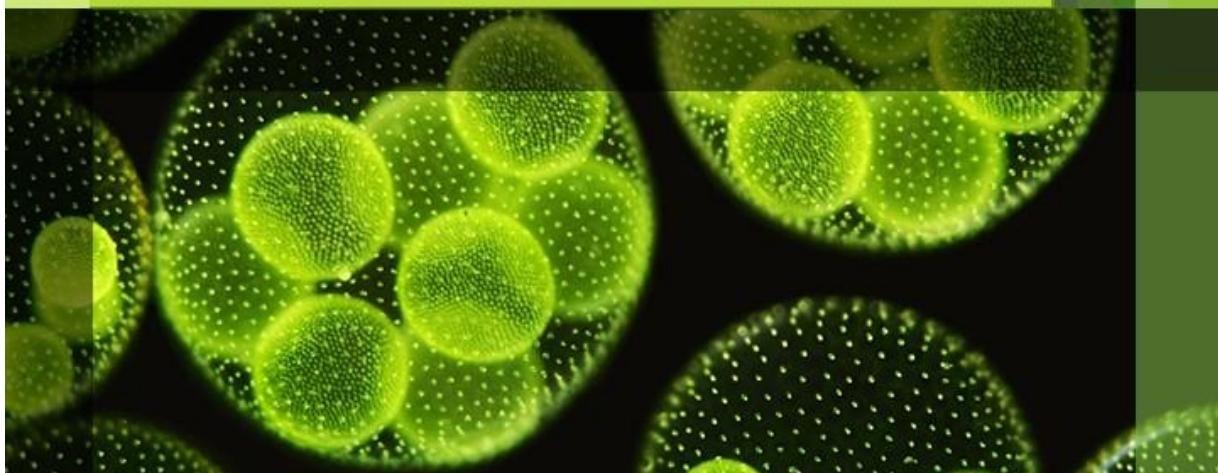
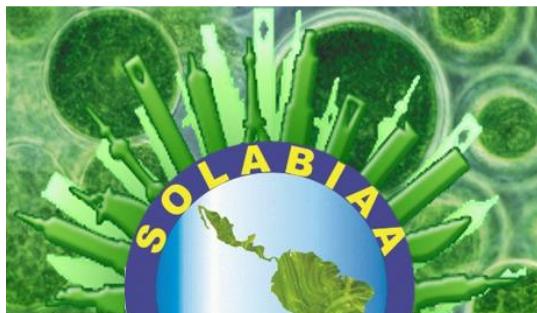


# Revista Latinoamericana de Biotecnología Ambiental y Algal

Latin American Journal  
of Algal and Environmental  
Biotechnology



Volumen 12 No. 2, 2021



**CURSO Online:**  
**“BIORREFINERÍAS**  
**a partir de**  
**MICROALGAS y PLANTAS”**  
**SOLABIAA-INECOL 2021**  
**28 Junio – 1 Julio**



Número Especial, Memorias del Curso en línea:  
*“Biorrefinerías utilizando Microalgas, Plantas y Aguas Residuales”*

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**Prólogo Número Especial:**  
**“Biorrefinerías utilizando Microalgas,**  
**Plantas y Aguas Residuales”**  
**Curso en línea**

La Sociedad Latinoamericana de Biotecnología Ambiental y Algal (SOLABIAA) organizó de manera conjunta con el Instituto de Ecología (INECOL) y la International Society for Environmental Biotechnology (ISEB) el Curso virtual “*Biorrefinerías Utilizando Microalgas, Plantas y Aguas Residuales*” del 28 de Junio al 1 de Julio de este año.

Los profesores participantes son de amplio y reconocido prestigio y representan Instituciones de México (INECOL, UAM-I y UNAM), de España (Universidad de Almería, Universidad de Politécnica de Cataluña y Universidad de Valladolid) y de Italia (Universidad de Florencia y Consejo Nacional de Investigación).

Este Número Especial de RELBAA (Vol. 12, Núm. 2) compila varios artículos cortos que resumen la parte medular de las presentaciones de los Profesores invitados. El propósito es proporcionar información de fácil acceso y que puede ser citada, por todos aquellos asistentes virtuales al curso.

Los organizadores del Curso están muy satisfechos por el gran número de personas registradas (578), las cuales provienen de múltiples países de la Región Latinoamericana. Este tópico es de gran relevancia actualmente, dado que representa una de las opciones de mitigación del cambio climático dentro del concepto de Bioeconomía Circular. De esta forma, estamos contribuyendo a la difusión del conocimiento entre el ambiente académico, profesional, empresarial y gubernamental de una manera amplia y efectiva.

**Special Issue Editorial:**  
**“Biorefineries Using Microalgae,**  
**Plants and Wastewater - Online**  
**Training Course”**

The Latin American Society of Environmental and Algal Biotechnology (SOLABIAA), the Institute of Ecology (INECOL-Mexico) and the International Society for Environmental Biotechnology (ISEB) have organized jointly the Course online “*Biorefineries using microalgae, plants and wastewater*” held from June 28<sup>th</sup> to July 1<sup>st</sup>, 2021.

The invited Professors are well known in their respective fields and represent multiple academic organizations in Mexico (INECOL, National Autonomous University of Mexico, and Autonomous Metropolitan University), Spain (University of Almeria, Polytechnic University of Catalonia, and University of Valladolid), and Italy (University of Florence and National Research Council).

This Special Issue presents short communications written by the invited Professors in which a review of the core items of their presentation in the course is summarized. The purpose is to provide open access information that can be formally cited providing the proper credit to the information online.

The Organizing Committee is very satisfied with the outcome of the Course, not only due to the large number of attendees (578), but also due to the large diversity of countries of the Latin American Region that participated. The topic of the course is quite relevant currently since it represents one of the options for global warming mitigation within the Circular Bioeconomy concept. In this way, we are contributing in an effective and wide manner to the dissemination of knowledge among the academic, professional, entrepreneurial, and governmental sectors.

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**Dra. Eugenia J. Olguín**

=~Editor en Jefe~=

*Revista Latinoamericana de Biotecnología Ambiental y Algal*

*Short communication*

**Photosynthesis basic principles to optimize growth of microalgae cultures outdoors**

[Fotosíntesis: Principios básicos para la optimización del crecimiento en cultivos de microalgas en condiciones exteriores]

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**Abstract**

Microalgae can play an important role in modern bioeconomy since they can be used as source of some important building blocks such as amino acids, polyunsaturated fatty acids, pigments, vitamins, and antioxidants. To date, the number of species being cultured on a large scale for commercial purposes is still small, the most used being *Arthrospira platensis* (Spirulina) and *Chlorella* spp., produced mainly for use as nutritional supplements, and *Dunaliella* and *Haematococcus* as source of carotenoids.

The production of sufficient amounts of biomass is a prerequisite for meeting large-scale demand and to reach economic viability. To date, in industrial scale microalgal production systems, light conversion efficiency ranges between 1-2% on solar basis, far short of the theoretical maximum of about 10%, owing to energy loss at all the stages of the process. Table 1 shows a summary of the expected energy losses of total incident solar radiation during the biomass production process.

**Resumen**

Las microalgas pueden desempeñar un papel importante en la bioeconomía moderna, ya que pueden utilizarse como fuente de algunos componentes básicos importantes, como aminoácidos, ácidos grasos poliinsaturados, pigmentos, vitaminas y antioxidantes. A la fecha, el número de especies que se cultivan a gran escala con fines comerciales es todavía pequeño, siendo las más utilizadas *Arthrospira platensis* (Spirulina) y *Chlorella* spp., producidas principalmente para su uso como suplementos nutricionales, y *Dunaliella* y *Haematococcus* como fuente de carotenoides.

La producción de cantidades suficientes de biomasa es un requisito previo para satisfacer la demanda a gran escala y alcanzar la viabilidad económica. A la fecha, en los sistemas de producción de microalgas a escala industrial, la eficiencia de conversión de la luz oscila entre el 1-2% en base solar, muy lejos del máximo teórico de alrededor del 10%, debido a la pérdida de energía en todas las etapas del proceso. La Tabla 1 muestra un resumen de las pérdidas energéticas previstas de la radiación solar incidente total durante el proceso de producción de biomasa.

**Table 1.** Summary of expected the energy losses of total incident solar radiation energy in outdoor microalgal cultures.

Process	Energy radiation losses (%)	Remaining energy (%)
Total solar radiation	-	100
Reflection/scattering	10	90
Radiation outside PAR	55	41
Loss of useful absorbed PAR energy at 680 nm (PSII) and 700 nm (PSI) due to non-photochemical processes	20	32.8
Conversion energy to biomass	71.3	9.4
Photosynthesis saturation and photoinhibition	80	1.88
Cell maintenance in cultures subjected to diurnal cycle	10	1.7
Actual light conversion efficiency under solar light		1.7

It is estimated that about 10% of the photosynthetically active radiation is reflected by the cultures. Microalgae, when grown under high light, also synthesize some protective pigments (xanthophyll cycle pigments, in green algae) that dissipate excess light as heat (Masojidek *et al.*, 1999). This photosynthetically inactive light absorption, to the extent it occurs, further lowers photosynthetic conversion efficiency.

Furthermore, photons above 700 nm and below 400 nm are not utilized by microalgae pigments (as well as by higher plants), and thus about 55% of incident solar light is unavailable to drive photosynthesis. The sum of losses by reflection and more importantly the amount of light out of the photosynthetically active radiation (PAR) range, reduces the available light for photosynthesis to about 41%.

The energy required to drive a charge separation event in PSII is approximately 176 KJ/mol (i.e., equal to the energy of a 680-nm wavelength photon), and 171 KJ/mol (i.e., the energy content of a photon

at 700 nm) for PSI. If we assume that the mean energy content of photons in the 400-700 nm range is about 218 KJ/mol, then the loss of energy between absorption and charge-separation in the two photosystems will be approximately:

$$\{[218-(171+176)/2]/218\} \times 100;$$

this means that approximately 20.4% of the incident solar energy is irretrievably lost as heat in the process, because of the relaxation of higher excited states of chlorophyll to the first excited singlet state (Zhu *et al.*, 2008). For light conversion to biomass, considering that 1 mol of hexose yields 2808 KJ mol<sup>-1</sup>, and that a minimum of 9.4 mol of quanta are required to release 1 mole of O<sub>2</sub>,

$$(2808 \text{ KJ mol}^{-1})/(173.5 \text{ KJ mol}^{-1} \times 6 (9.4 \text{ mol quanta})) \times 100 = 28.7 \%$$

(i.e. an energy loss of 71.3%),

then consequently the theoretical maximum light conversion efficiency for biomass production is about 9.4% of solar light. The calculated value of the light conversion efficiency can significantly change according to the biomass composition.

For example, biomass rich in carbohydrates there is a good agreement between theoretical and real quantum requirement, while for biomass rich in lipids or in proteins, the quantum requirement can increase by a factor of 2 (up to 24 photons/CO<sub>2</sub>) (Wilhelm and Torsten, 2011). On the other hand, the theoretical light conversion efficiency (LCE) for H<sub>2</sub> production, attainable by direct bio-photolysis, is about 13.4% of incident solar light. This theoretical maximum conversion efficiency is significantly higher than the theoretical limit for biomass or biodiesel production, but lower than present commercial single-junction (single photosystem) silicon solar cell modules, which is typically 18± 2% and photo-electrochemical water-splitting devices 15% (Green *et al.*, 2010).

These differences are only apparent and are explained by the fact that the efficiency of the process depends on the number of steps necessary to produce a certain compound (*i.e.*, the more steps required in the biomass case, the lower the efficiency of the process). For example, the annual averaged efficiency for solar water splitting by PV-driven electrolysis can drop to 10–11%, if the cascade of energy loss to produce H<sub>2</sub> is considered.

Measurements of the effective quantum yield of PSII using chlorophyll fluorescence, carried out at midday in summer usually shows a strong reduction indicating that up to 90% of the light energy is lost via non photochemical process, mainly heat. This drops the light conversion efficiency usually attainable in large scale to less than 2%. Finally, although at much lower extent, the night biomass loss occurring during the night must be considered, involving dissipation of energy through the respiration usually at the expenses of carbohydrates (or other stored products) synthesized during the light

period (Torzillo *et al.*, 1991). Bearing this information in mind, it is possible to estimate the amount and of biomass attainable in a precise location with known light energy available, provided that neither technological aspects (such as mixing, cell concentration), nor environmental constraints (such as temperature, pH, O<sub>2</sub>) are limiting.

For example, with an average mean solar energy of 18 MJ m<sup>-2</sup> day<sup>-1</sup>, and a cultivation period of 210 days, with a light conversion efficiency of 1.7%, the energy content of biomass being 20 KJ g<sup>-1</sup>, the corresponding biomass yield will be about 32 t ha<sup>-1</sup> year<sup>-1</sup>. The corresponding mean yield per square meter of reactor will be about 15 g m<sup>-2</sup> day<sup>-1</sup> (mean over the cultivation period of 210 days). Yet, if the theoretical efficiency could be reached, then the mean biomass per square meter would raise to about 83 g m<sup>-2</sup> day<sup>-1</sup>.

Unfortunately, neither with laboratory cultures nor outdoor ones, an efficiency of 9.4% has ever been attained. Continuous cultures of *Synechocystis* reached an efficiency of 12.5% on PAR, corresponding to 5.6% on solar basis (Touloupakis *et al.*, 2015). It must be pointed out that the first calculations of photosynthetic efficiency coming from laboratory experiments where microalgae were usually exposed to light irradiance within the PAR gave results that must not be confused with those obtained in sunlight (*i.e.*, full light spectra) which are 55% lower.

As can be argued from Table 1, the greatest energy losses are due to the conversion of solar energy into biomass (about 71%) and to light saturation of photosynthesis (80%). Microalgae, like C4 plants, usually have a well-functioning xanthophyll cycle which is necessary for the development of the non-photochemical quenching (NPQ) mechanism and can efficiently dissipate excess of light (Demmig-Adams, *et al.*,

2014; Masojidek *et al.*, 1999; Masojidek *et al.*, 2004).

Microalgae – unlike higher plants in which the amplitude of NPQ is proportional to the light intensity at which they are exposed, strongly upregulate their ability to switch on NPQ even under moderate light irradiance, and this causes a remarkable reduction in the light conversion efficiency (Bonente *et al.*, 2012), and in the ability to dissipate photons absorbed by the light-harvesting complexes under excess light. Obviously, while little can be done to improve the light conversion into biomass, a strong enhancement of yield could be attained if the problem of light saturation could be reduced.

To attenuate the effects of this physical constraint that actually acts as a strong drawback in algal biotechnology, some strategies have been proposed: 1) fast mixing in order to induce rapid light/dark cycles within the culture depth of dense cultures; 2) use of an optimal concentration; and more recently, 3) use of PBR designs in which it is possible to dilute light over a larger surface of the culture (Wijffels and Barbosa, 2010); and 4) use of organisms with small antenna size.

All these strategies aim at improving light conversion efficiency by enhancing the number of cells having access to light and reducing as much as possible the time the cells spend in the dark. Therefore, the optimization of the reactor design cannot exclude an appropriate fluid dynamics study.

## Conclusions

A better understand of the mechanisms that regulate light utilization/dissipation may shed light on the potential ways of optimizing productivity and product quality. However, these studies are made complicate by the fact that outdoors very often

environmental factors act in synergism between them. Therefore, pure laboratory study, on commercial microalgal species, although very important, must be considered carefully and always confirmed outdoors. On the other hand, in order to better understand the physiological basis of stress phenomena occurring outdoors, it is necessary to return to the laboratory where the effect of environmental factors can be studied separately, under well definite conditions. The critical factor which limits the productivity of the cultures is the low efficiency of light conversion. Indeed, although photosynthesis has been optimized over three billion years of evolution, it remains inefficient at converting solar energy into chemical energy and biomass. Microalgae with truncated antenna size may substantially increase the biomass productivity. This approach represents a synthetic variation of the natural photo adaptive- mechanism of microalgae in which pigments re-organize in response to high light. Unfortunately, mutants generated by random UV or chemical mutagenesis are likely to induce multiple mutations, and among them an increased respiration rate of the cells, which reduces the benefit of the reduced light absorption of the truncated antenna size cells. Therefore, in these studies, an important parameter that need to be addressed, other than the lower chlorophyll per cell and reduced PSII antenna size, is the photosynthesis to respiration ratio which should not significantly affected.

The progress in algal biotechnology could be strongly accelerated if basic research on microalgae were carried out taking into account the new necessities pointed out by applied research, and vice versa: in other words, biologists should understand more about bioengineering and engineers should understand more about biology.

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## References

- Bonente, G., Pippa, S., Castellano, S., Bassi, R., Ballottari, M. 2012. Acclimation of *Chlamydomonas reinhardtii* to different growth irradiances. *J. Biol. Chem.* 287: 5833-5847.
- Demmig-Adams, B., Gyozo, G., Adams, W., Govindjee. 2014. Non-photochemical quenching and energy dissipation in plants, algae and cyanobacteria. *Advances in Photosynthesis and Respiration Book Series*, Vol. 40. Springer Science+Business Media.
- Green, M.A., Emery, K., Hishikawa, Y., Warta, W. 2010. Solar cell efficiency tables (version 35) *Prog. Photovolt. Res. Appl.* 18: 144-150.
- Masojídek, J., Kopecký, J., Koblížek, M., Torzillo, G. 2004. The xanthophyll cycle in green algae (Chlorophyta): its role in the photosynthetic apparatus, *Plant Biol. (Stuttg)* 6: 342-349.
- Masojídek, J., Torzillo, G., Koblížek, M., Kopecký, J., Bernardini, P., Sacchi, A., Komenda, J. 1999. Photoadaptation of two members of the Chlorophyta (*Scenedesmus* and *Chlorella*) in laboratory and outdoor cultures: Changes of chlorophyll fluorescence quenching and the xanthophyll cycle. *Planta* 209: 126-135.
- Torzillo, G., Sacchi, A., Materassi, R., Richmond, A. 1991. Effect of temperature on yield and night biomass loss in *Spirulina platensis* grown outdoors in tubular photobioreactors. *J. Appl. Phycol.* 3: 103-109.
- Touloupakis, E., Cicchi, B., Torzillo, G. 2015. A bioenergetic assessment of photosynthetic growth of *Synechocystis* sp. PCC 6803 in continuous cultures. *Biotechnol. Biofuels* 8: 133-144.
- Wilhelm, C., Torsten J. 2011. From photons to biomass and biofuels: Evaluation of different strategies for the improvement of algal biotechnology based on comparative energy balances. *Appl. Microbiol. Biotechnol.* 92: 909-919.
- Wijffels, R., Barbosa, M.J. 2010. An outlook on microalgal Biofuels. *Science* 329: 796-799.
- Zhu X.G., Long, S.P., Ort, D.R. 2008. What is the maximum efficiency with which photosynthesis can convert energy into biomass? *Curr. Opinion Biotechnol.* 19: 153-159.

*Short communication*

## Aspectos Genéticos de Microalgas [Genetic Aspects of Microalgae]

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### Resumen

Desde hace décadas las microalgas son foco de estudio en todo el mundo, aunque en los últimos años han cobrado un gran interés, en particular para diversas aplicaciones bajo una perspectiva bio-tecnológica. Como consecuencia de su gran dispersión filogenética, ofrecen bio-productos complementarios a los de las plantas terrestres, además de contar con una mayor facilidad de manipulación genética. Sin embargo, son muchas las especies aún desconocidas. En la actualidad, se observa un interés cada vez mayor por la explotación de las microalgas ya sean de agua dulce o marinas como plataformas de expresión emergentes para la producción de proteínas terapéuticas recombinantes (humanas y animales) y de enzimas industriales, así como para modificar vías metabólicas, por ejemplo, biosíntesis de hidrocarburos para la generación de biocombustibles, pigmentos antioxidantes y ácidos grasos poliinsaturados. Por esta razón, las herramientas de genética molecular para la manipulación de las microalgas ha despertado un interés mundial. La biología sintética parece ser una buena estrategia para convertir las microalgas en verdaderas biofábricas para generar productos de gran valor. Más aún, con el uso de la ingeniería genética en microalgas podría hacer frente a la malnutrición e incluso incidir en el cambio climático.

### Abstract

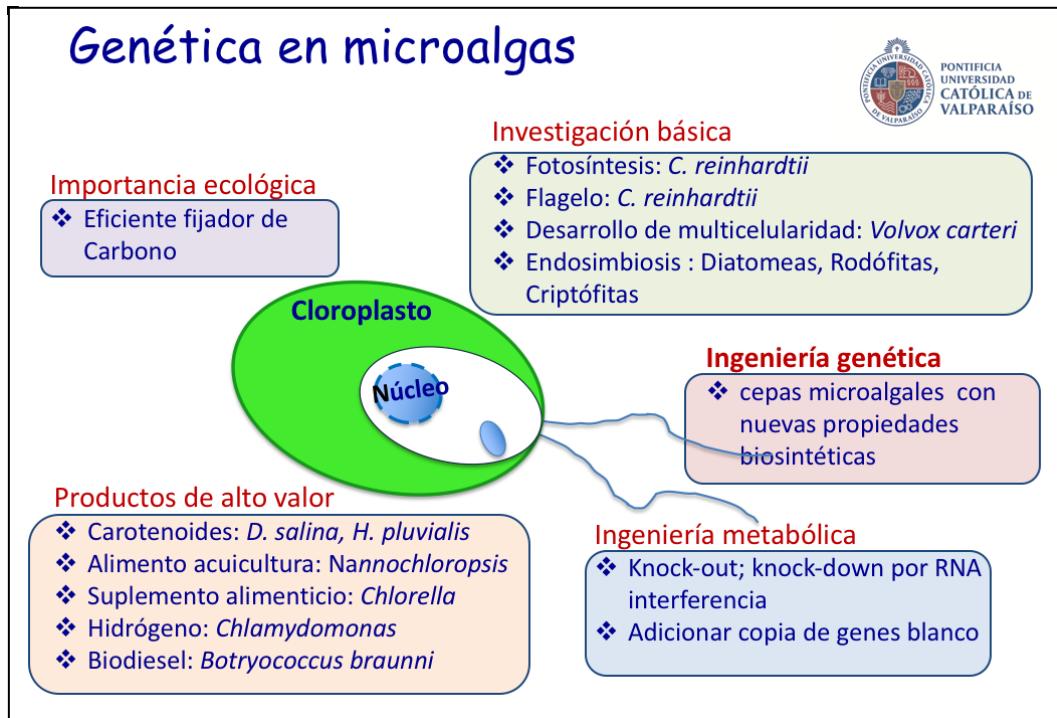
Microalgae have been studied worldwide for decades, although during the last couple of years they have gathered great interest under a biotechnological perspective. As a consequence of their large phylogenetic spread, they offer complementary bioproducts compared to land plants, together with greater ease of genetic manipulation. Nevertheless, many species are still unknown. Nowadays, an ever-increasing interest in the exploitation of either freshwater or marine microalgae are being considered as emerging expression platforms for recombinant therapeutic proteins (human and animal) and industrial enzymes production, as well as for modifying hydrocarbons biosynthesis for biofuels applications, antioxidant pigments, and polyunsaturated fatty acids. Hence, molecular genetic tools for microalgae manipulation have attracted global interest. Synthetic biology appears to be a good strategy to turn microalgae into real bio-factories for generating high-valuable products. Furthermore, microalgae genetic engineering could be useful in addressing malnutrition and even have an impact on climate change.

En este curso se revisarán los avances realizados en cuanto a las herramientas genéticas moleculares para la ingeniería genética del genoma de las microalgas con el fin de utilizarlas como potenciales sistemas de expresión. La investigación en ingeniería genética de microalgas comenzó en 1988 con la transformación del cloroplasto de *Chlamydomonas reinhardtii*. No obstante, el gran número de especies de microalgas conocidas, la ingeniería genética se ha limitado sólo a algunas de ellas, principalmente a los organismos modelo y a las microalgas que tienen importancia comercial. Cabe destacar que este escenario ha cambiado en los últimos años con la disponibilidad de genomas y transcriptomas de calidad junto a proteomas y metabolomas que han permitido la identificación de potenciales blancos para la manipulación biotecnológica de un número cada vez mayor de microalgas.

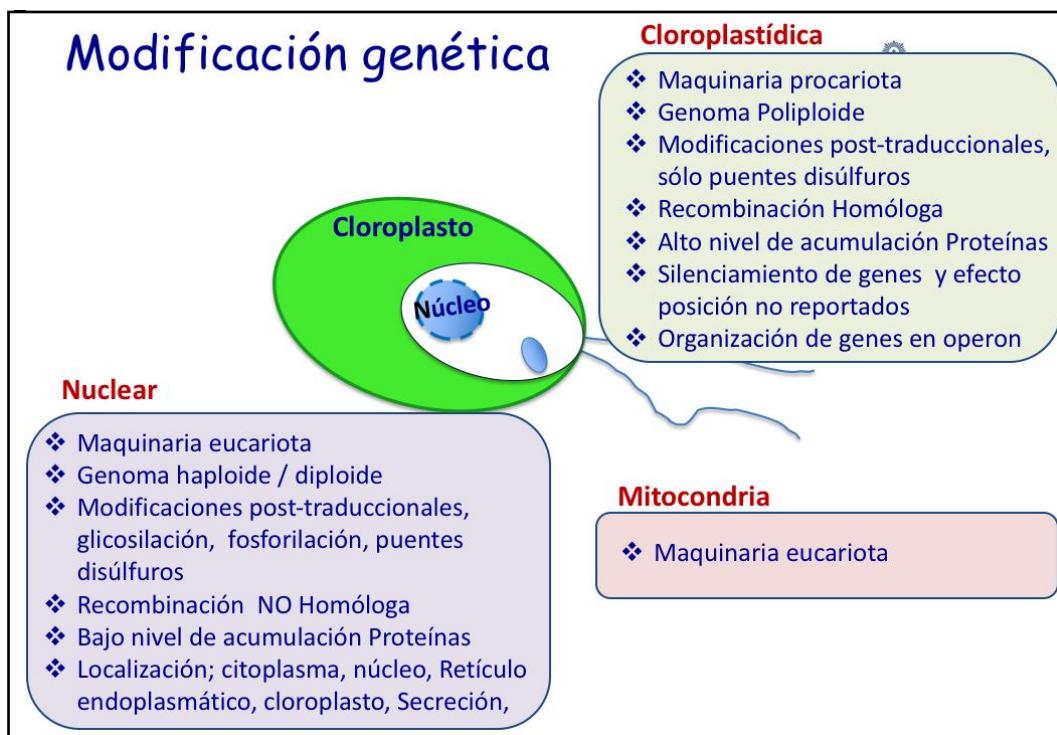
Los métodos de rutina para la manipulación genética de las microalgas son bien conocidos. Las microalgas ofrecen dos grandes alternativas de transformación, la nuclear y la cloroplastídica. La transformación del cloroplasto tiene características únicas por sobre la transformación nuclear, la más importante de ellas se debe a que los transgenes se integran específicamente en los genomas del plastoma mediante recombinación homóloga recíproca dirigida a secuencias no codificantes. Teniendo en cuenta que los promotores y las regiones reguladoras (UTR, sigla del inglés *untranslated regions*) son fundamentales para conducir altos niveles de transcripción de los transgenes, mediando a su vez la estabilidad y la acumulación de los ARNm. Cabe considerar además, que las microalgas presentan un fuerte sesgo de codones, definido por la redundancia inherente al código genético, lo que es también crucial para el logro de un alto nivel de expresión de proteínas heterólogas.

This course will review the progress regarding the generation of molecular genetic tools for genetic engineering the microalgal genome as potential expression systems. The timeline of microalgae genetic engineering research began in 1988 with the *Chlamydomonas reinhardtii* chloroplast transformation. Nonetheless, the great number of known microalgae species, genetic engineering has been limited only to a handful of them mainly to model organisms and to microalgae that have commercial significance. It is worth noting that this scenario has changed over the last years with the availability of high-quality genomes and transcriptomes along with proteomes and metabolomes which will allow the identification of potential targets for the biotechnological manipulation of an increasing number of microalgae

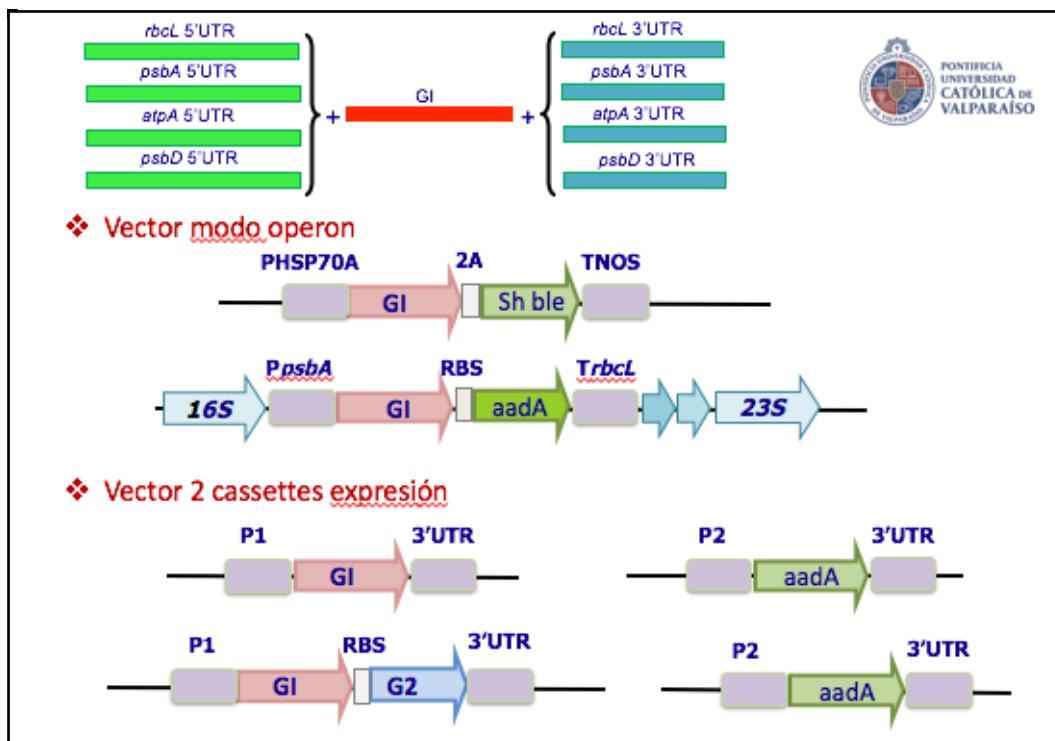
Routine methods for genetic manipulation of microalgae are well known. Microalgae offer two major transformation alternatives, nuclear and chloroplast transformation. Chloroplast transformation has unique features over nuclear transformation, the most important of which is that transgenes are specifically integrated into the plastome genomes through homologous recombination targeting non-coding sequences. Taking into consideration that promoters and regulatory regions (Untranslated regions, UTRs) are pivotal to drive high-level transcription of transgenes mediating mRNA stability and accumulation. In addition, microalgae exhibit strong codon bias, defined by the inherent redundancy of the genetic code which is also quite crucial for achieving high-level heterologous protein expression.



**Figura 1.** Aspectos a considerar para el estudio genético en microalgas.



**Figura 2.** Modificación genética en microalgas:  
Transformación Nuclear v/s Transformación Cloroplastídica.



**Figura 3.** Modalidades de diseño para vectores de expresión en microalgas.

En este contexto, los retos a los que nos enfrentamos hoy en día son avanzar en nuestra comprensión de la biología de las microalgas junto a la adaptación y mejora de las herramientas genéticas y los métodos de transformación existentes para ser usados exitosamente en la ingeniería genética microalgal con diversos fines biotecnológicos.

En conclusión, las herramientas de ingeniería genética para la modificación genética y metabólica de las microalgas, ya sea para producir proteínas recombinantes o para aumentar la producción de compuestos de alto valor como los ácidos grasos poliinsaturados, los pigmentos y los antioxidantes, darían entonces lugar a bioproductos asequibles y de alta calidad que ayudarían a reducir los costos de dichos productos.

In this context, the challenges we face today are to advance our understanding of microalgae biology and to adapt and improve genetic tools and existing transformation methods for microalgal genetic engineering for diverse biotechnological purposes.

In conclusion, the genetic and metabolic engineering tools for the modification of algal genome, either to produce recombinant proteins or to increase the production of valuable compounds such as polyunsaturated fatty acids, pigments, and antioxidants, would result in affordable and high-quality bioproducts that would help reduce the cost of such products.

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## Referencias

- Kumar, G., Shekh, A., Jakhu, S., Sharma, Y., Kapoor, R., Sharma, T.R. 2020. Bioengineering of microalgae: Recent advances, perspectives, and regulatory challenges for industrial application. *Front. Bioeng. Biotechnol.* 8; Article № 914.
- Naduthodi, M.I.S., Claassens, N. J., D'Adamo, S., van der Oost, J., Barbosa, M.J. 2021. Synthetic biology approaches to enhance microalgal productivity. *Trend. Biotechnol. Article in press.* Feb 2021. DOI: <https://doi.org/10.1016/j.tibtech.2020.12.010>
- Sproles, A.E., Fields, J.F., Smalley, T.N., Le, C.H., Badary, A., Mayfield, S.P. 2021. Recent advancements in the genetic engineering of microalgae. *Algal Res.* 53; Article № 102158.

*Short communication*

## Problemática de las Aguas Residuales

[Wastewater: General Aspects of its Problematic Issues]

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### Resumen

La biorrefinería de algas y plantas es un proceso de economía circular sustentable para producir biocombustibles y productos químicos de valor agregado por lo que se abordan los problemas y oportunidades de utilizar aguas residuales como insumo pues sus componentes son importantes y recuperables. El objetivo es provechar los componentes para cultivar algas y plantas junto con la producción de agua de mejor calidad y no el de exclusivamente producir agua tratada eliminando sus contaminantes. Se revisan las características de las aguas residuales y las operaciones unitarias necesarias para un aprovechamiento de los componentes para producir combustibles y sustancias químicas con la ayuda de algas y plantas. Se introducen los conceptos de descentralización y segregación de los efluentes para su procesamiento e integración a una economía circular sustentable y se repasan los distintos usos del agua tratada.

### Abstract

A biorefinery of algae and plants is a sustainable process of circular economy to produce biofuels and value-added chemical products, thus the problems and opportunities of using wastewater as an input is addressed. as the wastewater

components are important and recoverable. The objective is to take advantage of the components to grow algae and plants together with producing better quality water and not to exclusively to produce treated water by eliminating its pollutants. The wastewater characteristics and the necessary unit operations to prepare it for the production of fuels and chemical substances with the help of algae and plants are reviewed. The concepts of decentralization and segregation of effluents for their processing and integration into a sustainable circular economy are introduced and the different uses of treated water are reviewed.

### Introducción

Hay dos conceptos y, por lo tanto, procesos diferentes: si las aguas residuales se tratan con un proceso al final del tubo para producir agua más limpia para usos específicos o si se procesan para obtener subproductos como energía, alimentos, productos químicos finos utilizando procesos basados en la naturaleza. En el manejo de la economía que es el manejo de los bienes que tenemos en el planeta es conveniente aplicar los conceptos de **sustentabilidad** y **economía circular**.

**Sustentabilidad o sostenibilidad** viene de la palabra francesa *soutenir* que significa sostener o apoyar. Se habla de un acuífero sustentable o sostenible cuando no se le extrae más agua de la que recarga, o en silvicultura cuando no se cosecha más madera que la que se produce por el crecimiento de los árboles. En general, es respetar en la naturaleza la capacidad de auto-regenerarse o, no explotarla más rápido de lo que se puede regenerar.

La sustentabilidad depende de la población, del uso de los recursos y de las tecnologías, pero es un concepto tan importante que también incluye a la democracia, la justicia y la libertad.

**Economía circular.** Siendo la tierra un sistema cerrado se desprende que la economía y el medio ambiente deben estar en equilibrio. Entonces la economía circular se puede conceptualizar como una economía para describir estrategias industriales para la prevención de residuos, la creación de empleos locales, eficiencia en el uso de recursos y desmaterialización de la economía industrial (no vender la propiedad sino el uso de los productos) de tal manera que los beneficios o las utilidades industriales no dependieran de externalizar costos y riesgos (al ambiente o a la sociedad incluidos los trabajadores). Es en resumen una economía industrial intencionalmente diseñada para ser regeneradora. Sistema regenerativo en el que la entrada de recursos y el desperdicio, las emisiones y las fugas de energía se minimizan al reducir la

velocidad, cerrar y estrechar los circuitos de material y energía (Geissdoerfer *et al.*, 2017).

El manejo de agua en una economía circular implica tener una gran cantidad de agua en procesos de tratamiento y recirculación para solamente extraer el agua necesaria para compensar las pérdidas. Este manejo circular permitiría la recuperación de las sustancias contaminantes del agua como insumos de otros procesos como la **biorrefinería de algas y plantas** que es un proceso de economía circular sustentable para producir biocombustibles y productos químicos de valor agregado (Olguín, 2012). El agua residual que requiere como materia prima y su tratamiento debe ser estudiada para diseñar el proceso, los productos y el destino del agua.

Esto es clave porque las aguas residuales en flujo y composición son muy variables a lo largo del día, de la semana, de una estación y del año. Esto aplica tanto para las aguas industriales como para las domésticas y urbanas por lo que pone en riesgo la operación estable de una refinería. Por eso es importante caracterizar el agua residual (Cuadro 1) que se va a usar en la biorrefinería.

**Cuadro 1.** Características de las aguas residuales (AR)

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• **Clasificación**

- AR domésticas (cantidad generada por habitante, variaciones diarias , estacionales)
- AR industriales (variaciones del flujo por actividad, por campaña de producción)
- Escurrimientos agrícolas (contaminación difusa, drenes,)
- AR urbanas (combinación de ARd, ARI, escurrimientos urbanos)
- Necesidad y oportunidades de segregación de efluentes

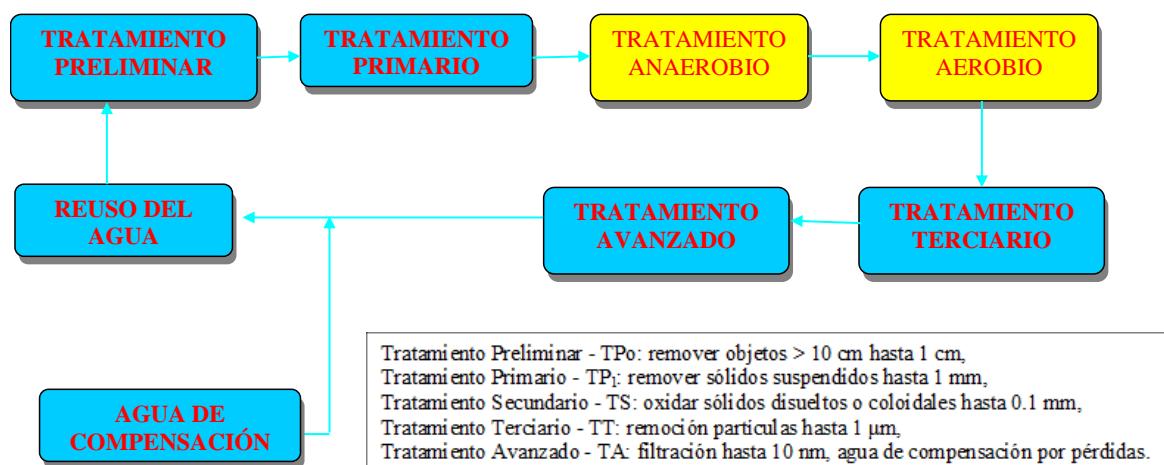
- Industriales
- Domésticos
- **Características físicas**
  - Sólidos suspendidos, microorganismos, estética, sedimentos
  - Sólidos disueltos, Conductividad (sales),
  - Temperatura, pH
  - Color, Olor
- **Características químicas**
  - Composición
    - Sustancias orgánicas medición por DQO
      - Degradables (medición por DBO)
      - No biodegradables (DBO/DQO)
    - Minerales: metales, nutrientes (P, N)
    - pH, alcalinidad
    - Relaciones C/N/P

Estas características las podemos relacionar para calcular la cantidad de un componente particular que se quiere eliminar o usar para una transformación.

Así una concentración ( $C_i$ ) que es la cantidad de un soluto (o material suspendido por unidad de volumen) al multiplicarla por el flujo ( $F$ ) nos da la velocidad mísica o carga de ese componente: ( $m_i = F \times C_i$ ) en donde el subíndice  $i$  nos indica el componente. Existen estimaciones de la cantidad de agua residual que puede generar

la población y los distintos tipos de industria (concentración, flujo, carga orgánica, población, equivalentes de población) con lo que se puede predecir la cantidad de agua que se puede producir y la que se puede transformar en productos útiles (von Sperling, 2007).

El tren de tratamiento de aguas residuales en economía circular (Fig. 1) para mantener la mayor cantidad de agua en reutilización permitiendo ahorrar y almacenar agua limpia para consumo humano.



**Figura 1.** Tren de tratamiento de aguas residuales en economía circular.

Para hacer más homogéneas las aguas que se van a tratar lo mejor es segregarlas. En la industria se hace; el agua de proceso tiene un tren de diferente al agua de enfriamiento y diferentes ambos al agua de vapor y al agua de los sanitarios. Lo mismo puede hacerse con las aguas domésticas que se pueden separar en aguas amarillas de alto contenido de urea, aguas grises y aguas cafés con baja y alta concentración de materia orgánica, respectivamente. Usando muebles ahorradores de agua la primera corresponde a 1.5 L/hab.d, las segundas son alrededor de 80 L/hab.d y la últimas 1.5 L/hab.d. (Fig. 2).

La urbanización contemporánea que se realiza en unidades habitacionales verticales u horizontales permite este tipo de tratamiento descentralizado y segregado de las aguas residuales pero también puede ser utilizado en comunidades donde se dificulta la construcción de drenajes.

Además de obtener energía y productos químicos el tratamiento descentralizado de aguas segregadas permite:

- Usar el agua residual *in situ*.
- Reducir longitud y diámetro de drenajes.
- Mayor control del flujo y crecimiento de la PTAR.

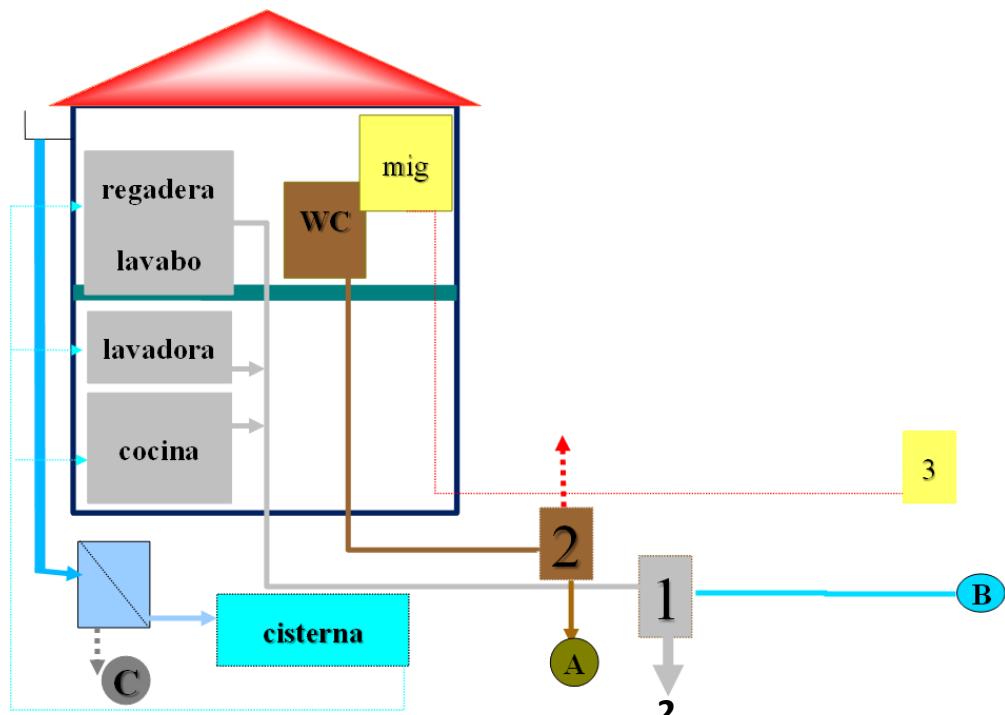


Figura 2. Segregación de efluentes domésticos en conjuntos habitacionales.

### Usos del agua

Dependiendo del grado de tratamiento y almacenamiento, los usos del agua son varios (Cuadro 2). Dentro de una economía

circular siempre se debe tener al agua en constante recirculación y tratamiento para poder almacenar agua para el consumo humano.

**Cuadro 2. Usos del agua con diferentes grados de tratamiento**

- 
- **Doméstica e Industrial** (para alimentos, medicamentos)
  - **Industrial en contacto con producto**
  - **Industrial para servicios**
  - **Irrigación** (hortícolas y otro tipo (árboles o granos))
  - **Pecuaria**
  - **Vida acuática**
  - **Acuicultura** (animal, planta)
  - **Recreación** (con contacto humano, sin contacto humano)
  - **Generación de energía** (vapor o hidroeléctricas)
  - **Transportación**
- 

## Conclusión

El tratamiento y reuso de aguas residuales es una práctica de la economía circular sustentable. En una biorrefinería el agua residual es un importante insumo por lo que debe caracterizarse bien para saber cómo aprovechar sus componentes y darl el uso adecuado al agua obtenida.

Es importante usar aguas segregadas para mantener una uniformidad en la materia prima, tener un mejor control de los componentes y procesos sustentables de manejo de agua.

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## Referencias

- Geissdoerfer, M., Savaget P., Bocken N.M.P., Hultink. E.J. 2017. The Circular Economy – A New Sustainability Paradigm? *J. Cleaner Prod.* 143: 757-768.
- Monroy, O. 2013. Manejo sustentable del agua en México. *Revista Digital Universitaria [en línea]* 14(10); Artículo electrónico.  
URL:  
<http://www.revista.unam.mx/vol.14/num10/art37/index.html>
- Olgún, E. 2012. Dual purpose microalgae–bacteria-based systems that treat wastewater and produce biodiesel and chemical products within a Biorefinery. *Biotechnol. Adv.* 30(5): 1031-1046.
- von Sperling, M. 2007. Wastewater characteristics, treatment and disposal. *Biological Wastewater Treatment Series Vol. 1. IWA Publishing*. 292 Pp. ISBN: 1843391619.

*Short communication*

**General Aspects of Phytoremediation**  
**[Aspectos Generales de la Fitorremediación]**

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**Abstract**

Phytoremediation is a set of viable technologies that uses selected plants and their microorganisms to degrade, extract, contain, or immobilize contaminants from soil and water. It is based on natural processes that can be effective at a variety of sites and on numerous contaminants. Processes are carried out by selected plant species that possess the genetic potential to remove, degrade, metabolize, or immobilize a wide range of contaminants.

**Resumen**

La fitorremediación es un conjunto de tecnologías viables que utilizan plantas seleccionadas y sus microorganismos para degradar, extraer, contener o inmovilizar contaminantes del suelo y el agua. Se basa en procesos naturales que pueden ser eficaces en una variedad de sitios y en numerosos contaminantes. Los procesos son llevados a cabo por especies vegetales seleccionadas que poseen el potencial genético para eliminar, degradar, metabolizar o inmovilizar una amplia gama de contaminantes.

**Constructed Wetlands**

Among other phytoremediation processes, constructed wetlands (CWs) are a consolidated eco-friendly, nature-based technology that has gained popularity for decentralized wastewater treatment in small communities and rural areas of both industrialized and less developed countries (Álvarez *et al.*, 2017, Machado *et al.*, 2017).

They are low-cost treatment systems, in terms of maintenance and operation, and have proven to efficiently remove organic matter, nitrogen (N) and pathogenic microorganisms from wastewater (Wu *et al.*, 2016, Castillo-Valenzuela *et al.*, 2017, Ilyas and Masih, 2017). During the last decades, this technology has greatly been developed, using, and evaluating different CW designs and operational modes. CWs have been successfully used for the treatment of various types of wastewaters such as textile waste, dairy waste, industrial waste, piggery waste, tannery waste, petrochemical waste, municipal waste (Parde *et al.*, 2021).

Constructed wetlands can be classified into free water surface flow constructed wetland (FW) CW and sub-surface flow constructed wetland (SSF) CW. Subsurface flow is divided, according to the flow direction, into vertical flow (VF) CW, horizontal flow (HF) CW, hybrid systems combining VF and HF CW are also used (Vymazal and Kröpfelová, 2008).

In constructed wetlands, several pollutants removal mechanisms act together, including physical, chemical, and biological processes. The physical process involves sedimentation of the suspended particles present in the wastewater, which leads to the removal of pollutants.

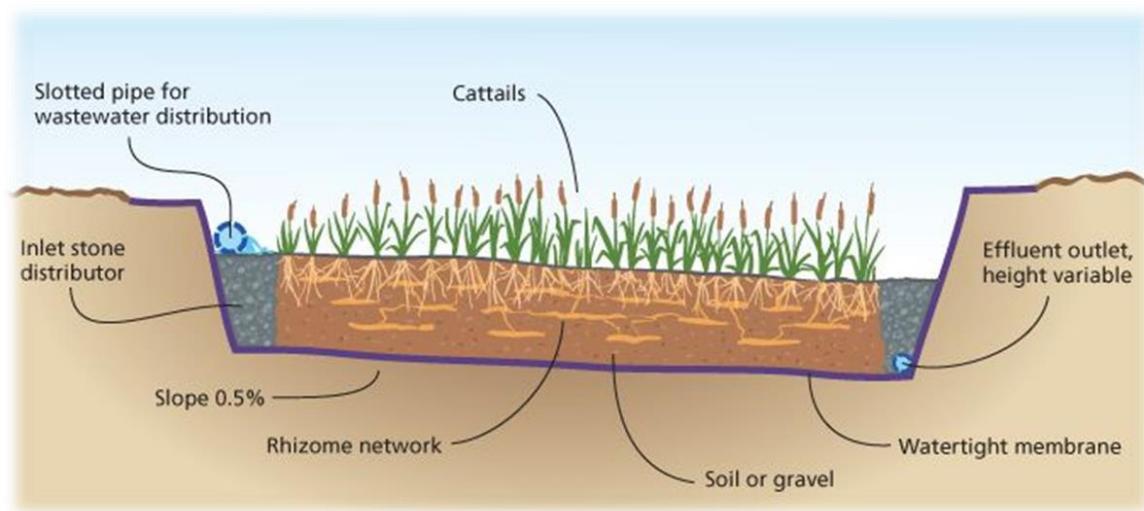
Sedimentation process not only reduce the organic matter but also eliminates the coliform bacteria (Dotro *et al.*, 2015). On the one hand, constructed wetland media is helpful for the accumulation of organic matter, phosphorus, sulphate, arsenate and removal of pathogens (Stanković, 2017). On the other hand, macrophytes used in the wetland provide huge surface area for the microbial growth, which helps in stabilizing the organic matter (Brix, 1994). It is important to take into account that constructed wetland performance depends upon the various factors like temperature, applied hydraulic load, vegetation, media, etc (Tilak *et al.*, 2016).

Sludge treatment wetlands, also known as sludge drying reed beds, are rather new

sludge treatment (ST) systems based on constructed wetlands. Sludge treatment wetlands have been used in Europe for sludge dewatering and stabilisation since the late 1980s. The largest experience comes from Denmark, where there are over 140 full-scale systems currently in operation (Nielsen, 2008).

Other systems implemented in northern Europe are located in Poland, Belgium, and the United Kingdom. In the Mediterranean region, full-scale systems are operating in Italy, France, and Spain (Uggetti *et al.*, 2010). Sludges from different sources have been treated in wetlands, including anaerobic digesters, aerobic digesters, conventional activated sludge systems, extended aeration systems, septic tanks, and Imhoff tanks.

Sludge is directly spread into the basins from the aeration tanks or is previously homogenised in a buffer tank before its discharge into the wetlands. From this tank, the sludge is diverted into one of the beds, following a semi-continuous regime. The number of beds may vary, according to the treatment capacity of the facility, between 3 and 18, which correspond to 400 and 123,000 population equivalent (PE), respectively. The result of sludge dewatering and stabilisation processes is a final product that is suitable for land application, either directly or after additional composting.

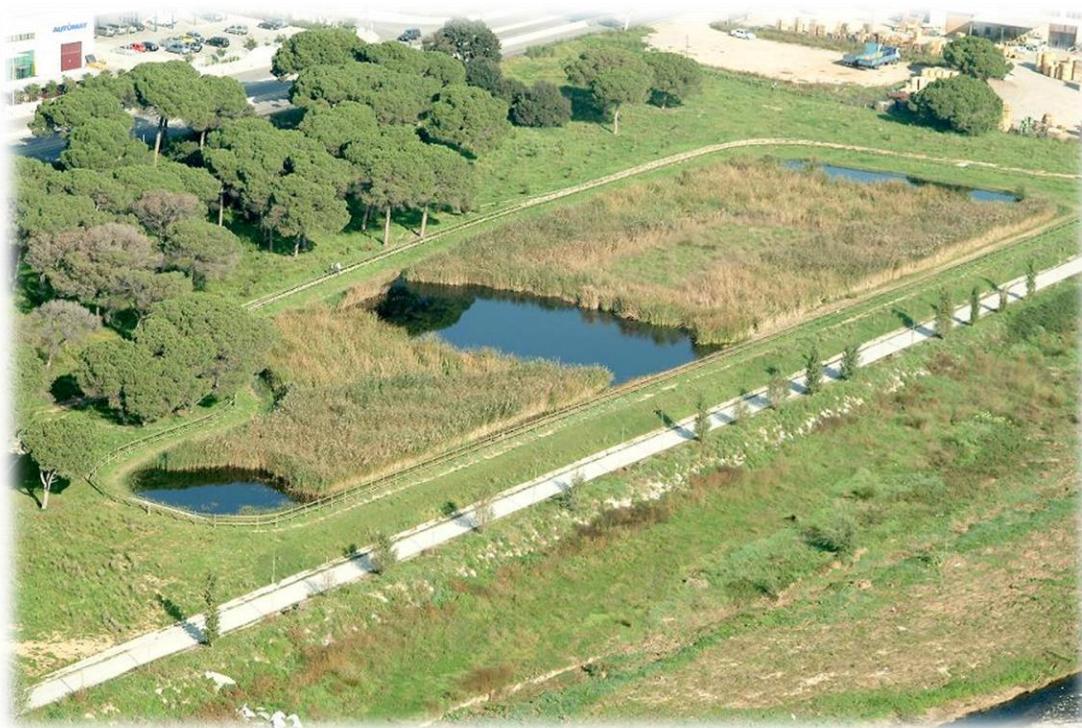


Grismar and Shepherd, 2011

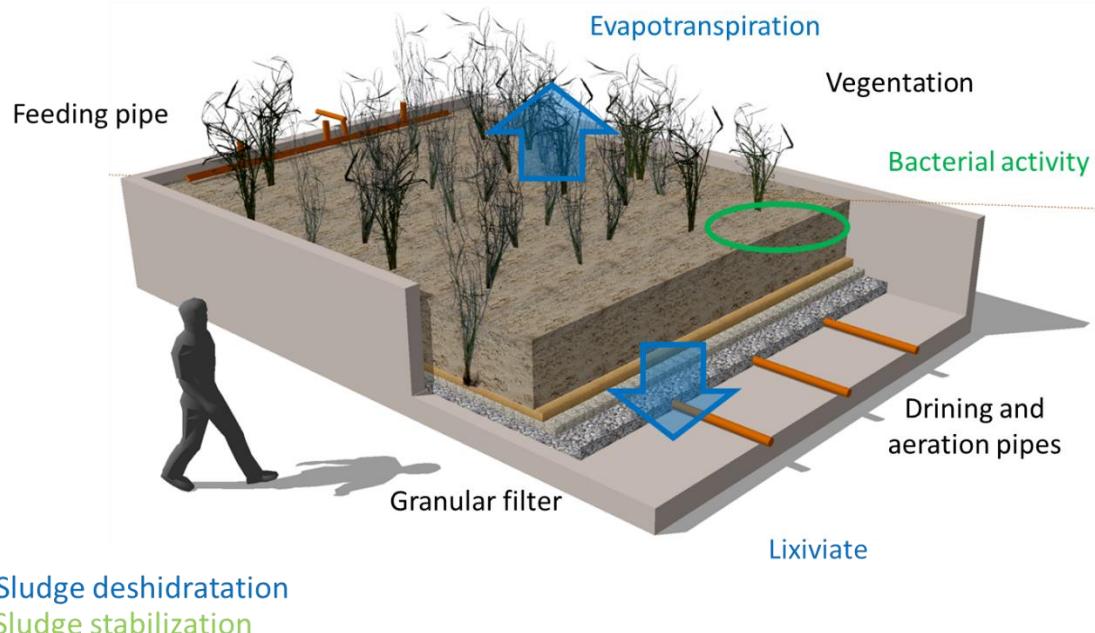
**Figure 1.** Scheme of a Constructed Wetland.



**Figure 2.** Aspect of a Vertical Flow Constructed Wetland located in Toulouse (France).



**Figure 3.** Constructed Wetland for ecosystem restoration located in Granoller, Barcelona (Spain).



**Figure 4.** Scheme of Constructed Wetlands for sludge treatment.

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## References

- Álvarez, J.A., Ávila, C., Otter, P., Kilian, R., Istenič, D., Rolletschek, M., Molle, P., Khalil, N., Ameršek, I., Mishra, V.K., Jorgensen, C., Garfi, A., Carvalho, P. Brix, H., Arias, C.A. 2017. Constructed wetlands and solar-driven disinfection technologies for sustainable wastewater treatment and reclamation in rural India: SWINGS project. *Water Sci. Technol.* 76: 1474-1489.
- Brix, H. 1994. Functions of macrophytes in constructed wetlands. *Water Sci. Technol.* 29(4): 71-78.
- Castillo-Valenzuela, J., Martínez-Guerra, E., Gude, V.G. 2017. Wetlands for wastewater treatment *Water Environ. Res.* 89: 1163-1205.
- Dotro, G., Fort, R.P., Barak, J., Jones, M., Vale, P., Jefferson, B. 2015. Long-term performance of constructed wetlands with chemical dosing for phosphorus removal. In: Vymazal, J. (Ed.) "The role of natural and constructed wetlands in nutrient cycling and retention on the landscape". Springer. Pp. 273-292.
- Ilyas, H., Masih, I. 2017. The performance of the intensified constructed wetlands for organic matter and nitrogen removal: A review. *J. Environ. Manage.* 198: 372-383.
- Machado, A.I., Beretta, M., Fragoso, R., Duarte, E. 2017. Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil. *J. Environ. Manage.* 187: 560-570.
- Nielsen, S. 2008. Sludge treatment and drying reed bed systems 20 years of experience. In: *Proceedings of the European Conference on Sludge Management*, Liège, Belgium.
- Parde, D., Patwa, A., Shukla, A., Vijay, R., Killedar, D.J., Kumar, R. 2021. A review of constructed wetland on type, treatment and technology of wastewater. *Environ. Technol. Innov.* 21; Article № 101261.
- Stanković, D. 2017. Constructed wetlands for wastewater treatment. *Gradevinar*, 69(08): 639-652.
- Uggetti, E., Ferrer, I., Llorens, E., García, J. 2010. Sludge treatment wetlands: A review on the state of the art. *Biores. Technol.* 101(9): 2905-2912.
- Tilak, A.S., Wani, S.P., Patil, M.D., Datta, A. 2016. Evaluating wastewater treatment efficiency of two field scale subsurface flow constructed wetlands. *Current Sci.* 110(9): 1764-1772.
- Vymazal, J., Kröpfelová, L. 2008. Wastewater treatment in constructed wetlands with horizontal sub-surface flow. Vol. 14. Springer Science + Business Media, 566 Pp.
- Wu, S., Carvalho, P.N., Müller, J.A., Manoj, V.R., Dong, R. 2016. Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators. *Sci. Total Environ.* 541: 8-22.

*Short communication*

**Procesos basados en microalgas: Tratamiento de agua y obtención de biocombustibles gaseosos**

[**Microalgae-based processes: Water treatment and obtention of gaseous biofuels**]

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El tratamiento aerobio de aguas residuales mediante lodos activados es costoso debido a los requerimientos asociados con el suministro de oxígeno mediante aireación, además de las grandes cantidades de lodo generadas en el tratamiento y los problemas que requiere su disposición. En este contexto, el tratamiento mediante un sistema microalga-bacteria apunta a ser un proceso más sustentable en términos de gasto energético y recuperación de nutrientes, teniendo en cuenta que el único requerimiento energético asociado es el mezclado y las múltiples ventajas de su biomasa por su alto contenido energético en forma de lípidos, proteínas y carbohidratos (Van Den Hende *et al.*, 2014; Muñoz y González-Fernandez, 2017). Para que lo anterior sea posible, se requieren métodos de fácil separación de la biomasa del reactor biológico (Quijano *et al.*, 2017).

El crecimiento de microalgas se puede llevar a cabo en lagunas algales de alta tasa o HRAP (*High Rate Algal Ponds*, por sus siglas en inglés; Fig. 1).

En estos sistemas se establece una relación mutualista en donde las microalgas generan oxígeno fotosintéticamente. El oxígeno generado es entonces utilizado por las bacterias para degradar la materia orgánica y producir bióxido de carbono. A su vez, las microalgas utilizan el bióxido de carbono para reproducirse. De esta manera, la materia orgánica, el nitrógeno y el fósforo, son removidos del agua residual y acumulados por las microalgas que los utilizan para su crecimiento.

Por sí solas, las microalgas crecen de forma muy dispersa por lo que son difícilmente sedimentables y causarán problemas para su separación del agua tratada. La formación de agregados de microalgas-bacterias son una alternativa para evitar los problemas de baja sedimentabilidad (Arcila y Buitrón, 2016; Quijano *et al.*, 2017). Para inducir la formación de agregados microalga-bacteria y alcanzar alta sedimentabilidad se han evaluado diferentes factores como tiempo de retención hidráulico y tiempo de retención de sólidos.

Por otro lado, se han generado de estructuras granulares en sistemas operados en sistemas en lote, que es otra estrategia para promover una alta recuperación de biomasa. Sin embargo, se ha observado que la irradiación solar tiene un impacto negativo en la estabilidad granular puesto que tienden a decrecer los exopolímeros y la remoción de nutrientes (Arcila y Buitrón, 2017).

Se ha observado que el tiempo de retención hidráulica influye en la morfología de los agregados obtenidos y aparentemente en las especies de algas presentes en los agregados (Arcila y Buitrón, 2016). También se observó que la producción de sustancias poliméricas extracelulares ligadas juega un papel muy importante en la formación de las estructuras granulares. La irradiancia solar tiene un efecto significativo en el desempeño del reactor y el desarrollo de agregados compuestos principalmente por microalgas verdes, diatomeas, cianobacterias filamentosas y hongos (Arcila y Buitrón, 2017).

La pared celular de algunas especies de microalgas es bastante resistente, lo que dificulta el proceso de digestión pues la materia orgánica retenida en el citoplasma no se encuentra disponible a los microorganismos anaerobios para la producción de biocombustibles gaseosos (Carrillo Reyes *et al.*, 2016a). De modo que para incrementar la digestibilidad de la microalga por los microorganismos es necesario llevar a cabo un pretratamiento, el cual puede ser termoquímico (Passos *et al.*, 2013), mecánico (Cadeña *et al.*, 2017) o biológico (Barragán-Trinidad *et al.*, 2017). Los pretratamientos biológicos han despertado gran interés debido a que se pueden realizar en condiciones suaves de reacción, no hay formación de compuestos inhibitorios y baja demanda energética (factor crucial para el escalamiento). En este sentido se ha evaluado la hidrólisis utilizando microrganismos ruminales para la producción de hidrógeno y metano (Carrillo Reyes *et al.*, 2016b; Cea-Barcia *et al.*, 2018; Barragán-Trinidad *et al.*, 2020)



**Figura 1.** Laguna algal de alta tasa (HRAP) utilizada para el tratamiento de aguas residuales.

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## Referencias

- Arcila, J.S., Buitrón, G. 2016. Microalgae-bacteria aggregates: effect of the hydraulic retention time on the municipal wastewater treatment, biomass settleability and methane potential. *J. Chem. Technol. Biotechnol.* 91: 2862-2870.
- Arcila, J. S., Buitrón, G. 2017. Influence of solar irradiance levels on the formation of microalgae-bacteria aggregates for municipal wastewater treatment. *Algal Res.* 27: 190-197.
- Barragán-Trinidad, M., Carrillo-Reyes, J., Buitrón, G. 2017. Hydrolysis of microalgal biomass using ruminal microorganisms as a pretreatment to increase methane recovery. *Bioresour. Technol.* 244: 100-107.
- Barragán-Trinidad, M., Buitrón, G. 2020. Hydrogen and methane production from microalgal biomass hydrolyzed in a discontinuous reactor inoculated with ruminal microorganisms. *Biomass Bioenergy.* 143; Article № 105825.
- Cardeña, R., Moreno, G., Bakonyi, P., Buitrón, G. 2017. Enhancement of methane production from various microalgae cultures via novel ozonation pretreatment. *Chem. Eng. J.* 307(1): 948-954.
- Carrillo-Reyes, J., Barragán-Trinidad, M., Buitrón, G. (2016a). Biological pretreatments of microalgal biomass for gaseous biofuel production and the potential use of rumen microorganisms: A review. *Algal Res.* 18: 341-351.
- Carrillo-Reyes, J., Buitrón, G. 2016b. Biohydrogen and methane production via a two-step process using an acid pretreated native microalgae consortium. *Bioresour. Technol.* 221: 324-330.
- Cea-Barcia, G., Pérez, J., Buitrón, G. (2018) Co-digestion of microalga-bacteria biomass with papaya waste for methane production. *Water Sci. Technol.* 78 (1): 125-131.
- Muñoz, R., Gonzalez-Fernandez, C. (Eds.) 2017. "Microalgae-based biofuels and bioproducts - From feedstock cultivation to end-products". Woodhead Publishing Series in Energy. 560 Pp.
- Passos, F., Solé, M., García, J., Ferrer, I., 2013. Biogas production from microalgae grown in wastewater: Effect of microwave pretreatment. *Appl. Energy.* 108: 168-175.
- Quijano, G., Arcila, J. S., Buitrón, G. 2017. Microalgal-bacterial aggregates: Applications and perspectives for wastewater treatment. *Biotechnol. Adv.* 35(6): 772-781.
- Van Den Hende, S., Carre, E., Cocaud, E., Beelen, V., Boon, N., Vervaeren, H. 2014. Treatment of industrial wastewaters by microalgal bacterial flocs in sequencing batch reactors. *Bioresour. Technol.* 161: 245-254.

*Short communication*

## Biorefineries of energy products [Biorrefinerías de productos energéticos]

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### Abstract

Algal biotechnology represents a very versatile platform for environmental applications, contributing to heavy metal removal, organic matter stabilization and nutrient valorization from wastewaters, carbon dioxide capture and sustainable biofuel production. Biodiesel, biohydrogen, biogas and bioethanol constitute the main energy vectors obtained from microalgae. This short communication reviews the potential of microalgae for biofuel production.

### Resumen

La biotecnología de las algas representa una plataforma muy versátil para las aplicaciones medioambientales, contribuyendo a la eliminación de metales pesados, la estabilización de la materia orgánica y la valorización de los nutrientes de las aguas residuales, la captura de dióxido de carbono y la producción sostenible de biocombustibles. El biodiésel, el biohidrógeno, el biogás y el bioetanol constituyen los principales vectores energéticos obtenidos a partir de las microalgas. Esta breve comunicación revisa el potencial de las microalgas para la producción de biocombustibles.

### Microalgal Biorefineries

Under nutrient starvation and excess of CO<sub>2</sub> and light, some microalgae can store lipids (10- 80% on a dry weight basis) as energy source, which represents a valuable feedstock for the production of biodiesel (with an average calorific value of 35.8 Kg g<sup>-1</sup>). Microalgal triglycerides need to be extracted from the cell to be further transesterified catalytically using methanol, with the concomitant production of biodiesel and glycerol (as a byproduct). The interest in microalgae biodiesel boomed in 2007 in a global context of rising oil prices and concern about climate change. Unfortunately, the high cost of microalgae cultivation (4-10 € kg<sup>-1</sup>) jeopardized the widespread production of algal biodiesel (Peng *et al.*, 2020).

Biohydrogen is the gaseous fuel with the highest calorific value (138 KJ g<sup>-1</sup>) and the lowest CO<sub>2</sub> footprint, although entails technical problems during storage, high explosion risks and low production rates in microalgal photobioreactors. Biohydrogen can be produced via direct biophotolysis or indirect biophotolysis, but the maximum reported production rates are typically lower (0.07-0.36 mmol H<sub>2</sub> L<sup>-1</sup> h<sup>-1</sup>) than those achieved during dark fermentation of organic substrates (64-76 mmol H<sub>2</sub> L<sup>-1</sup> h<sup>-1</sup>) (Buitrón *et al.*, 2017).

Microalgae can be used as a feedstock for the production of methane via anaerobic digestion (55 KJ g CH<sub>4</sub><sup>-1</sup>), with the first studies dating back to 1950s in California using the algal biomass generated from domestic wastewater treatment (Golueke *et al.*, 1957). The methane productivity yields of microalgae typically range from 0.09 to 0.45 LCH<sub>4</sub> g VS<sup>-1</sup>, and depend on the microalgal species and growth conditions, which ultimately determine the Redox state and biodegradability of the carbon present in the biomass. The generation of biogas from residual algal biomass is conducted in anaerobic digesters engineered with internal gas or liquid recirculation, or mechanical agitation, in order to provide the required mixing between the algal substrate and the anaerobic microbial community. Substrates to inoculum ratios of 0.5 were shown optimal for the determination of the biochemical methane potential in batch tests, with ratios over 3 inducing inhibition of the anaerobic community (Alzate *et al.*, 2012).

The development of algal biorefineries for bioenergy production can entail an initial extraction of the algal lipid for biodiesel production, and the further digestion of the lipid-exhausted biomass. This lipid-free biomass supports similar methane yields but significantly faster kinetics due to the partial disruption of cell integrity during lipid extraction (Alzate *et al.*, 2014). On the other hand, the presence in the algal cell wall of recalcitrant compounds has been shown to typically hinder microalgae biodegradability, which requires the implementation of biomass pretreatments such as chemical, thermal, steam explosion, microwave, ultrasound, and enzymatic pretreatments.

Table 1 shows the main algal pretreatments along with their key operational parameters, enhancement potential and their pro and cons. Among the pretreatments reported in

literature, thermal and steam explosion pretreatments have shown the largest microalgal biodegradability enhancements, while ultrasound pretreatments typically require more energy than the chemical energy contained in the target biomass.

This biogas can be upgraded to biomethane in order to be used as a substitute of natural gas in natural gas grids or as a gas fuel in vehicles. Membrane-based separation is currently the commercial technology with the largest increases in market share in the past 10 years (WBA, 2019). Hence, membrane technology, which consists of the selective permeation of biogas pollutants such as CO<sub>2</sub> and H<sub>2</sub>S through membranes, is a competitive and attractive alternative to conventional upgrading technologies due to its decreasing energy consumption (brought about by the rapid advances in material science), simple and compact engineered modules and small footprint. Although the number of commercially operated plants is still limited, membrane technology is currently undergoing rapid development thanks to the use of new polymer materials with promising properties and enhanced performance and is set to play an increasingly important role in reducing environmental impact and cost of industrial biogas upgrading (Awe *et al.*, 2017).

Among biological biogas upgrading technologies, photosynthetic biogas purification with microalgae represents the only biotechnology capable of simultaneously removing CO<sub>2</sub> and H<sub>2</sub>S from biogas, while fixing the nutrients present in the digestate in the form of biomass. Photosynthetic biogas upgrading is based on the combined action of alkaliphilic microalgae and bacteria prior transfer of the main contaminants of biogas into the cultivation broth (CO<sub>2</sub>, H<sub>2</sub>S, NH<sub>3</sub>).

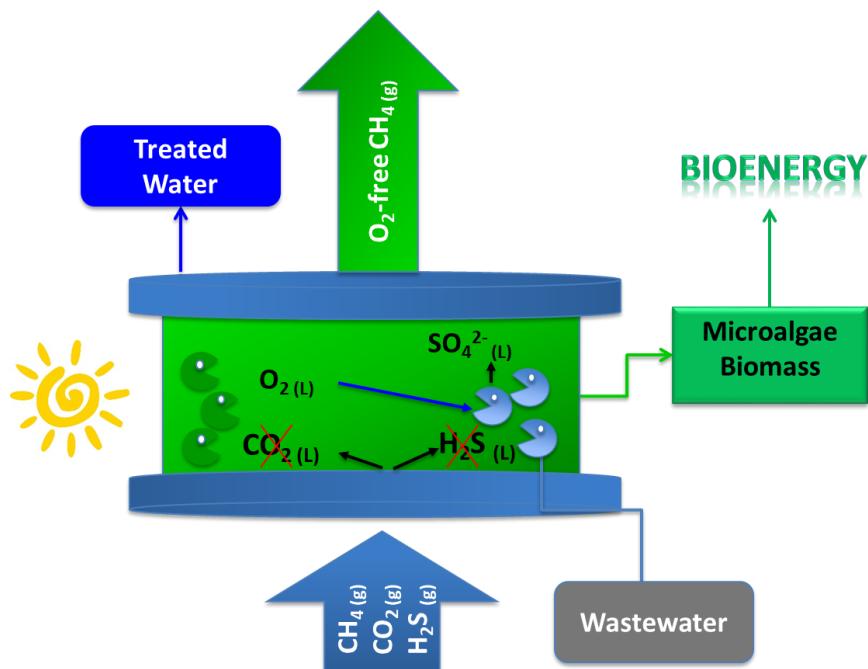
**Table 1.** Pre-treatments enhancing the anaerobic biodegradability of microalgae.

Pre-treatment	Operational parameters	Anaerobic biodegradability Enhancement	Advantages	Disadvantages
Thermal hydrolysis	Temperature; HRT	++	Lower energy demand; Easy scalability	High HRT
Steam explosion	Temperature; Pressure HRT	+++	Short HRT Easy scalability	High energy demand; High investment cost
Microwave	Power; HRT	++	Less risk of byproduct formation	High electricity demand; Easy scalability
Ultrasound	Energy input; HRT	+	Easy scalability	High electricity demand
Chemical (Acid/Alkaline)	Reagent dose; HRT	+	Low energy demand	Chemical contamination; Risk of formation of inhibitors; High operating cost
Enzymatic	Enzyme dose; HRT pH, temperature	+	Low energy demand	High operating cost, Need for sterile conditions

HRT- Hydraulic Retention Time.

Solar energy drives the photosynthetic assimilation of the CO<sub>2</sub> present in biogas into algal biomass, with the concomitant production of O<sub>2</sub> (~1.5-1.9 g O<sub>2</sub> g CO<sub>2</sub>fixed<sup>-1</sup>). This oxygen is used *in-situ* by chemolithotrophic bacteria to oxidize H<sub>2</sub>S to SO<sub>4</sub><sup>2-</sup>, and NH<sub>3</sub> to NO<sub>3</sub><sup>-</sup> (Figure 1). The process is typically carried out at high pH (Rodero *et al.*, 2020) in order to improve the mass transfer of the main biogas pollutants (i.e., CO<sub>2</sub> and H<sub>2</sub>S). The nutrients and water

required to support the growth of microalgae and bacteria can be obtained from the digestate produced in the anaerobic digester, which partially mitigates the eutrophication potential of these high-strength effluents. Methane concentrations over 95 % with CO<sub>2</sub> concentrations below 2% and a complete depletion of H<sub>2</sub>S have been recorded in pilot and demo scale photobioreactors using this technology (Marín *et al.*, 2021).



**Figure 1.** Fundamentals of photosynthetic biogas upgrading.

Bioethanol, with a calorific value of  $30 \text{ KJ g}^{-1}$ , can be obtained via fermentation of the sugars contained in microalgae. The carbohydrate content of microalgae, which can reach levels ranging from 16.4% to 60%, is extracted via cell disruption using enzymatic, chemical, thermal or supercritical extraction, and further fermented using fungi or yeast such as *Saccharomyces cerevisiae*, *Kluyveromyces fragilis*, *Torulaspora* and *Zymomonas mobilis* (Chen *et al.*, 2013). Ethanol concentrations of  $12\text{-}15 \text{ g L}^{-1}$  can be achieved when processing microalgae concentrations of  $50 \text{ g L}^{-1}$ .

Finally, it should be highlighted that the high costs of microalgae production, which directly impacts on the cost of biofuels, can be mitigated by using residual  $\text{CO}_2$  sources (such as industrial emissions) and wastewaters.

## Acknowledgments

The financial support from the Regional Government of Castilla y León, the EU-FEDER Programme (CLU 2017-09 and UIC 071) and the Spanish Ministry of Science and Innovation (IJC2018-037219-I and FJC2018-038402-I) are gratefully acknowledged.

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## References

- Alzate, M.E., Muñoz, R., Rogalla, F., Fdz-Polanco, F., Pérez-Elvira, S.I. 2012. Biochemical methane potential of microalgae: Influence of substrate to inoculum ratio, biomass concentration and pretreatment. *Bioresour. Technol.* 123: 488-494.
- Alzate, M.E., Muñoz, R., Rogalla, F., Fdz-Polanco, F., Perez-Elvira, S.I. 2014. Biochemical methane potential of microalgae after lipid extraction. *Chem. Eng. J.* 243: 405-410
- Awe, O.W., Zhao, Y., Nzhou, A., Minh, D.P., Lyczko, N. 2017. A review of biogas utilisation, purification and upgrading technologies. *Waste Biomass Valor.* 8(2): 267-283.
- Buitrón, G., Carrillo-Reyes, J., Morales, M., Faraloni, C., Torzillo, G. 2017. Biohydrogen production from microalgae. In: Muñoz, R. Gonzalez-Fernandez, C. (Eds.) "Microalgae-based biofuels and bioproducts - From feedstock cultivation to end-products". Woodhead Publishing Series in Energy. Pp. 209-234
- Chen, C.Y., Zhao, X.Q., Yen, H.W., Ho, S.H., Cheng, C.H., Lee, D.J., Bai, F.W., Chang, J.S. 2013. Microalgae-based carbohydrates for biofuel production. *Biochem. Eng. J.* 78: 1-10.
- Golueke, C., Oswald, W., Gotass, H. 1957. Anaerobic digestion of algae. *Appl. Microbiol.* 5(1): 47-55.
- Marin, D., Carmona-Martinez, A.A., Blanco, S., Lebrero, R., Muñoz, R. 2021. Innovative operational strategies in photosynthetic biogas upgrading in an outdoors pilot scale algal-bacterial photobioreactor. *Chemosphere* 264(1); Article № 128470.
- Passos, F., Mota, C., Donoso-Bravo, A., Astal, D., Jeison, D., Muñoz, R. 2018. Biofuels from microalgae – Biomethane. In: Jacob-Lopes, E., Queiroz-Zepka, L., Queiroz M.I. (Eds.) "Energy from Microalgae" Springer-Nature. Pp. 247-270.
- Peng, L., Fu, D., Chu, H., Wang, Z., Qi, H. 2020. Biofuel production from microalgae: A review. *Environ. Chem. Lett.* 18(2): 285-297.
- Rodero, M.R., Severi, C.A., Rocher-Rivas, R., Quijano, G., Muñoz, R. 2020. Long-term influence of high alkalinity on the performance of photosynthetic biogas upgrading. *Fuel* 281; Article № 118804.
- World Biogas Association, "Global Potential of Biogas," June 2019. [Online]. Available at URL: [http://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4\\_digital-Sept-2019.pdf](http://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4_digital-Sept-2019.pdf) [Accessed June 2021].

*Short communication*

## **Microalgae-Based Biorefineries Integrating Phytoremediation and Wastewater Treatment**

**[Biorrefinerías integrando Microalgas con Fitorremediación y Tratamiento de Aguas Residuales]**

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### **Abstract**

Biorefineries are currently recognized as a sound and environmentally friendly strategy to mitigate the global climate threat. Furthermore, they are now widening their capacity and high added value products are also produced from various types of biomasses. Microalgae-based biorefineries are now recognized as the most promising alternative compared to first and second generation biorefineries. Furthermore, there is a current trend for including the treatment of wastewater as a means of increasing their economic feasibility. On the other hand, the use of aquatic plants for phytoremediation and production of biofuels is also an active research field. However, there is scanty information about the integration of the biomass of microalgae, aquatic plants, and the use of wastewater within a biorefinery. In this short article, a review of the design and implementation of a biorefinery integrating microalgae, aquatic plants, and wastewater to produce biofuels and high-added value products is presented.

### **Resumen**

Las biorrefinerías están reconocidas actualmente como una estrategia ambientalmente amigable para mitigar la amenaza del cambio climático. Actualmente, el concepto incluye también la generación de productos de alto valor agregado a partir de varios tipos de biomasas. Las biorrefinerías basadas en microalgas se reconocen como la alternativa más prometedora en comparación con las biorrefinerías de primera y segunda generación. Además, existe una tendencia actual a incluir el tratamiento de las aguas residuales como medio para aumentar su viabilidad económica. Por otro lado, el uso de plantas acuáticas para la fitorremediación y la producción de biocombustibles es también un campo de investigación activo. Sin embargo, hay poca información sobre la integración de la biomasa de microalgas, plantas acuáticas y el uso de aguas residuales dentro de una biorrefinería. En este breve artículo se presenta una revisión del diseño e implementación de una biorrefinería que integra microalgas, plantas acuáticas y aguas residuales para la producción de biocombustibles y productos de alto valor agregado.

## Introduction

The most widely used “**Biorefinery**” definition is the one launched by the IEA (International Energy Agency) Bioenergy Task 42: “Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)” (IEA, 2014).

The feedstock for biorefineries can be classified into three main groups (Moncada *et al.*, 2014): the first generation uses crops; the second generation uses residues and non-edible crops while algae are considered as the third-generation feedstock. Furthermore, algae and especially wastewater-grown microalgae appears as the appropriate feedstock for feasible integrated double purpose systems for production of biodiesel and treatment of the wastewater within a biorefinery (Olguín, 2012).

However, it is clear currently that numerous technological and economic barriers must be overcome to increase the economic feasibility of microalgae-based biorefineries. The key issues to tackle have been identified by different research groups. For example, improvements in the harvesting system, algae farm construction, algae yield, and integrative end-life of the co-products, have been highlighted as key issues (Flesch *et al.*, 2013). Moreover, various reports have stressed the need to enlarge the number of value-added products from both, the microalgae and the oil-extracted microalgae biomass in order to increase the economic feasibility of the microalgae-based biodiesel (Brownbridge *et al.*,

2014). These authors have also stressed that the production costs depend mainly on factors in the following order: algae oil content > algae annual productivity > plant production capacity > carbon price increase rate > photobioreactor unit capital expenditure.

## Microalgae-based biorefinery design at INECOL

In this section, a brief description of the design and performance of a pilot-scale microalgae-based biorefinery integrating phytotechnologies and other wastewater treatment technologies to produce biofuels and high added value products within the circular economy concept is discussed. This biorefinery has been designed and built in the grounds of the Institute of Ecology (INECOL), located in the city of Xalapa, Veracruz, Mexico.

To increase the environmental feasibility, the critical resources such as water and nutrients for microalgae cultivation must be integrated into a 3-R policy (Reuse, Recover, and Recycle). Bearing this objective in mind, the use of phytofiltration to treat the water from an urban river polluted with domestic wastewater has been demonstrated as a feasible option (Robles-Pliego *et al.*, 2015) to recycle water and to recover nutrients to produce plant biomass. Furthermore, a 13,000 L phytofiltration lagoon using *Pistia stratiotes* for the treatment of a polluted river has been evaluated throughout various seasons (Fig. 1) and it has been demonstrated that with a short hydraulic retention time (7-14 days), the quality of the water improved significantly (Olguín *et al.*, 2017).



**Figure 1.** A phytofiltration lagoon (13,000 L) with *P. stratiotes* is the first module at INECOL's biorefinery.

The biomass of *P. stratiotes* needs to be harvested frequently and it is digested anaerobically for biogas production. A two-phase digestor has been used and it was demonstrated that a good productivity of volatile fatty acids (VFA) was obtained within the range of 1867-2207 mgCOD/L during the first stage (Hernández-García *et al.*, 2015).

Biohydrogen has been produced at a good yield using *P. stratiotes*. The biomass was first hydrolyzed with ruminal fluid, then it was subjected to a nitrogen-stripping process. Finally, photofermentation with *Rhodospseudomonas palustris* 42OL yielded a Biochemical Hydrogen Potential of 1224 mL/L (Cornelli *et al.*, 2017).

The treated water in the phytofiltration lagoon has been used for cultivation of various species of microalgae. A strategy of inducing lipid accumulation by nitrogen deficiency resulted in a very high lipid accumulation of 27.4 % d.w. by *Neochloris oleoabundans*, cultivated using

pig waste digestate (Olguín *et al.*, 2015a) and 38.5 % d.w. when it was cultivated using stillage's digestate (Olguín *et al.*, 2015b).

On the other hand, a strain of *Chlorococcum* sp. was isolated from a wastewater treatment plant and cultivated with pig waste digestates under uncontrolled conditions. In this case, the nitrogen deficiency resulted in accumulation of total carbohydrates in a high percentage (45% d.w.) after 24 days, showing the high potential of this strain for production of bioethanol (Montero *et al.*, 2018).

To increase the economic viability of the biorefinery at INECOL, production of phycocyanin (PC) from *Arthrospira maxima* in a two-phase process, using 2000 L raceways (Fig. 2), has been shown to release PC of high purity (3.7) in the category of reactive grade (García-López *et al.*, 2020).



**Figure 2.** Raceways with *A. maxima*.

## Conclusions

The integration of a microalgae-based biorefinery with a phytofiltration lagoon as a first module to treat polluted water from a river and to provide treated water for cultivation of microalgae using agricultural wastes (stillage and pig waste) digestates as source of nutrients has been shown to be a feasibly and novel design. Furthermore, the economic feasibility increased while producing also phycocyanin (reactive grade) from *A. maxima*.

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## References

- Brownbridge, G., Azadi, P., Smallbone, A., Bhave, A., Taylor, B., Kraft, M. 2014. The future viability of algae-derived biodiesel under economic and technical uncertainties. *Bioresour. Technol.* 151: 166-173.
- Corneli, E., Adessi, A., Olguín, E.J., Ragaglini, G., García-López, D.A., De Philippis, R. 2017. Biotransformation of water lettuce (*Pistia stratiotes*) to biohydrogen by *Rhodopseudomonas palustris*. *J. Appl. Microbiol.* 123(6): 1438-1446.
- Flesch, A., Beer, T., Campbell, P.K., Batten, D., Grant, T. 2013. Greenhouse gas balance and algae-based biodiesel. In: Borowitzka, M.A., Moheimani, N.R. (Eds.) "Algae for Biofuels and Energy- Developments in Applied Phycology". Vol. 5. Springer. Pp. 233-254.

- García-López, D.A., Olguín, E.J., González-Portela, R.E., Sánchez-Galván, G., De Philippis, R., Lovitt, R.W., Llewellyn, C.A., Fuentes-Grünewald, C., Parra, R. 2020. A novel two-phase bioprocess for the production of *Arthrospira (Spirulina) maxima* LJGR1 at pilot plant scale during different seasons and for phycocyanin induction under controlled conditions. *Bioresour. Technol.* 298; Article № 122548.
- Hernández-García, H., Olguín, E.J., Sánchez-Galván G., Monroy-Hermosillo O. 2015. Production of volatile fatty acids during the hydrolysis and acidogenesis of *Pistia stratiotes* using ruminal fluid. *Water Air Soil Pollut.* 226(9); Article № 317.
- International Energy Agency (IEA). 2014. IEA BIOENERGY Task42 BIOREFINING, In: van Ree, R. and van Zeeland, A., (Eds.) "Sustainable and Synergetic Processing of Biomass into Marketable Food & Feed Ingredients, Chemicals, Materials and Energy". IEA, Wageningen, The Netherlands. Available from URL: [http://www.ieabioenergy.com/wp-content/uploads/2014/09/IEA-Bioenergy-Task42-Biorefining-Brochure-SEP2014\\_LR.pdf](http://www.ieabioenergy.com/wp-content/uploads/2014/09/IEA-Bioenergy-Task42-Biorefining-Brochure-SEP2014_LR.pdf)
- Moncada, J., Tamayo, J.A., Cardona, C.A. 2014. Integrating first, second, and third generation biorefineries: Incorporating microalgae into the sugarcane biorefinery. *Chem. Eng. Sci.* 118: 126-140.
- Montero, E., Olguín, E.J., De Philippis, R., Reverchon, F. 2018. Mixotrophic cultivation of *Chlorococcum* sp. under non-controlled conditions using a digestate from pig manure within a biorefinery. *J. Appl. Phycol.* 30(5): 2847-2857.
- Olguín, E.J. 2012. Dual purpose microalgae-bacteria-based systems that treat wastewater and produce biodiesel and chemical products within a biorefinery. *Biotechnol. Adv.* 30: 1031-1046.
- Olguín, E.J., Dorantes, E., Castillo, O., Hernández-Landa, V.J. 2015a. Anaerobic digestates from vinasse promote growth and lipid enrichment in *Neochloris oleoabundans* cultures. *J. Appl. Phycol.* 27(5): 1813-1822.
- Olguín, E.J., Castillo, O.S., Mendoza, A., Tapia, K., González-Portela, R.E., Hernández, V.J. 2015b. Dual purpose system that treats anaerobic effluents from pig waste and produce *Neochloris oleoabundans* as lipid rich biomass. *New Biotechnol.* 32(3):387-395.
- Olguín, E.J., García-López, D.A., González-Portela, R.E., Sánchez-Galván, G. 2017. Year-round phytofiltration lagoon assessment using *Pistia stratiotes* within a pilot-plant scale biorefinery. *Sci Total Environ.* 592: 326-333.
- Robles-Pliego, M., Olguín, E.J., Hernández-Landa J., González-Portela, R.E., Sánchez-Galván, G., Cuervo-López F.M. 2015. Dual purpose system for the treatment of water from a polluted river and the production of *Pistia stratiotes* biomass within a biorefinery. *Clean Soil Air Water* 43(11): 1445-1558.



**CURSO Online:  
“BIORREFINERÍAS  
a partir de  
MICROALGAS y PLANTAS”  
SOLABIAA-INECOL 2021  
28 Junio – 1 Julio**



Lunes, 28 de Junio

10:00-10:15

Bienvenida al Curso por la Dra. Eugenia J. Olguín, Dra. Luddy Patricia Nieto y el Dr. Gabriel Acién

Hora	Profesor	Tópico
10:15-11:15	Giuseppe Torzillo	Photosynthesis basic principles to optimize growth of microalgae culture outdoors
11:15-12:15	Vitalia Henriquez	Aspectos genéticos de microalgas
12:15-13:15	Silvia Bolado	Ingeniería de Biorrefinerías / Fraccionamiento de biomasa algal

Martes, 29 de Junio

10:00-11:00	Oscar Monroy	Problemática de las Aguas Residuales
11:00-12:00	Enrica Uggeti	Aspectos generales de Fitorremediación
12:00-13:00	Germán Buitrón	Procesos basados en Microalgas

Miércoles, 30 de Junio

10:00-11:00	Gabriel Acién	Biorrefinerías de Productos Agrícolas
11:00-12:00	Raúl Muñoz	Biorrefinerías de Productos Energéticos
12:00-13:00	Roberto De Philippis	Productos de Alto Valor Agregado

Jueves, 1 de Julio

10:00-11:00	Eugenia J. Olguín	Biorrefinería con microalgas, plantas acuáticas y aguas residuales
11:00-13:00	Moderador: Prof. Roberto De Philippis	Mesa Redonda: “Major bottlenecks limiting the development of plant/algae based biorefineries”

Nota: Las horas son en tiempo de la Ciudad de México; revise la diferencia de horas en su localidad en: [https://time.is/es/Mexico\\_City](https://time.is/es/Mexico_City). Retransmisión en vivo vía Facebook Live: <https://www.facebook.com/Solabiaa-101486878828902>