Nat. Volatiles & Essent. Oils, 2021; 8(6): 619-633

Renewable Energy Source Using Primary And Organic Nutrients, Biocells, And Wastewater From The Banks Of The Estero Salado Guayaquil

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Abstract

Renewable energy alternatives currently constitute new paradigms of sustainability, microbial fuel cells (MFC) allow the accumulation of energy and, in another context, one of the major environmental problems is water pollution as a result of irregular settlements in urban areas. The research was oriented to identify the potential for obtaining electric energy using primary and organic nutrients in biocells. For its development, wastewater was used and a prototype was designed in which three treatments were evaluated (flowers, NPK and the interaction between both), finding the effectiveness of the nutrients applied. A statistical design was used using the analysis of variance with multiple observations applying an experimental design with factorial arrangement to evaluate the effectiveness of the treatments. As a result, it was established that the cell that used flowers as a nutrient produced a greater amount of energy, which leads to the conclusion that it is possible to obtain electrical energy from wastewater by manipulating variables and applying experimental methods and interactions between primary and organic nutrients.

Keywords: Bacteria, contaminant, eutrophication, fertilizer, waste.

1 Introduction

Industrial and technological development, since the second half of the 21st century, has led to an increasing exploitation of fossil fuels, causing these non-renewable sources to run out as time goes by (Correa Álvarez, González González, and Pacheco Alemán 2016).

The year 2015 marked a relevant milestone in the global energy debate with the adoption by the United Nations (UN) of the Sustainable Development Goals (SDGs), including the specific purpose of energy (SDG 7) "to ensure access to affordable, reliable, sustainable and modern energy for all." (Parra Cortés 2018). The above implies an expectation for industries, which must make the efficient production of heat and electricity from various primary energy sources viable.

As the world's population increases, there is a greater demand for electrical energy; studies referring to Say's law, which postulates that supply creates its own demand (Jiménez 2010);(Anón n.d.); (Barón Ortegón 2018).

According to the 2030 agenda and the (SDGs), in Latin America and the Caribbean, more than 26 million people (4% of the population) lack access to electricity and at least 87 million people (15% of the population) use biomass from unsustainable sources - firewood and charcoal - for heating purposes (Am 2017). As a result, people are looking for subsistence alternatives to deal with the problem.

Global population growth generates greater demand for consumption in all contexts and, at the same time, implies resource depletion, by increasing consumption and thus increasing energy costs and greenhouse gases (Guillén Mena et al., 2015)

As industrial production increases, so does resource depletion, pollution, food demand and population, since these elements are interrelated and constitute a dynamic exponential system of behavior (Bellaubí Favá 2016).

In environmental matters, there are several problems caused by different anthropogenic aspects (Cedeño 2020). Hence, it is important to determine the alterations caused by anthropogenic factors on the services provided to the environment (Menchaca Dávila and Alvarado Michi 2011).

Everything that produces pollution not only alters the ecological balance of the planet, but also threatens the life and health of living beings. This is so true that it is necessary to consider different resources and include, in the foreground, one of capital importance for the maintenance and development of life: water, which is being polluted and, if not treated properly, brings great risks to the environment and health (Pang et al., 2017).

The main reasons for water pollution are to be found in the anthropic occupations of the disorderly and irregular settlements of human beings (Suárez y Trujillo 2018), which causes that, in places where there is no sewage system, these waters are expelled towards the outdoors, which undoubtedly has as final destination the streets, roads, estuaries, rivers, etc.

The problems of water pollution are also evident in large metropolises, which are affected, regardless of whether they have the best sewage system or an optimal river network; there will always be water waste that is directed to and reaches inadequate locations.

According to the definitions established in the Regulations to the Environmental Management Law for the Prevention and Control of Environmental Contamination of Ecuador, wastewater is considered to be that of varied composition, coming from domestic, industrial, commercial, agricultural, livestock or other public or private use, and that for such reason has suffered degradation in its original quality (Ministerio del Ambiente 2003).

In Ecuador, the second city with the largest number of inhabitants is Guayaquil which, in the last decade, has grown impressively, with a population of 2723665 inhabitants, according to population projection figures. (INEC 2021). Its territorial extension is 347 km^2, it has an estuary called Estero Salado, which is considered as a system composed of a complex network of drains. From the geomorphological and oceanographic point of view, it is an arm of the sea (Teodoro Wolf, 1892)

The generation of water discharges from domestic and industrial use, as well as the dumping of solid waste on the banks and branches of the estuary, is an environmental problem. There is a growing interest in improving the water that accumulates there through treatment plants, as well as implementing reuse and recycling systems (Carlos-Hernández et al., 2014); (Floramis, Ordóñez, and Hernández 2016).

Wastewater can be reused by means of different types of special treatments, depending on the need. In this context, it is important to carry out research specifically designed to access new technologies based on the use of clean energies, which provide new and better procedures for the adequate use of renewable sources (EnerLAC 2020).

This is also one of the great challenges worldwide, and in underdeveloped countries, especially in Latin America, the problem has not been solved.

Technologies applied to wastewater treatment pursue objectives related to human health and community wellbeing, concerning achieving environmental sustainability (Moeller, G.; Escalante 2012).

For the sanitation of these waters, a set of technologies have been designed, mainly oriented to health prevention, since they are the main causes of diseases and infectious outbreaks due to the high contamination that originates from them.

Influent: water, wastewater or other liquid that enters a receiving water body, reservoir, treatment plant or treatment process. As opposed to effluent: liquid discharge or discharge from a production process or a specific activity (Ministerio del Ambiente 2003)

Contaminated water comes from a variety of sources, including industrial and residential areas, and is therefore made up of a wide variety of particles, both in size and composition.

In the case of domestic water the structure is similar among populations, managing to vary in consensus to the population size, water consumption, culture, climate and other components(Nohelia and Salgado, 2015).The result of its contamination is given with food waste, grease, sanitary waste, used soap, toilet cleaning, clothing and many organic and inorganic materials that are discarded (Rodie, 2013); (León et al., 2018).

There are different types of effluent treatments that have the possibility of discharging into oceans or rivers without environmental inconveniences, generally they are technologies with a high energy cost, mostly aeration and pumping. Selecting a particular method to reduce wastewater pollutants will depend on the initial characteristics of the effluent (Behling, Marín, y Gutiérrez 2003).

In view of this problem, different sources consider that hydrogen and fuel cells will be fundamental solutions for the 21st century. (Comisión Europea. Dirección General de Investigación, 2003). Therefore, it is very important that an industrial composition implemented on primary energy sources is required to achieve the necessary services.

It is important to indicate that in a biocatalytic microbial fuel cell (MFC), the anode reactions (the transfer of electrons from the microorganism to the anode) are used for the production of current (Páez et al., 2019)(Revelo Romo et al., 2019), while cathodic reactions (electron transfer from the cathode to the microorganism) have recently been applied for current consumption.

In CBMs, water from different natural sources, such as lakes, can be used as the main raw material (Zhao et al., 2012). It can also be obtained from marine sediments (Dumas et al., 2007)from domestic or industrial wastewater effluents, from domestic or industrial wastewater effluents (Rabaey et al., 2005) or industrial wastewater, (Velasquez-Orta, Curtis, and Logan 2009).

In the cells (MFC), an anodic biocatalyst must be used (Xue et al., 2017)in which prokaryotic bacteria such as Geobacter Metallireducens, Geobacter Sulfurreducens, and Geobacter Sulfurreducens are usually used (Vargas Arce et al., 2018).

In correspondence with the above, which includes from the general goals of the UN to the specific interests of specific territories and regions, the following scientific question should be established:

How to use wastewater from the Estero Salado to produce electricity?

Additionally, if there are primary and organic nutrients that can be used together with the wastewater, it is pertinent to determine what characteristics the wastewater from Estero Salado must have to produce electricity?

Consequently, the objective of the work is to generate electricity using primary and organic nutrients in biocells, taking advantage of the wastewater from the banks of the Guayaquil salt marsh.

To this end, the study proceeded to

a) Characterize the compounds present, dissolved or in suspension, in the wastewater through laboratory analysis.

b) Design a microbial fuel cell system to obtain potential energy.

c) Evaluate treatments applying primary and organic nutrients.

d) Measure the amount of potential energy obtained from the geographic points in a fuel cell circuit produced by wastewater.

2 Methodology

2.1 Study Area

The study was conducted on the banks of the salt marsh in the city of Guayaquil (Figure 1). Wastewater and sediment samples were collected following the guidelines of the Ecuadorian Technical Standard INEN 2169-2013 "sampling, handling and conservation of samples" (INEN 2013).

To select the three points of the site, the technique of convenience sampling was applied for ease of access, the three points found along the banks of the salt marsh are indicated in (Figure 1).

Figure 1 Map of the Salado estuary, Source: GoogleEarth.

Once the samples were collected in the three geographical points indicated, the inspection protocol, sampling, filling of the container and corresponding transfer were applied, following the recommendations of the LASA laboratory and the protocol of the aforementioned INEN standard, which includes the performance of the physical-chemical analysis, using the regulations of Ministerial Agreement 097 A Permissible Limits. (Ministerio del Ambiente 2015).

Table 1 describes the three georeferenced points through their coordinates, the characteristics of the sample and the amount of liquid and mass that were obtained for subsequent analysis.

Table 1. Samples on site with coordinates.

Sample Collection	Sample Quantity	Liquid content ml / mass gr	Coordinates
1	1000 ml	880 ml 200 gr (solids)	-2.216480541531051, -79.94705716960296
2	1000 ml	880 ml 200 gr (solids)	-2.208641354217444, -79.94472654227374
3	1000 ml	880 ml 200 gr (solids)	-2,2259375, -79,9466232

Source: Own elaboration.

2.2 Characterization of samples

The characterization of the wastewater samples obtained from the sampling points was delivered to the laboratory to perform the physical-chemical analysis and obtain the description of the physical-chemical characteristics of the wastewater, such as pH, conductivity, turbidity, BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand), which are the most important parameters in the characterization for the purpose.

2.3 Fuel cell design

Double chamber cells (Figure 2) separated by an activated carbon membrane were used. Carbon cloth (Circular 4cm radius) was used for both the anodic and cathodic chambers.

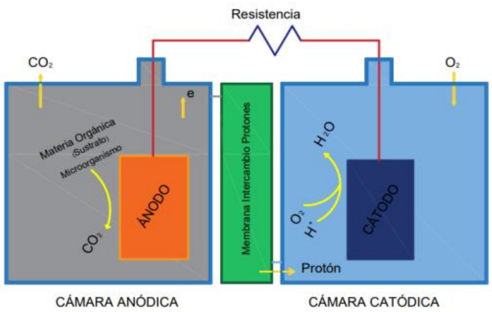

Figure 2:Schematic of fuel cell based on (Sánchez et al., 2021)

The anode chamber is composed of 200 ml of wastewater, 200 grams of organic waste, 20gr of NPK, An external 2kΩ resistor connected to the MFC circuit, and the potential was measured by a digital multimeter.

2.4 Treatments and nutrients

For the first treatment (T1), 60 grams of crushed rose petal residues were used. In the second treatment (T2), a composition of 60 grams of nitrogen (N), phosphorus (P) and potassium (K) was used. In the third treatment (T3), an interaction between 30 grams of NPK plus 30 grams of rose petals was used to evaluate the effect obtained. The fourth treatment, without application, was called control (T4). In addition, wastewater, substrate and solids-sludge were applied (Table 2).

Table 2. Microbial cells with their respective treatments.

Treat ments	Mud(Mass)	Water ml	Substr ate gr	gross weight gr
T1	200	200	60	460
T2	200	200	60	460
T3	200	200	60	460
T4	200	200	0	400

Source: Own elaboration.

The analysis of the data collected as a result of the experimental process was carried out using infostat statistical software, which allowed to arrive at specific conclusions, according to the independent and dependent variables, in which explanations of cause-effect relationships can be found.

2.5 Measurement

To carry out the measurement of the resulting variables, a multimeter was used; the measurements were taken every 12 hours for 5 days, since after this time the voltage began to decrease, losing the effect of the treatments.

The basic quantities used in electricity (voltage, current intensity and electrical resistance) are measured with measuring equipment that is essential for any electrical or electronics technician.

1. A voltmeter was used to measure the voltage (V) (voltage), whose unit of voltage measurement is the volt.
2. The intensity of the electric current (I) was measured using an ammeter. The unit of measurement of the current intensity is the ampere.
3. Electrical resistance (R) is used in the ohmmeter. The unit of measurement of electrical resistance is the ohm.
4. The electrical power was obtained with the same instrument.

Measurements can also be obtained using the formulas:

Intensity ($i = w / v$)

Where: I=Intensity; w=power; v=voltage; v=voltage.

Resistance: $R = V / I$

Where: R= resistance; V= voltage; I= current.

Voltage $v = P / I$

V= Voltage; P=Power; I= electric current in amperes.

Power: P= I*V
P=Power; I=intensity V=voltage-

2.6 Statistical analysis

The data were statistically evaluated by analysis of variance ANOVA, the scheme of which is detailed in Table 3.

Table 3. Outline of the analysis of variance

Variation Source	Freedom grades
Treatments (T-1) 4	3
Repetitions (R - 1) 5	4
Experimental error	12
Total	19

Source: Own elaboration

Comparison of means was performed using Tukey's test, at 5% significance level ($p<0.05$).
In addition, a 3-factor factorial design was applied to determine the efficacy between treatments and interactions.

In order to carry out the evaluation in the statistical software, the study variables must be clearly specified:
Independent Variables:
Sources of variability, treatments.
Dependent variable:
Voltage/resistance/amperage/power.

3 Results and Discussion

3.1 Physical-chemical analysis of samples

The physical-chemical analysis of the three samples obtained from the selected sites are shown in Table 4.

Table 4. Physical-chemical analysis

Sample	PH	Conductivity	Turbidity	Dbo	Dqo
1	7,58	30470	657	67,20	620
2	7,63	30542	665	67,40	625
3	7,89	30523	663	66,10	620

Source: Lasa Laboratories

It can be seen that the following parameters were measured:
Hydrogen potential: Hydrogen potential is measured on a scale of 1 to 15.
All three samples are considered slightly basic, with a tendency to alkalinity.

As for conductivity, its unit of measurement is microsiemens per centimeter (µS/cm), which was obtained by APHA Method 2510: Standard Methods for the Examination of Water and Wastewater. High conductivities were recorded, located in the range of 30000 to 50000 µS/cm Marine Water (Claude E. Boyd 2017) which affirms that in the three samples there is a high charge of salt concentration or a high degree of acidity, favoring to be able to conduct the amountof ions having high electrical charges. (Hach Company, 2017)

The turbidity found in the samples ranged from 657 to 665 Formazin Turbidity Unit F.T.U. obtained by Standard Methods Apha 2130 B: Turbidity by nephilometry.

Chemical oxygen demand determined the amount of gas necessary for the biotic degradation of organic compounds in wastewater elements.

The assessment of the biological oxygen demand allowed to know the amount of dioxygen consumed when degrading the organic matter in the waste samples.

Table 5 shows the evaluation of the use of microbial fuel cells, in which primary and organic nutrients were used, manipulating the variables for experimentation and waiting for the effect provided by each of the treatments and the interaction between both factors.

Table 5. Average measurements 5 replicates.

TREATMENTS	VOLTAGE	RESISTANCE	AMPERAGE	POWER
T1 FLOWERS	0,38	0,27	7,33	0,66
T2 NPK	0,35	0,24	7,66	0,65
T3 FLORES+NPK	0,35	0,23	7,72	0,65
T4 WITNESS	0,34	0,23	7,71	0,64

Source: Experimental data

The treatments applied were as follows: T1 Flowers; T2 NPK; T3 NPK+ Flowers; T4 No application (Control).

Without performing the respective statistical analysis, it can be seen that the T1 treatment shows superior results than the other treatments.

The results obtained with a multimeter at the output of the cell for 5 days show that the voltage registered a progressive increase. Figure 3

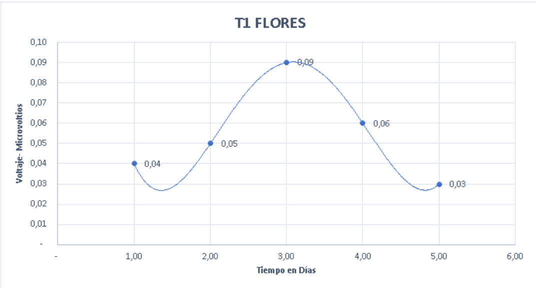

Figure 3: Voltage and Time Relationship

Once the global statistical analysis was performed, Figure 4 shows the data shown in the form of a bar. The evaluation of the treatments with respect to voltage, where T1 is above the other treatments.

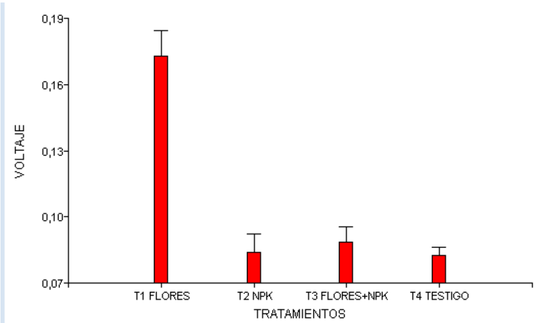

Figure 4: Voltage or Voltage produced by treatments.

Franzen et al. (2016) characterized eight ornamental flower species for the chemical composition and caloric value of petals, and found, per 100 g of fresh rose petals, the following proportions: 72 calories, 10.9 g carbohydrate, 1.84 g protein, 0.28 g ethereal extract, and 3.5 g fiber.

Table 6 Analysis of Variance (SC type III)

F.V.	SC	gl	CM	F	p-value
Model	0.10	3	0.03	29.16	<0.0001
TREATMENTS	0.10	3	0.03	29.16	<0.0001
Error	0.06	56	1.1E-03		
Total	0.16	59			

Table 6 shows the analysis of variance which indicates that there are significant differences in both the model and the treatments.

Table 7. Test: Tukey Alpha=0.05 DMS=0.03276

Error: 0.0011 gl: 56

TREATMENTS	Stockings	n	E.E.	
T1 FLOWERS	0.17	15	0.01	A
T3 FLOWERS+NPK	0.08	15	0.01	B
T2 NPK	0.08	15	0.01	B

T4 CONTROL 0.07 15 0.01 B

Note: Means with a common letter are not significantly different (p > 0.05).

Table 7 shows the results of the types of treatments used with their respective means, in which there is a difference with T1, so it is concluded that there is a significant difference, P<0.05, which allows to affirm that the alternative hypothesis is accepted.

H_1 = Microbial fuel cells will allow the production of electrical energy from the wastewater of the Estero Salado.

The results recorded show that the treatment of wastewater with flowers obtained better results.

Several studies conclude that it is possible to obtain energy from wastewater, in accordance with (García et al., 2017). They consider the possibility of using diverse substrates and microbial communities that propitiate that fuel cells constitute an eco-friendly and feasible technology to develop from any other type of nutrients, because these components are found in abundant form and are easily accessible.

The resistance depends on three factors: the larger the cross-section, the lower the resistance; the length is directly proportional to the resistance, i.e., the longer the cross-section, the higher the resistance; and finally, the current flow depends on the conductivity of the materials.

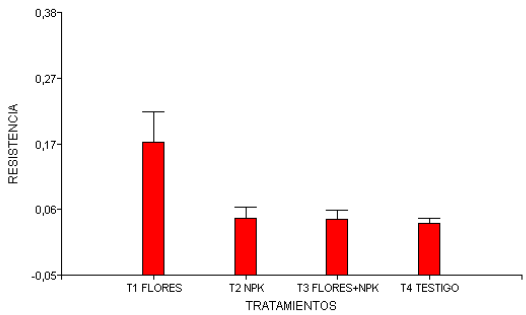

Figure 5.Resistance produced by treatments

The T1 treatment produced greater resistance.

Table 8 Analysis of Variance Table (SC type III)

F.V.	SC	gl	CM	F	p-value
Model	0,19	3	0,06	26,90	<0,0001
TREATMENTS	0.19	3	0.06	26.90	<0.0001
Error	0,13	56	2,4E-03		
Total	0.32	59			

Table 9 Tukey Test: Tukey Alpha=0.05 DMS=0.04697

Error: 0.0024 gl: 56

TREATMENTS	Stockings	n	E.E.	
T1 FLOWERS	0.17	15	0.01	A

T2 NPK 0.04 15 0.01 B
T3 FLOWERS+NPK 0.04 15 0.01 B
T4 CONTROL 0.03 15 0.01 B
Note: Means with a common letter are not significantly different (p > 0.05).

In Table 8 and 9, the value of p<0.05 therefore there is a significant difference and, at the same time, indicates that the treatment with the highest effectiveness is T1.

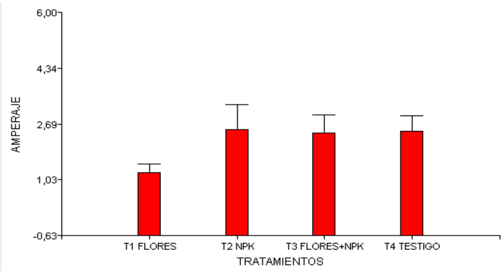

Figure 6.Amperage produced by the treatments

Table 10 Analysis of Variance Table (SC type III)

F.V.	SC	gl	CM	F	p-value
Model	25.83	3	8.61	7.63	0.0002
TREATMENTS	25.83	3	8.61	7.63	0.0002
Error	63.20	56	1.13		
Total	89.03	59			

Table 11 Tukey Test: Tukey Alpha=0.05 DMS=1.02718
Error: 1.1286 gl: 56

TREATMENTS	Stockings	n	E.E.	
T4 CONTROL	2.86	15	0.27	A
T3 FLOWERS+NPK	2.59	15	0.27	A
T2 NPK	2.52	15	0.27	A
T1 FLOWERS	1,17	15	0,27	B

Means with a common letter are not significantly different (p > 0.05).

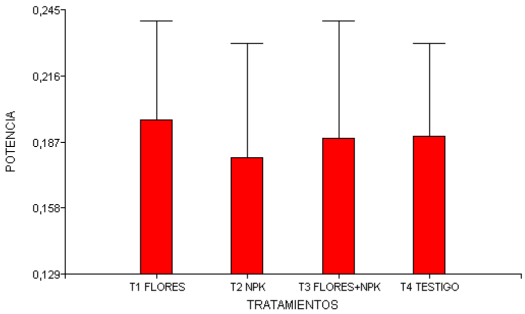

Figure 7. Power produced by treatments.

The power obtained in each of the treatments performed shows that, although there are high records, they cannot be differentiated with the naked eye.

Tables 12 and 13 present the analysis of variance for power; the results show that there is no significant difference, which is confirmed when the Tukey test is applied at 0.05 significance.

Table 12 Analysis of Variance Table (SC type III)

F.V.	SC	gl	CM	F	p-value
Model	9.9E-04	3	3.3E-04	0.42	0.7415
TREATMENTS	9.9E-04	3	3.3E-04	0.42	0.7415
Error	0,04	56	7,9E-04		
Total	0.05	59			

Table 13. Tukey Test: Tukey Alpha=0.05 DMS=0.02725

Error: 0.0008 gl: 56

TREATMENTS		Stockings	n	E.E.	
T1	FLOWERS	0.19	15	0.01	A
T4	CONTROL	0.19	15	0.01	A
T3	FLOWERS+NPK	0.19	15	0.01	A
T2	NPK	0.18	15	0.01	A

Note: Means with a common letter are not significantly different ($p > 0.05$).

The higher the resistance, the lower the current flow, and vice versa.

4 Conclusions

The physical-chemical characteristics of the wastewater were determined by identifying pH, conductivity, turbidity, BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand), which are the most important parameters in the characterization to measure the degree of contamination.

A microbial fuel cell system was designed, which obtained electric current, obtaining favorable results in its variables, voltage, resistance, amperage and resistance.

The treatments were evaluated by applying primary and organic nutrients, with the cell containing flower substrate being the most effective.

The measurements obtained were adequate, however a large number of cells are required to power an electronic device.

5 Recommendations

Design new research to expand the microbiological analysis to identify if there are alterations in the water related to the presence of (Geobacter sulfurreducens and Rhodoferax).

Establish the number of cells required to power an electronic appliance and determine the average consumption time based on demand.

Microbial cells can be an important source of renewable energy as long as the amount of energy they produce can be accumulated to provide a constant rectified voltage output that lasts over time.

Conflict of Interest

There is no conflict of interest.

Acknowledgment

The authors thank the Academy, the authorities and teachers of the Master's Degree in Environmental Management of the Universidad Estatal del Sur de Manabí, as well as the Universidad Agraria del Ecuador, to which I belong.

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