestion to treat wastewater from a fish processing company and produce biogas. Biogas is a renewable resource because its production and use cycle is continuous, and it generates no net carbon dioxide. We explain how the use of biogas within the production cycle guarantees a high return of investment, making companies more inclined to pursue ecological goals.

Fishing Industry

The industry of fish, seafood and aquaculture has recently amplified its impact on food supply, with a growth in production of 2.6% in 2015. Half of fish exports by value originate from developing countries: they also contribute to growth in fish consumption, with Vietnam and the Republic of Korea at the top of the export list. 37% of global seafood volume is traded internationally, which makes seafood more highly traded than sugar (34%), wheat (19%), beef (13%), or poultry (12%). [2]

A trend toward increasing consumption of processed seafood, as opposed to fresh seafood, is resulting in increased quantities, up to 70%, of offal and other by-products. [2]
In the past, fish by-products, including waste, were considered to be of low value, and used as feed for farmed animals, or thrown away. However, in the last two decades, utilization of fish by-products has been gaining attention, because they can represent a significant additional source of nutrition.

Ecuador is one of the main canned tuna producers globally, only recently outdone by Thailand in the production of loins. In 2014, Ecuador exported US$2.9 billion of fish products, the second largest fish exporting country in Latin America after Chile. 70% of Ecuador's fish processing operations are concentrated in the southern port city of Manta (Manabí Province). The balance is split between Guayaquil (Guayas Province) and Posorja (Santa Elena Province). Sources report that some 25,000 people are directly employed by the sector. [3]

Wastewater and Waste-to-Energy Technology

Corporate sustainability has become a driver in customers' choice, and fishing industries, as well as other food & beverage companies, have a range of options to implement this business approach. On the environmental side, fossil fuel reduction and water/energy savings can be achieved with Waste-to-Energy technology. At the same time, inevitable wastes and wastewater from processing are reduced or re-used. Wastewater from seafood-processing operations can be very high in biochemical oxygen demand (BOD), fat, oil and grease (FOG), and nitrogen content. [4]

BOD originates mainly from the butchering process and general cleaning, and nitrogen is derived predominantly from blood in the wastewater stream. The major types of wastes found in seafood processing wastewaters are blood, offal products, viscera, fins, fish heads, shells and skins. These wastes contribute significantly to the suspended solids concentration of the waste stream. However, most of the solids can be removed from the wastewater and collected for animal food applications. Another important pollutant parameter for measuring the organic content of wastewater in the seafood industry is chemical oxygen demand (COD). Fats, oil, and grease (FOG) is another significant parameter of seafood processing wastewater. The presence of FOG in an effluent is mainly due to processing operations such as canning, and seafood processing. Nutrients such as nitrogen and phosphorus are of environmental concern. They may cause proliferation of algae and affect the aquatic life in a water body if they are present in excess.

Economic considerations are always the most important parameters that influence the final decision as to which process should be chosen for wastewater treatment. The addition of a Waste-to-Energy plant to a wastewater treatment facility can turn the costs of treatment and disposal into revenues.

The main concept behind a Waste-to-Energy (WTE) facility is to completely utilize the energy contained in the wastes prior to disposal. The WTE facility converts the wastes to biogas (a mixture of methane and carbon dioxide), using a biological process called anaerobic digestion. The produced biogas is pure energy and is easy to handle. It can be used as is for electrical and thermal energy generation in an engine, or in a boiler, or purified and injected into the grid.

Eurofish Case Study

The Eurofish Group is a leading firm in Ecuador's tuna industry as well as in the global market. Eurofish processes roughly 200 tons of tuna a day, predominantly for international export. Lately, the company has been moving into processing other types of fish, including sardines and mackerel. Eurofish owns a processing factory in Manta, Ecuador, a large city on the Pacific Ocean that is a center for fishing and seafood processing. In 2014, the company had a surge in production and the existing wastewater treatment plant was not suitable to keep up with the increase. Eurofish contacted Fluence to upgrade the facility, adding waste-to-energy to the plant's capabilities. The company is committed to the well-being of its employees, neighbors, and environment and it is constantly striving to incorporate sustainability in their business operations. At the time of the upgrading decision, they did not only want to comply with regulations, but also to reduce wastes and energy consumption.

Fluence developed a tailor-made solution to meet Eurofish needs. To address especially the high chemical oxygen demand, Fluence designed first a pilot plant on site to test the processes.

Pilot Plant

The nitrification-denitrification pilot plant was built using two existing fiberglass tanks: one tank was used for denitrification, while the second as an oxidation-nitrification section. The second tank also has a clarification system. A centrifugal pump was used to recycle the mixed liquor between nitrification and denitrification, while a second pump was connected to the clarifier for recycling the separated sludge. The air necessary for the process was supplied through an existing blower in the WWTP. The characteristics of the pilot plant are shown in the table below:

PARAMETER	U.M.	VALUE
Denitrification volume	m^3	73
Nitrification volume	m^3	55
Clarifier volume	m^3	18
Wastewater treated volume	m^3/d	48
COD (DAF outlet)	mg/L	3.200
TKN (DAF outlet)	mg/L	560

The test lasted 3 months. Following the test, the wastewater had the following characteristics:

PARAMETER	U.M.	VALUE
COD outlet	mg/L	<200
BOD outlet	mg/L	<40
N-NH4 outlet	mg/L	<10
N-NO3 outlet	mg/L	<20

All the phases were fully tested before the renovation and construction started. A lab was built with all the instrumentation needed to monitor water quality on an ongoing basis.

Project Challenge

One of the most significant technical challenges was the wastewater quality, which is tough to treat because of high levels of organic/biological compounds, including nitrogen and denatured proteins. The chemical oxygen demand is about 8,000 mg/l.

The below table notes the composition of the main streams:

Raw Wastewater		
PARAMETER	U.M.	VALUE
Flowrate	m^3/d	1.300
COD	mg/L	8.000
TKN	mg/L	620
P-PO4	mg/L	80

Marine Protein		
PARAMETER	U.M.	VALUE
Flowrate	m^3/d	40
COD	mg/L	15.000
TKN	mg/L	1.500
P-PO4	mg/L	1.300

Another significant challenge was the need to build and commission the new facility without interrupting existing operations, no small feat since a complete renovation of the wastewater treatment plant was required. Previously, the facility used only a dissolved air flotation (DAF) pretreatment to clarify effluent before discharge. To accommodate both existing operations and the intended expansion, the system's total flow rate had to be increased from 600 to 1,300 m^3/d.

A third challenge was regarding the plant start up. The building of the WWTP took place during the normal operation of the facility. The intake of an adequate amount of primer for the aerobic system, allowed the treatment of water at the exit of the DAF. The sludge of DAF was progressively treated in the digester within 2 months, to promote the development of methanogenic bacterial flora suitable for treatment. From the beginning, the plant immediately reduced the amount of untreated sludge for disposal. The water at discharge was within the limits imposed by local law.

Process Treatment Description

The treatment system consists of a pretreatment by DAF to remove fats and proteins in the form of floated sludge to be sent to anaerobic digestion, and by a nitrification-denitrification system.

DAF is a clarification process utilized for the separation and recovery of suspended solids and/or dispersal in water. The process works by producing a stream of micro-fine bubbles that attach to solids and lift the solids to the surface, where a surface scraping device transports the floating solids into a collection hopper.

The coagulation of suspended solids and colloidal compounds in the wastewater is carried out using coagulants, or a mixture of these. Generally, cationic polyelectrolyte solutions are used as such, or a primary inorganic flocculant ($FeCl_3$, PAC, etc.) is combined with an anionic polyelectrolyte.

In addition to the contact tank, a device that produces micro-bubbles of air is required. This effect is obtained by saturating the water with air by means of a multistage centrifugal pump and then letting it expand at atmospheric pressure in the contact tank. During the expansion, the water, which is now oversaturated, releases excess air in the form of micro-bubbles.

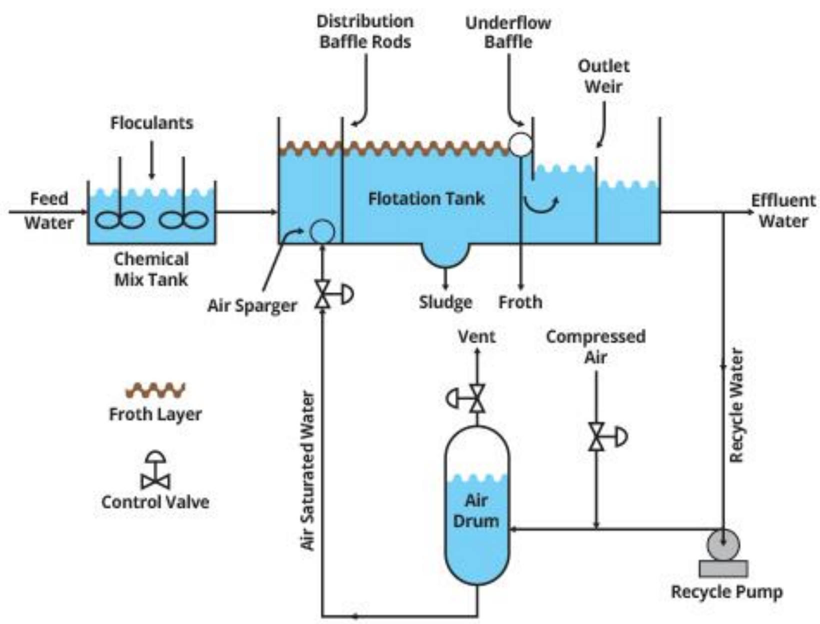

Figure 1. Process Description

Regarding the aerobic treatment of water containing large quantities of nitrogen, both ammoniacal and organic, nitrification - denitrification treatment is very important. This is the only treatment that complies with the legal requirements for ammonia nitrogen, nitrous and nitric. The nitrification consists in the biochemical oxidation of ammoniacal and organic nitrogen by means of bacteria, called "nitrifying", according to the reactions:

$$NH_4^+ + \frac{3}{2}O_2 \rightarrow NO_2^- + 2H^+ + H_2O \qquad NITROSOMONAS$$
$$NO_2^- + \frac{1}{2}O_2 \rightarrow NO_3^- \qquad NITROBACTER$$

Global reaction:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

The nitrification reaction is required when the nitrogen concentration in the raw sewage exceeds 15-20 mg/L.

After nitrification, all the various forms of nitrogen are transformed into nitric nitrogen (after this treatment a subsequent "denitrification" treatment is necessary, as we will see later); the concentration of ammonia nitrogen decreases to values below 1 mg/L. It should be noted that no distinction is made between ammonia nitrogen and organic nitrogen in the sewage to be treated; in fact, organic nitrogen (protein) is rapidly transformed into ammonia form by suitable bacterial species before being "taken" by nitrifying bacteria.

To promote a good nitrification process, it is necessary that in the biological reactor (oxidation tank) an adequate mass of nitrifying bacteria develops: the conditions for this to happen are the following:

a) Adequate aerobic sludge age. Since nitrifying bacteria grow much slower than oxidizing bacteria, the sludge present in the plant must be of sufficient age to ensure that the sludge extractions do not deplete the nitrifying bacteria reactor. Given that a high sludge age corresponds to a low sludge load, a biological oxidation plant capable of also implementing nitrification must be sized, with the latter parameter rather low.
b) Sufficiently high temperature in the oxidation tank; the nitrification speed is significantly affected by the temperature. At temperature increases of 10 °C causes an increase in reaction speed of 2.6 times and vice versa. Hence the importance of designing a plant with all the necessary precautions to prevent excessive cooling of the oxidation tank in the winter months. Technically, nitrification under 8-10 °C is impossible.
c) Adequate oxygen concentration. Nitrification is also sensitive to the concentration of O_2, so if this drops below 20% of the saturation value, this process is inhibited.

Once nitrification has been carried out, the issue of compliance with the legal limits for all forms of nitrogen is not completely overcome. The limit for nitric nitrogen in Europe is 20 mg/L, so if the total nitrogen entering is higher than this value, the treated water will have a nitrogen concentration nitric higher than allowed. In this case, in addition to nitrification, we must also denitrify. Denitrification occurs by means of bacteria capable of using nitrates, breaking them down according to the reaction:

$$NO_3^- + COD \rightarrow N_2 + HCO_3^- + H_2$$

In practice, these bacteria use the oxygen "contained" in the nitrates and release gaseous nitrogen, which is dispersed in the atmosphere. The normal bacteria that oxidize the organic substance by means of oxygen are also able to use nitrates (they are optional aerobes); in order for this to happen, however, the reaction environment must be free of oxygen. Since the oxidation reaction by means of oxygen is more energy-efficient, in the presence of oxygen the bacteria "neglect" the nitrates and breathe the oxygen. A reactor suitable for denitrification must therefore be mixed, but not oxygenated. A second condition necessary for a sufficiently rapid denitrification is the availability of organic matter to be processed.

In a Wastewater Treatment Plant (WWTP) there is an organic substance that is readily available and at no cost: the waste in the wastewater itself. In order to use it for denitrification, the diagram shown below must be implemented:

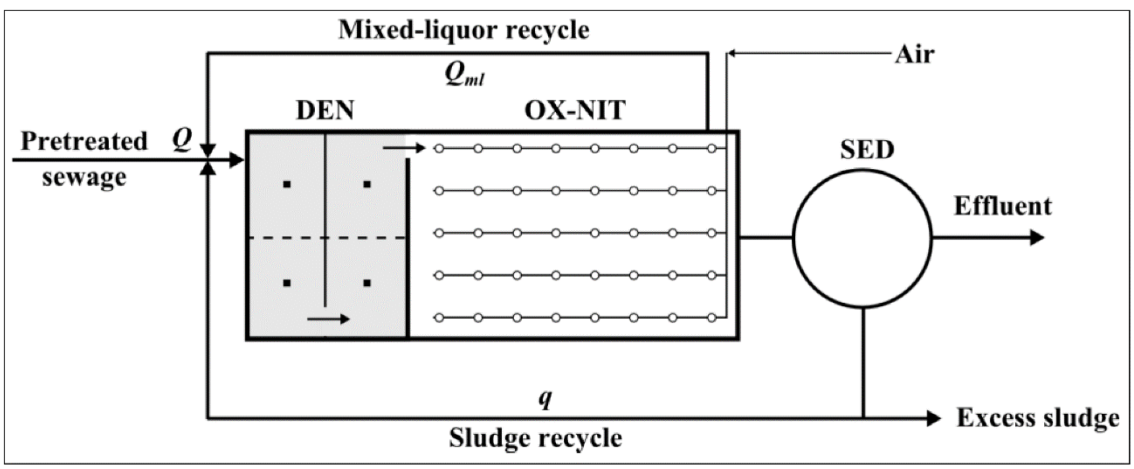

Figure 2 Denitrification-Nitrification Process

The raw sewage arrives at the denitrification tank, the organic substance necessary for the process. The nitrates and the denitrifying biomass are introduced by the recycling coming from the oxidation tank; these are continuously formed in this tank starting from the ammonia and organic nitrogen of the raw water. The denitrification step acts only on nitric nitrogen, so ammoniacal and organic nitrogen pass unaltered through it. The efficiency of the system is conditioned by the Recycling Rate (RT), from which the recycling flow rate to be set in a denitrification tank is obtained, according to the feeding capacity.

Compared to classic nitrification-denitrification systems, Fluence has adopted a two-stage nitro-denitro system, consisting of a 1st stage denitrification tank, followed by a 1st stage nitrification, 2nd stage denitrification and 2nd stage nitrification. This system, at the same load, ensures lower energy and chemical products (i.e. acetic acid) consumption, and smaller plant size, as well as greater operational reliability, compared to the single-stage process. Reduced energy consumption can be confirmed through an example of calculation of the recycling flow rate necessary for a single stage and a double stage:

Example

If the Nitrified Nitrogen inlet (Nin) is 190 mg/L and a Nitrogen outlet (Nout) lower than 15 mg/L is required at the outlet with a flow rate of food Q of 250 mc/h, the formula to be applied is as follows:

$$Recycle\ Rate\ R_T = \frac{N_{IN} - N_{OUT}}{N_{OUT}} = \frac{(250\ x\ 0,190) - (250\ x\ 0,015)}{(250\ x\ 0,015)} = \frac{47,5 - 3,8}{3,8} = 11,50$$

$$Recycle\ Flowrate = R_T\ x\ Q = 11,50\ x\ 250 = 2.875\ m^3/h$$

The presence of a high quantity of nitrogen to be broken down makes the recycling rate very high and difficult to manage, therefore for this solution a two-part division with partially denitrification in the first stage (30 mg/L) has been studied according to the scheme of where the following flow rates are satisfied:

Denitrification 1 (Q_{den1} =190 m^3/h)

$$Recycle\ Rate\ R_T = \frac{N_{IN} - N_{OUT}}{N_{OUT}} = \frac{(190\ x\ 0,190) - (190\ x\ 0,030)}{(190\ x\ 0,030)} = \frac{36.1\ Kg - 5,7\ Kg}{5,7\ Kg} = 5,33$$

$$Recycle\ Flowrate = R_T\ x\ Q = 5,33\ x\ 180 = 959\ m^3/h$$

Denitrification 2 (Q_{den2} = 190 + 60 = 250 m^3/h)

$$Recycle\ Rate\ R_T = \frac{N_{IN} - N_{OUT}}{N_{OUT}} = \frac{((60\ x\ 0,190) + (190\ x\ 0,030) - (250\ x\ 0,015)}{(250\ x\ 0,015)} = \frac{17,1 - 3,8}{3,8} = 3,50$$

$$Recycle\ Flowrate = R_T\ x\ Q = 3,50\ x\ 250 = 875\ m^3/h$$

Total recycle = 959 m3/h + 875 m3/h = 1834 m3/h

The DAF sludge is continuously extracted and sent to the digester for energy recovery. In an anaerobic reactor (digester), many bacterial species coexist in balance, which together cooperate to transform organic pollutants into CH_4 and CO_2.

The methanogenic bacteria act essentially on two substrates, namely acetic acid (CH_3COOH) and hydrogen (H_2) through the following reactions:

a) CH_3COOH + acetoclastic methanigens ---> $CH_4 + CO_2$
b) 4 $H_2 + CO_2$ + methanigens, users of hydrogen ---> $CH_4 + 2\ H_2O$

These are the two terminal reactions of the process of transformation of organic matter into methane, carbon dioxide and water.

In the reactor there are, in addition to the methanigens, other species of anaerobic bacteria able to "process and prepare" the raw organic substance to "methanation", with a series of transformations. These "biochemical reactions" produce hydrogen and acetic acid starting from proteins, fats, sugars etc. present in the water to be treated.

In summary, it can be said that anaerobic digestion is a process produced by a community of anaerobic bacterial colonies (anaerobic active sludge) which, maintained in equilibrium with each other, form a stable system capable of transforming organic waste into methane, carbon dioxide and water.

The figure below shows the digestion process synthetically and highlights the two main phases, which are acidification and methanation. The efficiency of the reactor depends essentially on the balance between these two phases.

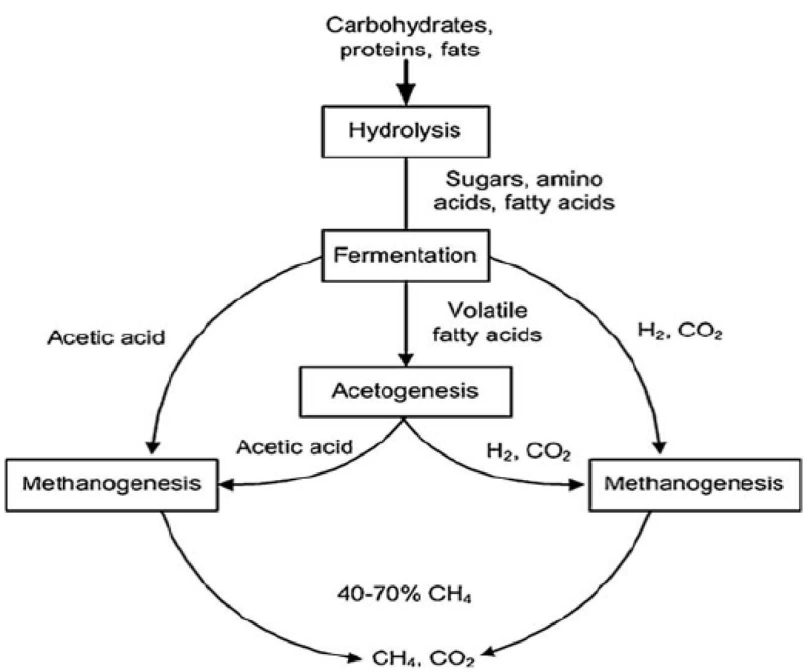

Figure 3 Digestion Process

Acidification is the fastest phase, because the reactions that produce it provide bacteria with three quarters of the entire energy jump between the initial substances, i.e. fats, proteins, carbohydrates and the final products, i.e. CH_4, CO_2, H_2O.
Methanation, on the other hand, is the most delicate phase, due to the small useful energy jump, while the effects of purification (that is the elimination of the COD) are responsible for 99% of the pollution. This concept becomes more apparent to us by examining the COD of the initial and final products in the digestion of a sugar such as glucose:

$$C_6H_{12}O_6 + H_2O \rightarrow 2\ CH_3COOH + 4\ H_2$$

What is written in weight form on a COD basis becomes (reaction 1):

$$^{1Kg}{}_{(COD)}\,C_6H_{12}O_6 + H_2O \rightarrow$$
$$\rightarrow\ ^{0,666Kg}{}_{(COD)}\,CH_3COOH + CO_2 + {}^{0,33Kg}{}_{(COD)}H_2$$

If all the hydrogen produced in the acidification was lost, the reduction of the COD would have been only 33%. The methanation phase expressed in a weighted manner on a COD basis is as follows (reaction 2):

$$^{0,666Kg}{}_{(COD)}\,CH_3COOH \rightarrow CO_2 + {}^{0,666Kg}{}_{(COD)}\,CH_4$$
$$^{0,33Kg}{}_{(COD)}H_2 + CO_2 \rightarrow\ ^{0,33Kg}{}_{(COD)}\,CH_4 + H_2O$$

From these last reactions, we can see that it is the methanation stage of acetic acid which transforms the soluble COD of acetic acid into COD, which is not soluble in methane.

This reaction transforms 66% of the initial COD of glucose into methane. The remaining 33% of the COD of glucose is represented by the hydrogen released in the acidification that is subsequently transformed into methane by the hydrogen-making methanigens.
Another important aspect to highlight of these two main reactions is that the former produces acidity and the latter consumes it.

In a completely mixed reactor (anaerobic digester of traditional sludge), the two reactions occur homogeneously throughout the reactor, the acids produced by the acidification are transformed into CO_2 and CH_4 both gaseous that leave the reactor as BIOGAS.
A small ammonium bicarbonate buffer capacity, present in solution, is sufficient to perfectly buffer the pH of the reactor.

For the digester to function properly, it is necessary to control the concentration of volatile acids (acetic acid and higher fatty acids), monitoring, in particular in the starting phase, the quantity of daily feed, so as to maintain the ratio between volatile acids and bicarbonates lower than 0.3.
The anaerobic digester of 600 m^3 is able, through the reactions described above, to produce 60 Nm^3/h of biogas with 70% of methane of excellent quality (sulfides below the limit of detection), sufficient to preheat the water feed to steam generators, reducing the consumption of fuel used.

This renovation gave Eurofish a chance to make other improvements benefitting the operation and the surrounding community: reducing disposal costs, meeting national environmental standards, and reducing odors.

Results and Conclusion

The plant has been in operation since March 2016, making it the first complete industrial wastewater treatment plant in Ecuador. The facility can efficiently treat wastewater with very high levels of nitrogen and chemical oxygen demand. Eurofish has reduced its sludge waste volume by 75% since the new facility went online. The improved quality of treated wastewater meets the Unified Text for Secondary Environmental Legislation (TULAS), Ecuador's national standards for environmental compliance. With the addition of Waste-to-Energy technology, Eurofish has reduced its wastewater treatment costs by 50% and its energy consumption by 35 – 40%. This highly efficient renewable energy source saves Eurofish more than $120,000 a year.

The plant is under permanent observation for improvement and its results are reported to the environmental authorities weekly, and the plant's quality is audited every three months.

The sustainability of fisheries production is crucial to the livelihoods, food security and nutrition of billions of people. According to MSC Consumer Perceptions Study,[5] sustainability is a stronger starting motivator than price in seafood purchases globally. Seafood consumers seek out environmentally friendly seafood over price and brand. This trend can function both as a reward for well-managed fisheries, and as a lever to improve fisheries sustainability.

Maintaining the structure, productivity, function, and diversity of the ecosystem is crucial, and seafood companies should lead the field in guaranteeing the health of the oceans. With their immediate high return of investment, water treatments and anaerobic digestion to produce biogas make companies more inclined to pursue these ecological goals.

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