Laboratório Nacional de Energia e Geologia, I. P.

Biotecnologia de microalgas: novas soluções para velhos desafios

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LABORATÓRIO NACIONAL DE ENERGIA E GEOLOGIA, I.P.-LNEG
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AMBIENTE E AÇÃO CLIMÁTICA

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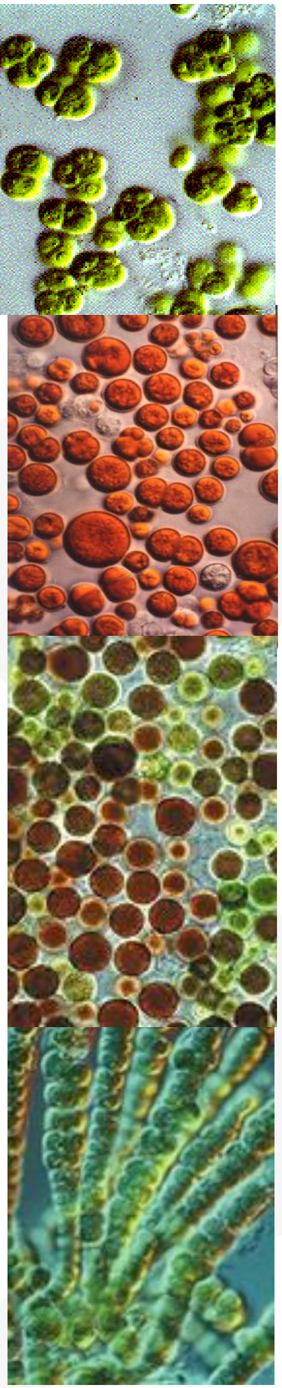


Foram identificadas mais de 30 000 espécies de microalgas até hoje

a biotecnologia de 50 espécies é conhecida

10-15 espécies são exploradas e comercializadas

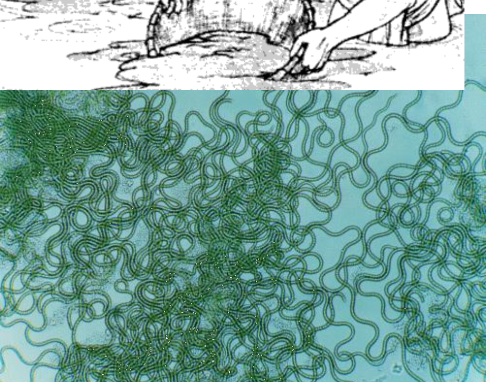
TCHAD, Africa

Spirulina

(*Arthrospira*)

platensis

MEXICO



Spirulina

(*Arthrospira*)

maxima

blooms – crescimento massivo e descontrolado de microalgas

anoxia – falta de O_2 e morte nos ecossistemas aquáticos

FOULING


TRÉVI
ALGICIDE
40%


BAQUACIL


ClearView
alga strike
Copper Algaecide

DETERIORAÇÃO DE MONUMENTOS

Siegwardskirche - Microsoft Internet Explorer

Address: http://english.denkmalschutz.de/wastun/treuhand/denkmal19_a.html

WHAT YOU CAN DO

DEUTSCHE STIFTUNG DENKMALSCHUTZ

Donations | Trustee foundations | Legacies | Local committees | HOME

Trustors Sought!

Precious frescos threatened by moisture

Very valuable and very much in danger: the Romanesque paintings in the Sigward Church in

The Sigward Church in Idensen, located to the west of Hanover, is a Romanesque church in its original form, a rarity seldom found in Germany. But after the initial enthusiasm, aroused above all by the radiant Romanesque ceiling paintings in the church's interior, the visitor soon becomes aware of a drone that recurs at regular intervals, a drone that comes from a ventilator system in the tower. If the visitor now takes a closer look around they soon see that some of the floor slabs have an alga-green patina and the plastered walls appear moist.

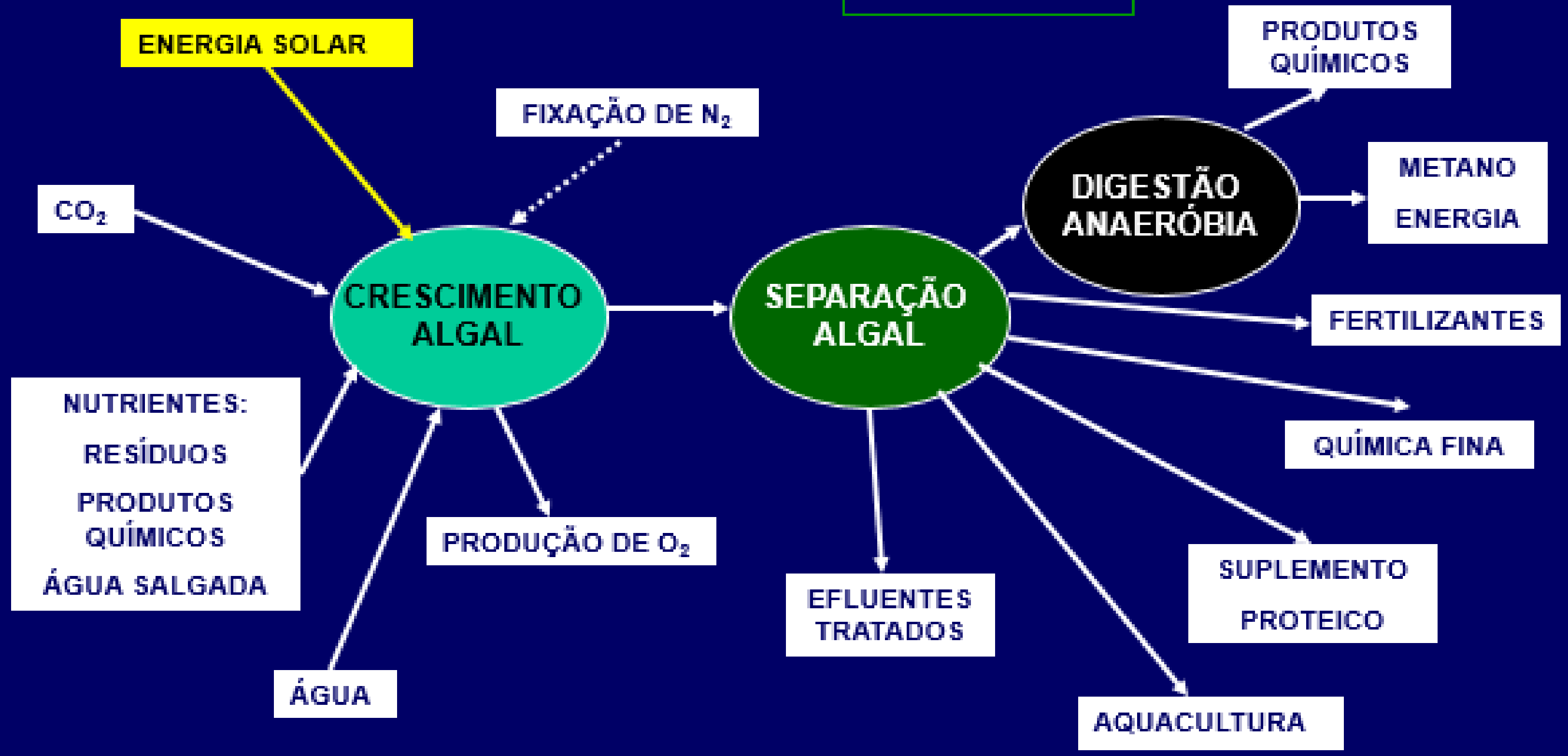
The latest restoration measures for draining the church were first completed at the beginning of the year, but the basic problem plaguing the old building could not

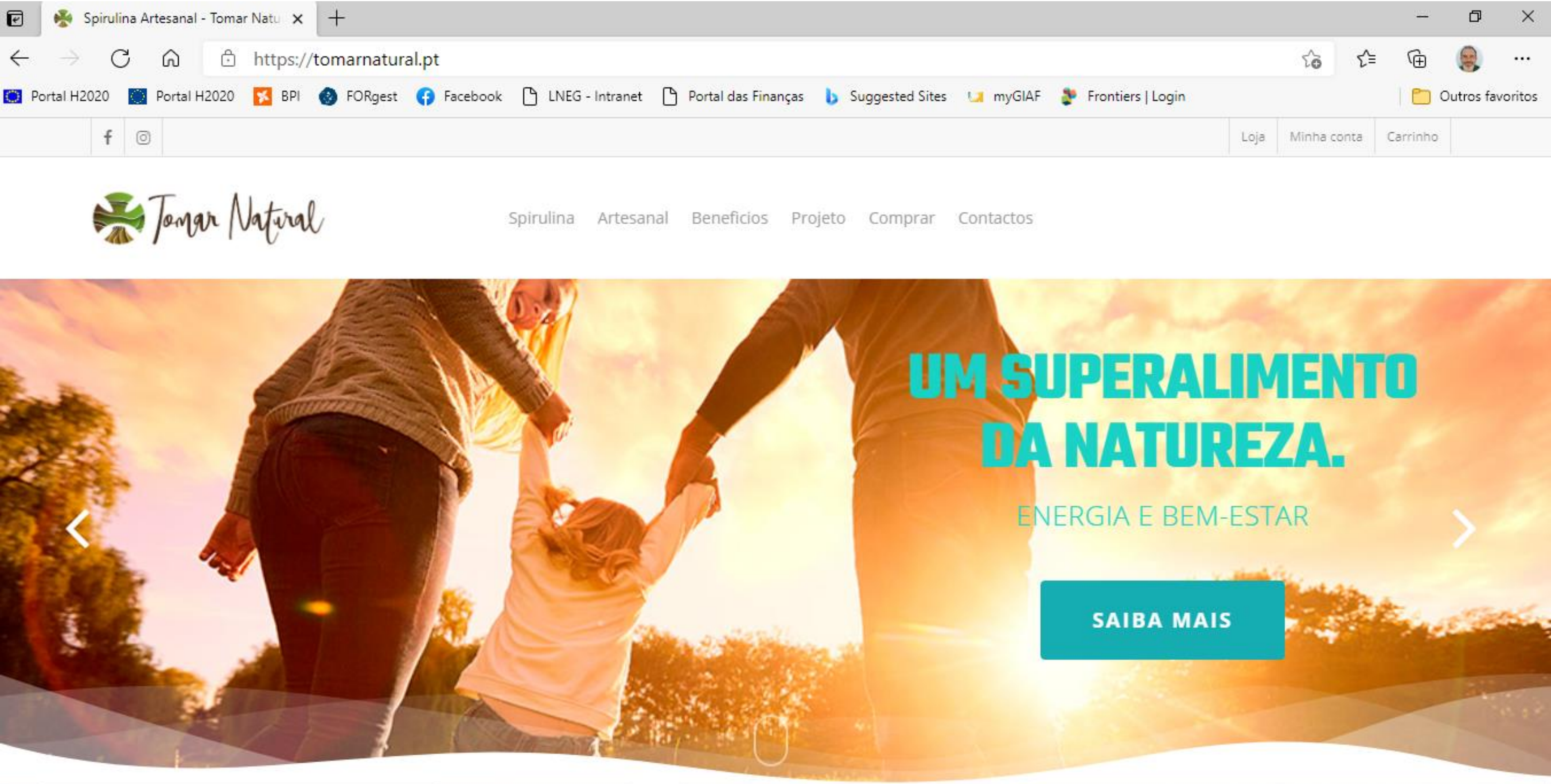
If you would like to support the Romanesque Sigward Church by becoming a co-trustor: Dresdner Bank AG, account no.: 263604906, Bank Code Number: 370 800 40. Please enter the following identification number and heading on your bank transfer slip: "700021 Sigward Church". If you any further queries, the German Foundation for Monument Protection Foundation Centre

REACÇÃO FOTOSSINTÉTICA

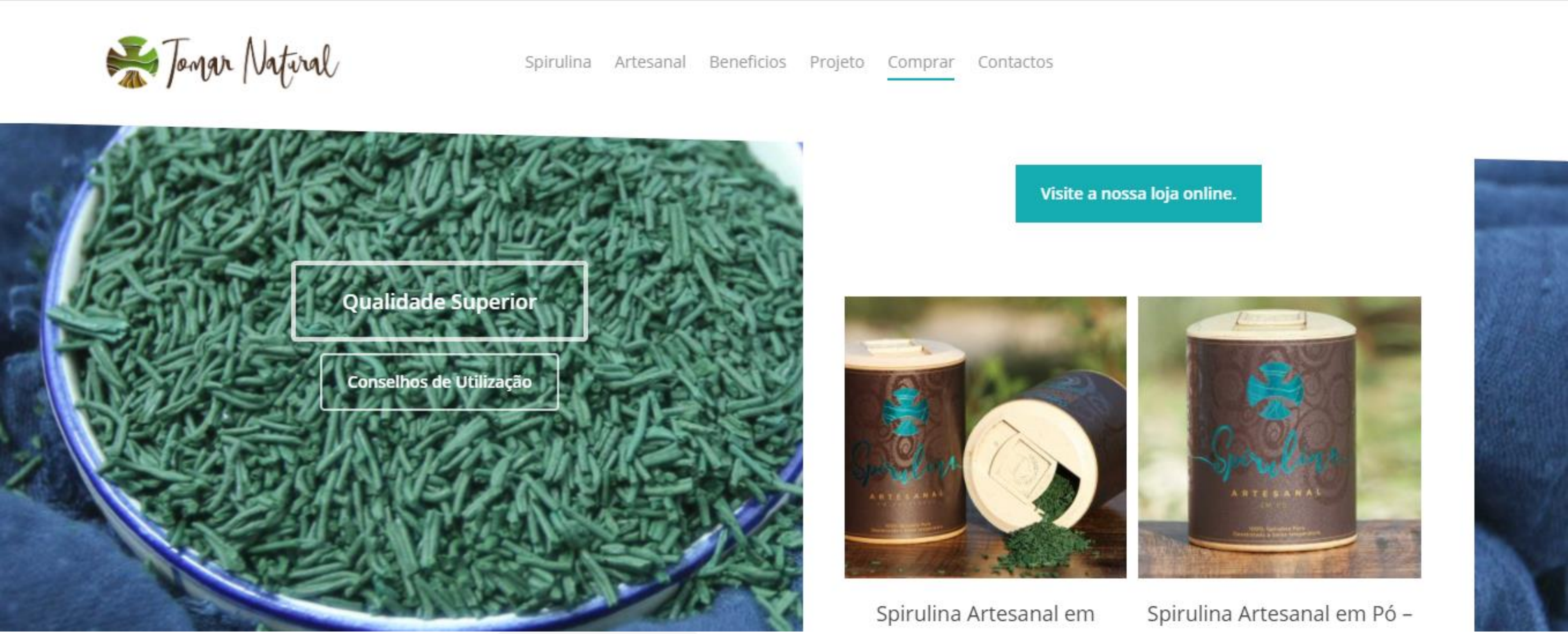
$$CO_2+NO_3^{-}+PO_4^{-3}+H_2O \xrightarrow{\text{ENERGIA SOLAR}} [CH_nONP] + O_2$$

BIOMASSA ALGAL



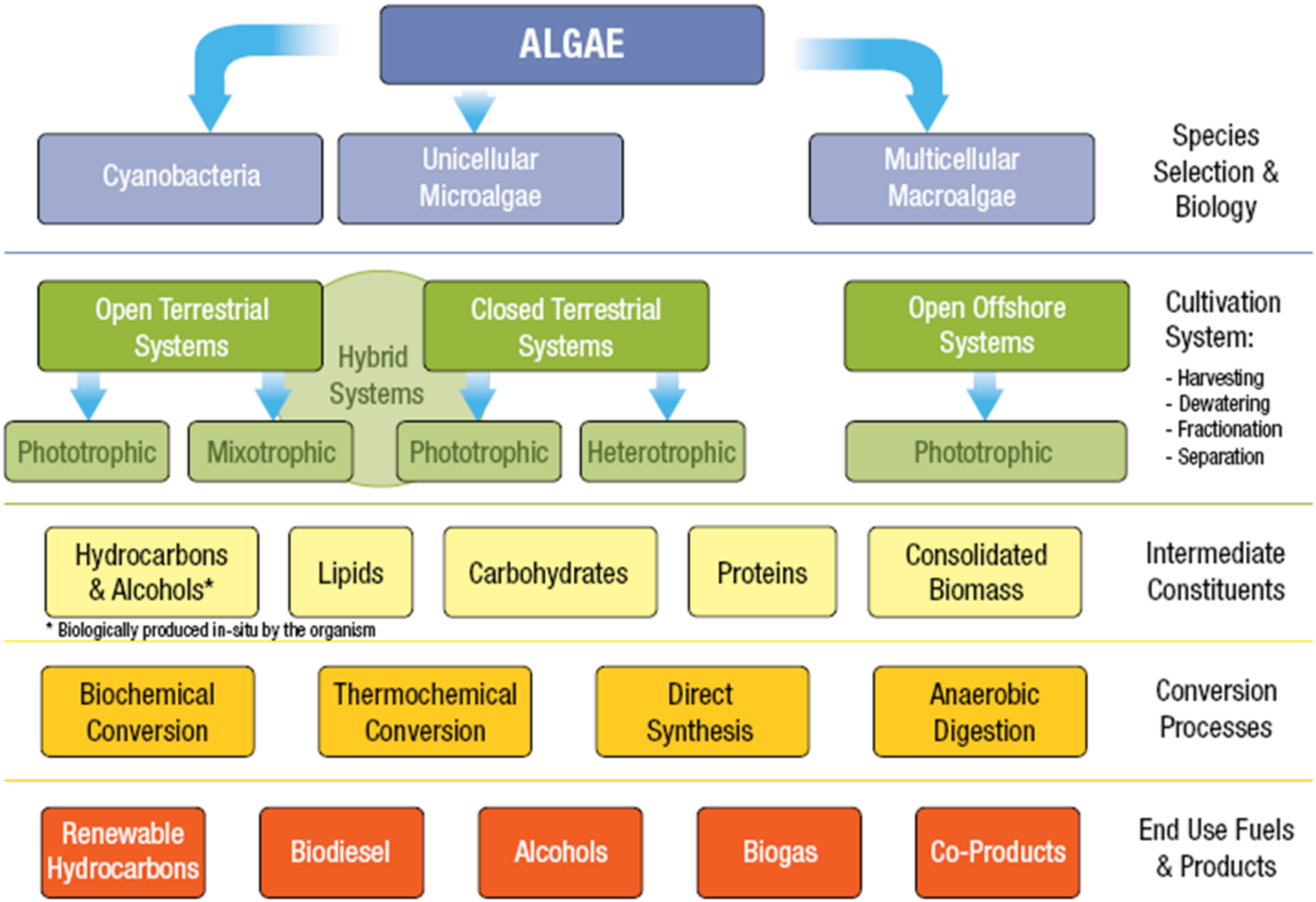

Spirulina Artesanal - Tomar Natu
https://tomarnatural.pt
Portal H2020
Portal H2020
BPI
FORgest
Facebook
LNEG - Intranet
Portal das Finanças
Suggested Sites
myGIAF
Frontiers | Login
Outros favoritos
Loja
Minha conta
Carrinho
Tomar Natural
Spirulina
Artesanal
Benefícios
Projeto
Comprar
Contactos
UM SUPERALIMENTO DA NATUREZA.
ENERGIA E BEM-ESTAR
SAIBA MAIS

LNEG


Tomar Natural
Spirulina
Artesanal
Benefícios
Projeto
Comprar
Contactos
Qualidade Superior
Conselhos de Utilização
Visite a nossa loja online.
Spirulina Artesanal em
Spirulina Artesanal em Pó –

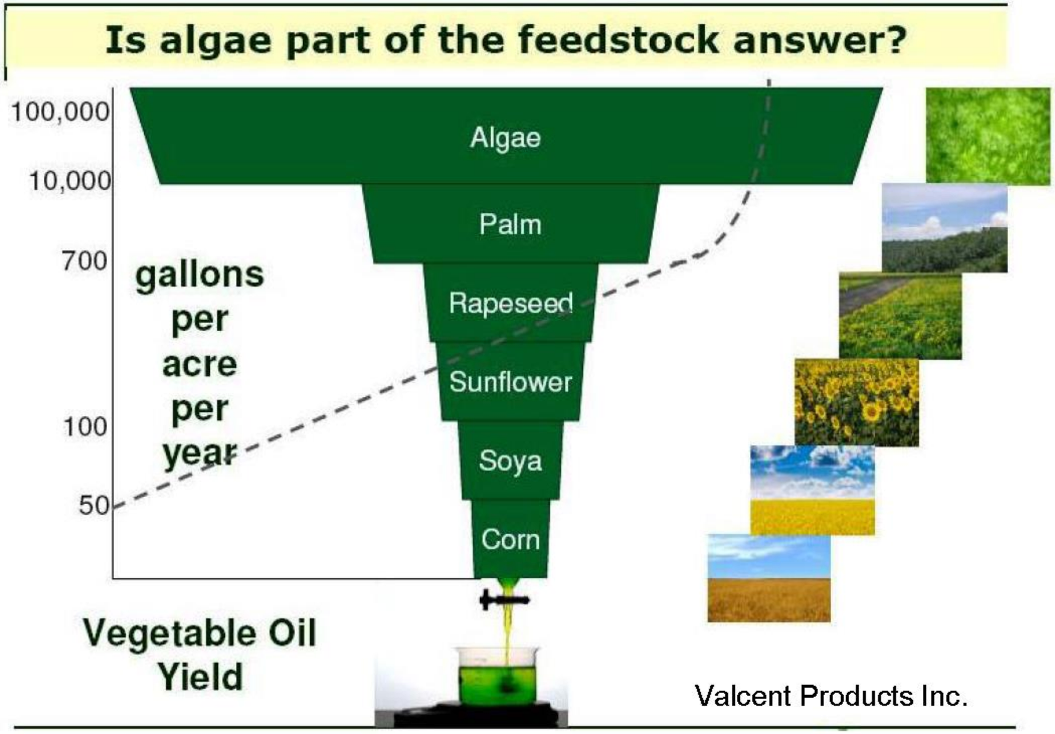
170 €/ Kg

various approaches and pathways to developing algae-derived biofuels and co-products



EXPECTATIONS

The **theoretical maximum productivity in oil from microalgae** (354 m^3 ha^{-1} $year^{-1}$) **is several orders of magnitude higher than the most productive terrestrial oleaginous culture** so far (palm) but **still very remote and unlikely from real values** obtained according with the present state-of-the-art and technical knowledge.



REALITY OR FICTION?

TO REPLACE ALL TRANSPORTATION FUELS IN EUROPE

- 400 MILLION m^3 OIL REQUIRED
- 9.25 MILLION ha SURFACE AREA (ANDALUSIA OR PORTUGAL AREA EQUIVALENT!)
- 400 MILLION TONS OF PROTEINS PRODUCED

(20X THE QUANTITY OF SOY PROTEIN IMPORTED IN EUROPE)

(Wiffels et al, 2010. Microalgal Biotechnology Workshop, Germany)

VERY UNLIKELY !

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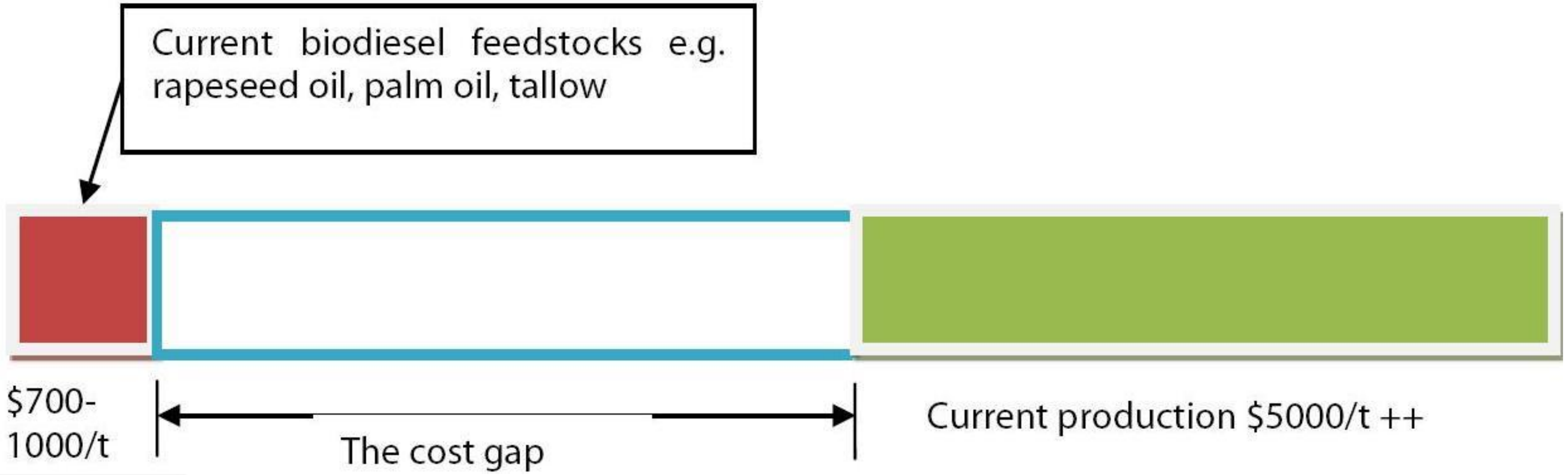
REALITY

still prohibitive costs?



COST ESTIMATION *vs* SCALE

Cost estimation for algae production

- At 1 ha scale → 10 €/Kg
- At 100 ha scale → 4 €/Kg
- What can be achievable → 0.4 €/Kg ?

Still too expensive for biodiesel alone (or even other fuel)

(Wiffels et al, 2010, Microalgal Biotechnology Workshop, Germany)

Upper limit for success:
0.2€/Kg?

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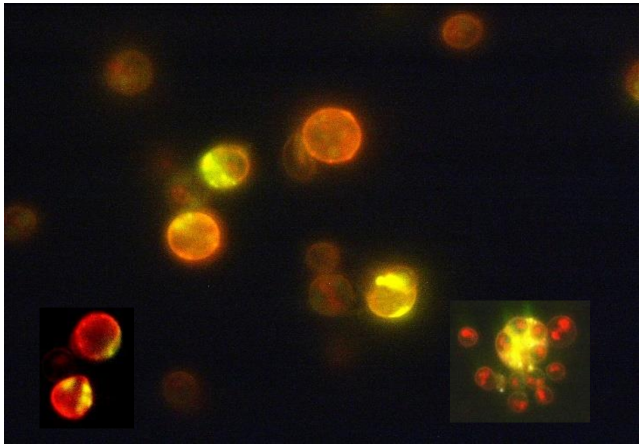
PARADOX

High lipid content
= Low biomass productivity
=Low lipid Productivity
=High production costs
☹



an unsolved (biological/physiological) paradox !!!

No Cost-effectiveness of biodiesel production from algae
(the way it is…unless…)

low-cost feedstocks

are used

low-cost production of microalgal biomass
ideal situation would be the

→use of **wastewater** as the nutrient (nitrogen and phosphorus) source,

+

→together with the addition of free **CO_2** from **flue gases** as the carbon source,

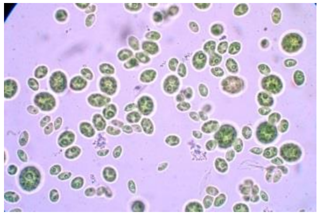
→purified water and profits obtained from the wastewater treatment process and
→carbon credits (Reis & Gouveia, 2015)

significant (>50%) cost reductions may be achieved if **CO_2, nutrients and water**
can be obtained at a **low cost** (Slade & Bauen)

water demanding and has been criticized (high water footprint) ☹
1 L of microalgal biodiesel requires approximately 3000 L of freshwater !!
(Farooq et al.)

WHY MICROALGAE-BASED WWT?

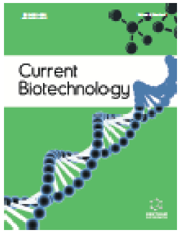
The major economic factor for biofuel production from microalgae is the feedstock cost, which accounts for 75-80% of the total costs Dermibas M F 2009. Biofuels from algae for sustainable development. Applied Energy, 88(10), 3473-3480.



WW- The cheapest feedstock ever!

REVIEW ARTICLE

Low Cost Microalgal Production for Biofuels: A Review



Alberto Reis* and Luísa Gouveia

Bioenergy Unit, LNEG- National Laboratory for the Energy and Geology, I.P., Lisboa, Portugal

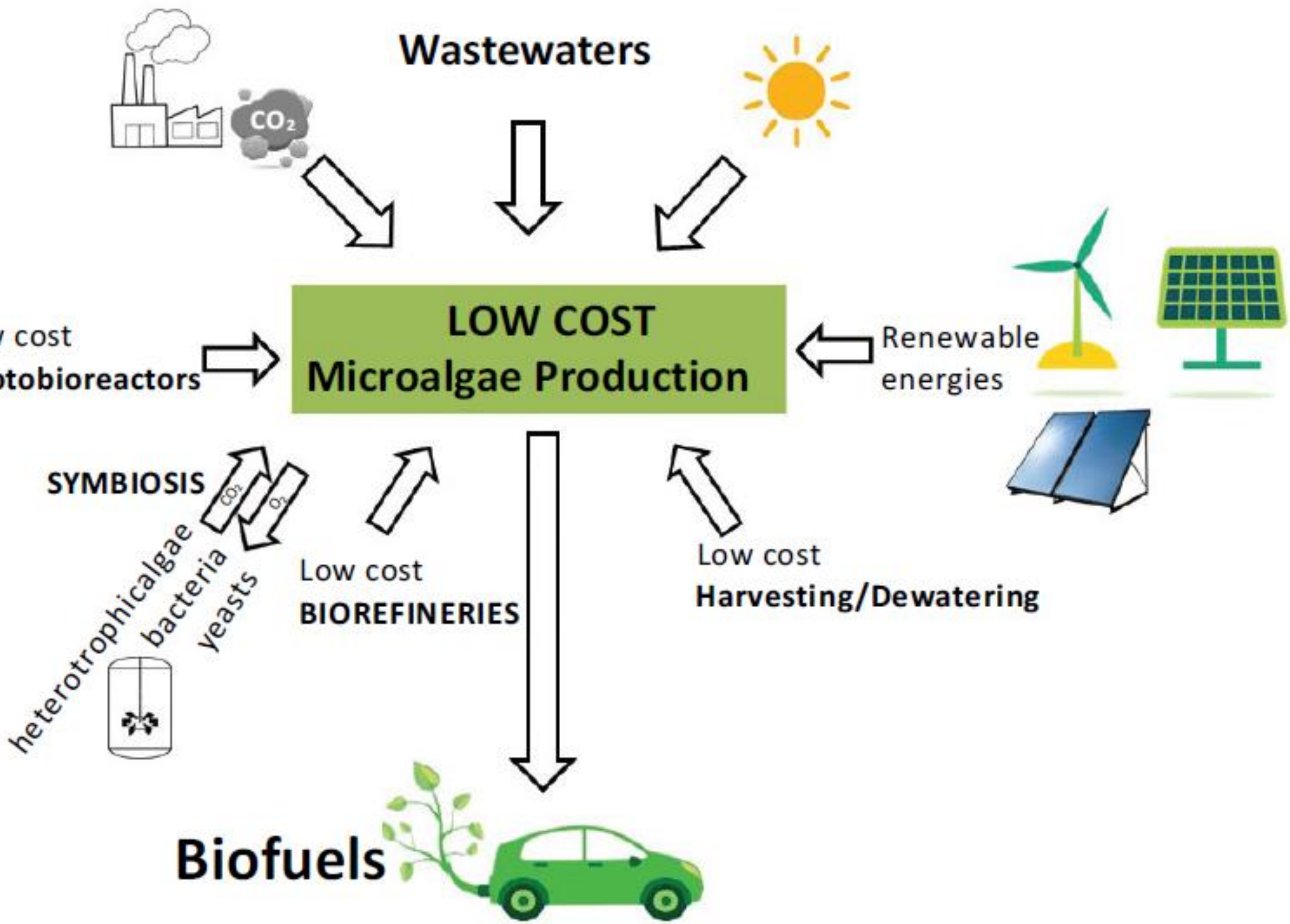
Alberto Reis

Abstract:

Background: Autotrophic microalgae carry out the photosynthetic conversion from light into organic compounds. Microalgal cultivation brings environmental advantages, highlighting the capability of nutrient recycling from wastewater combined with CO2 fixation from flue gases towards a wide range of 3G biofuels and bioproducts.

These micro-organisms have been widely recognized as having huge potential as feedstock for food and feed industries, as "nutraceutical" agents (carotenoids, antioxidants, polyunsaturated fatty acids, single-cell proteins (SCP), phycobiliproteins, polysaccharides, vitamins, phytosterols, minerals), for the cosmetic industry, bioplastics, agriculture biofertilizers and recently as an energetic vector towards the production of a wide range of biofuels. Microalgae exhibit clear advantages when compared with higher plants, such having a higher photosynthetic efficiency, higher areal biomass productivities, higher CO2 biofixation rates from flue gases emitting plants, higher O2 production rates, non-competition for agricultural areas (marginal lands such as deserts, rocky areas and salt

ARTICLE HISTORY



Wastewaters
CO_2
LOW COST
Microalgae Production
Low cost
Photobioreactors
Renewable
energies
SYMBIOSIS
CO_2
O_2
heterotrophicalgae
bacteria
yeasts
Low cost
BIOREFINERIES
Low cost
Harvesting/Dewatering
Biofuels

A FOTOSSÍNTESE e as MICROALGAS já têm contribuído para tratar efluentes

LAGOAS DE ESTABILIZAÇÃO

São lagoas constituídas de forma **simples** onde os esgotos entram em uma extremidade e saem na oposta. A matéria orgânica em forma de suspensão fica no fundo da lagoa , formando um lodo que vai aos poucos sendo estabilizado . O processo baseia-se nos princípios da respiração e da fotossíntese: as algas existentes no esgoto na presença de luz , produzem oxigénio que se liberta através da fotossíntese .Esse oxigénio dissolvido é utilizado pelas bactérias aeróbias (respiração) para se alimentarem da matéria orgânica em suspensão e dissolvida presente no esgoto. O resultado é a produção de sais minerais (nutrientes para as algas) e CO_2

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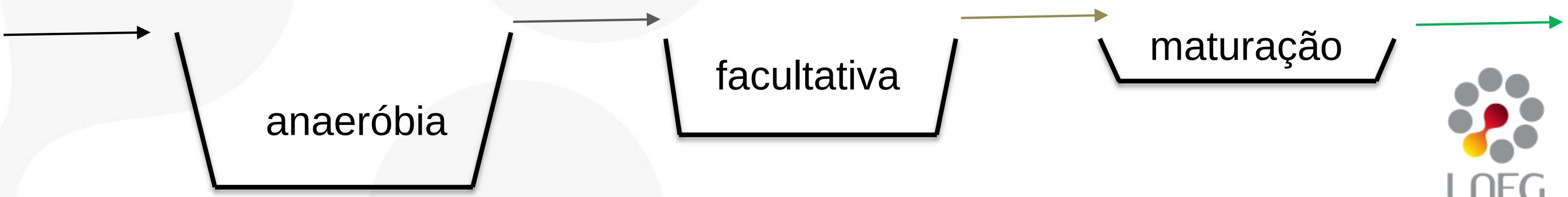
A **FOTOSSÍNTESE** e as **MICROALGAS** já têm contribuído para tratar efluentes

LAGOAS DE MATURAÇÃO

O sistema pode consistir numa única lagoa ou várias lagoas em série (anaeróbia, facultativa, maturação). Após o tratamento o efluente pode ser devolvido às águas superficiais ou reutilizado como água de irrigação se o efluente cumprir os padrões de efluentes requeridos na legislação.



HÁ PRODUÇÃO COMERCIAL DE MICROALGAS EM LAGOAS SEM AGITAÇÃO IMPOSTA PELO HOMEM

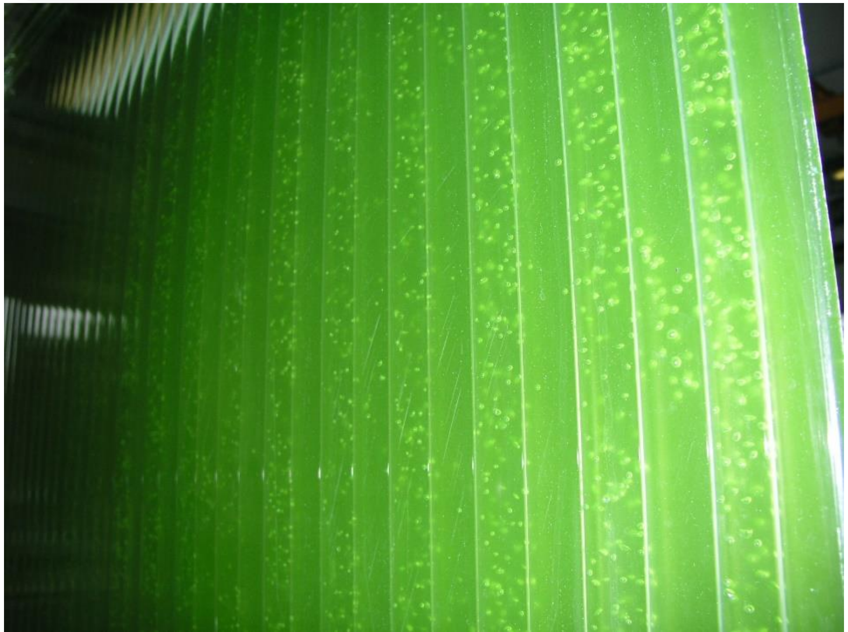
Produção extensiva de *Dunaliella salina* na Austrália

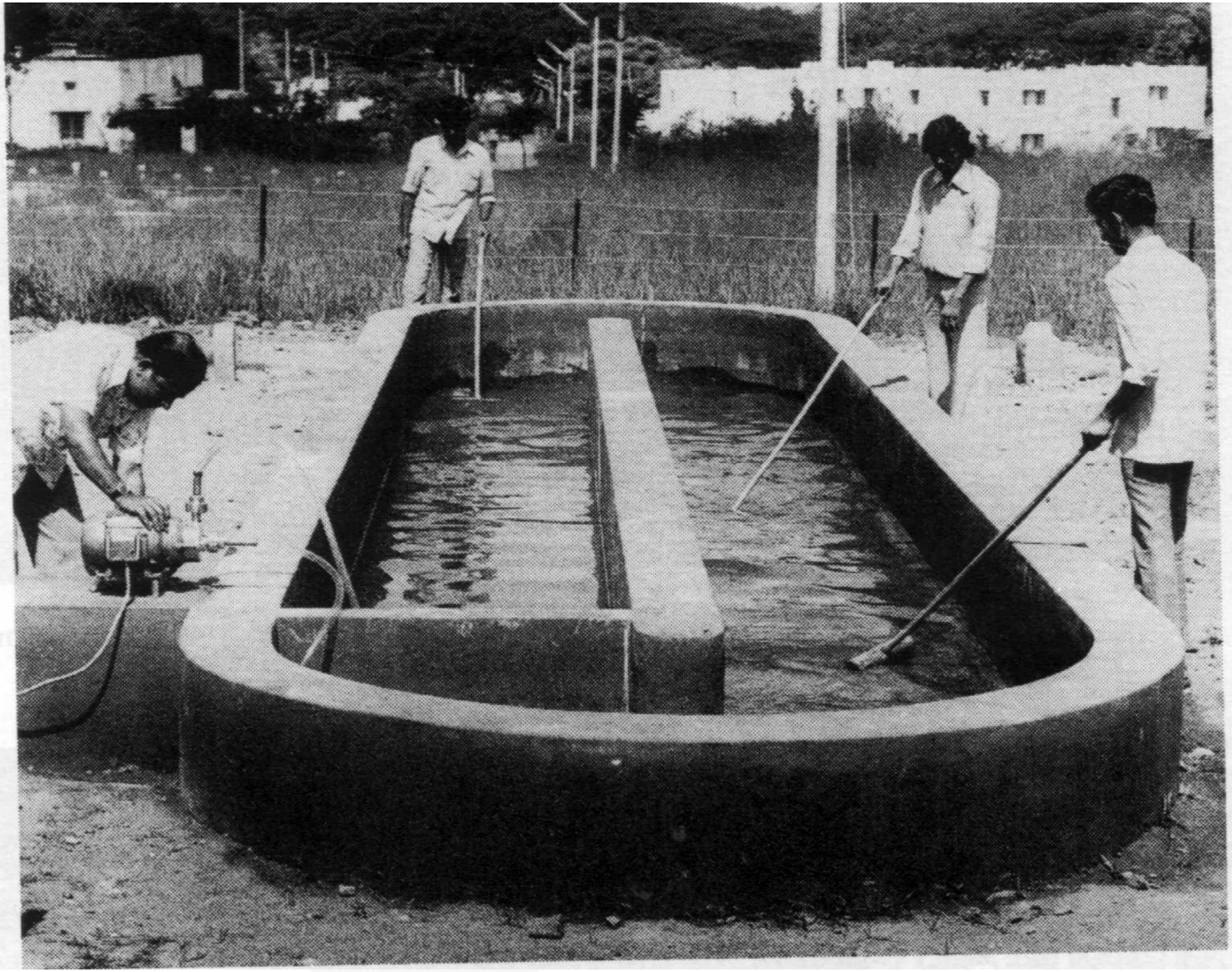
Para corantes/pigmentos (β-caroteno->pro-vitamina A)

A **FOTOSSÍNTESE** e as **MICROALGAS** já têm contribuído para tratar efluentes

A imposição de agitação e turbulência permite intensificar o processo

- BORBULHAMENTO
- AGITAÇÃO MECÂNICA



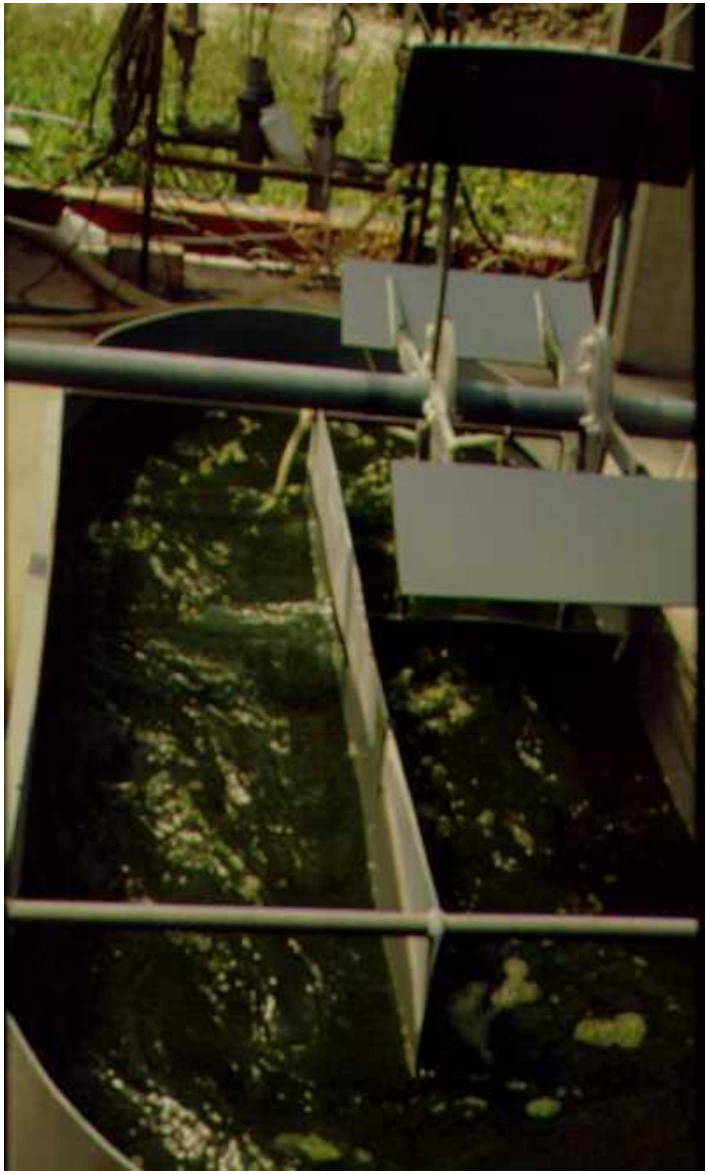


LNEG, Lisboa,
Portugal

Lagoas raceways- LATs-
Lagoas de Alta Taxa

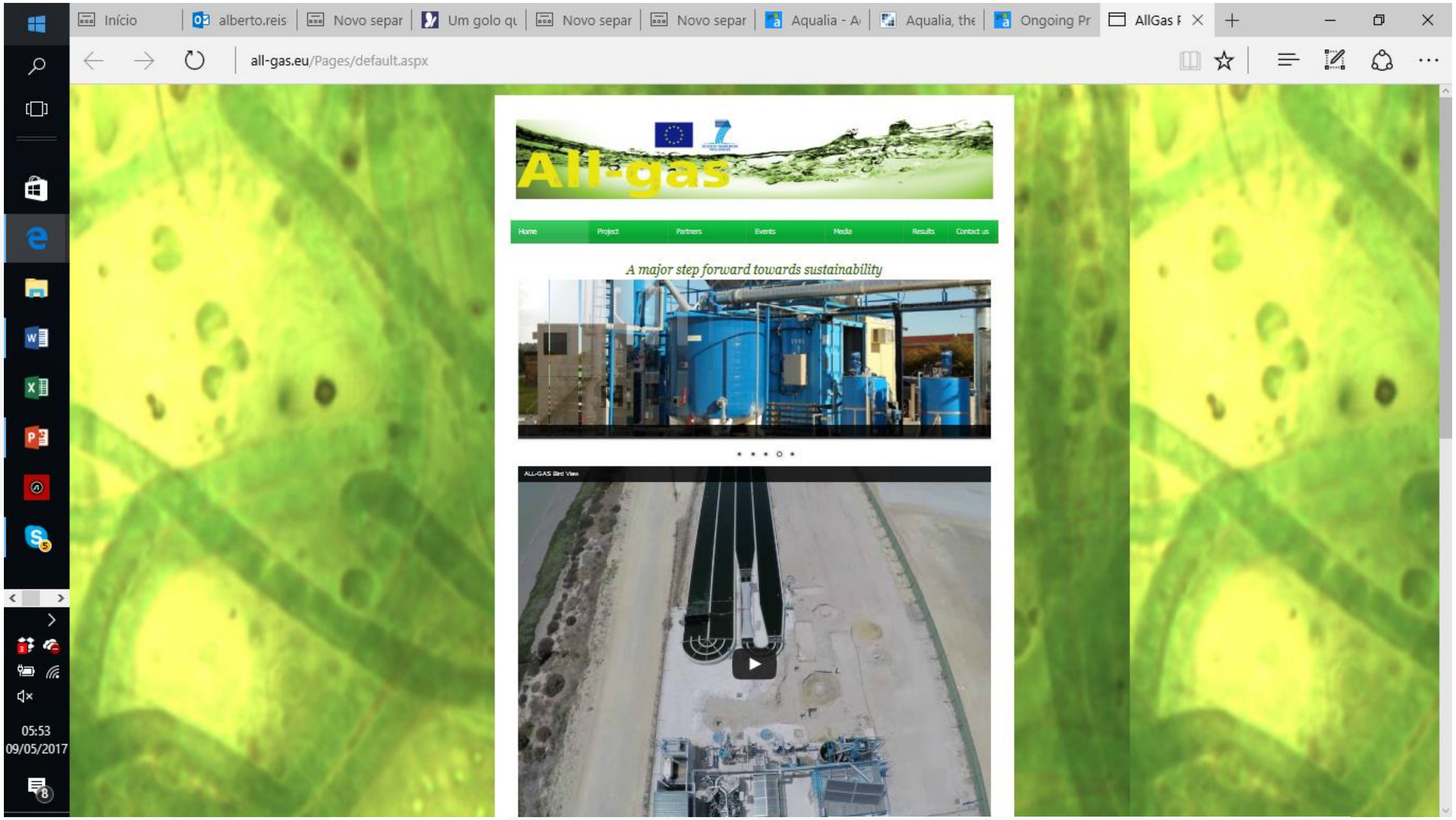
LNEG

Lagoas raceways- LATs- Lagoas de Alta Taxa



LNEG, Lisboa, Portugal

All gas

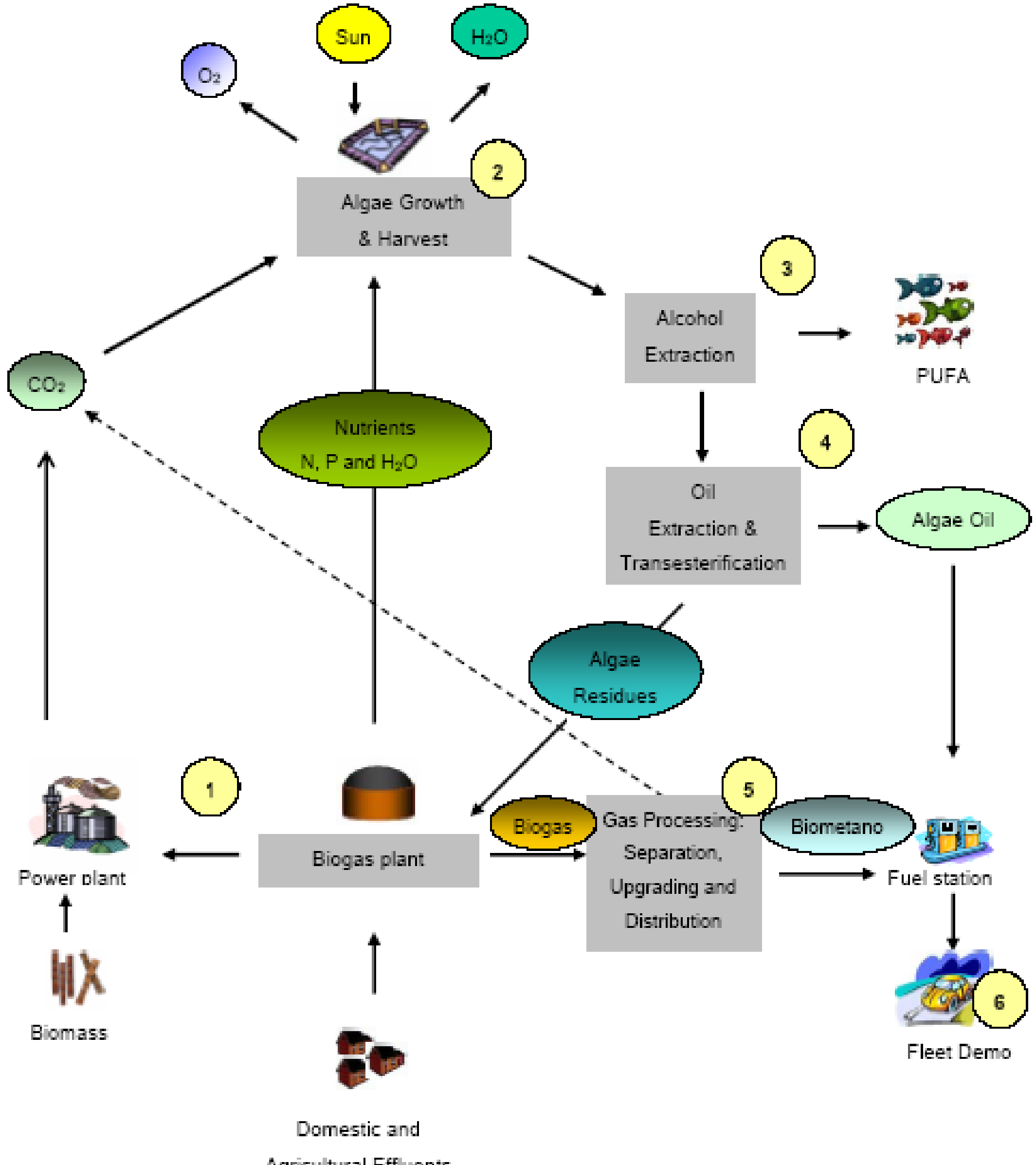


El Torno WWTP, Chiclana, Espanha

Digestor Anaeróbio de 2750 m³ para processamento de microalgas

Automóvel movido a Gás natural liquefeito (GNL)

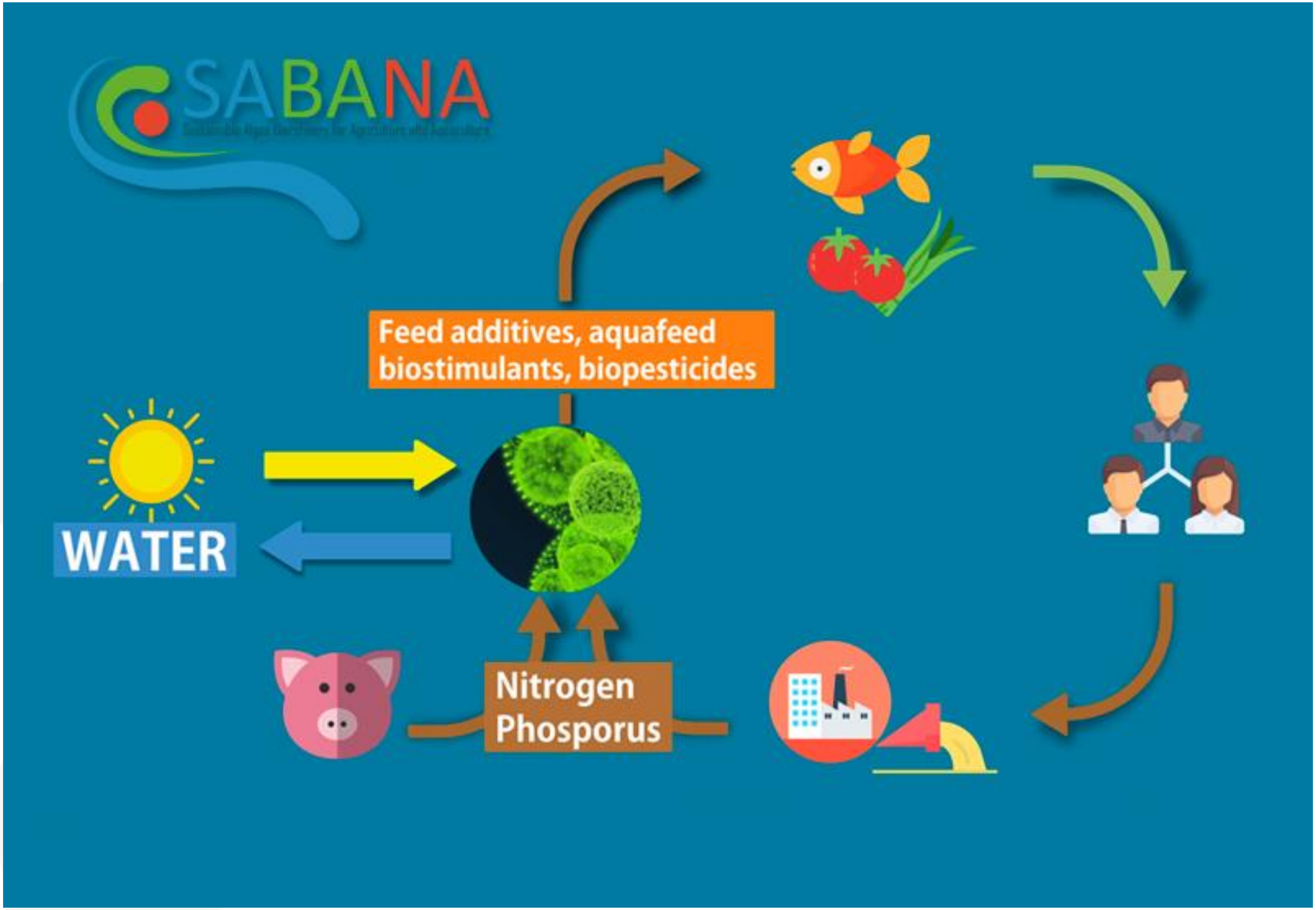
Lagoa raceway convencional (esquerda)
vs Low Energy Algae Reactor –LEAR (direita)



http://www.all-gas.eu/Pages/default.aspx

Fluxograma do projeto **All-gas**

aqualia · University of Southampton · BDI · Fraunhofer UMSICHT · HYGEAR · VW · LNEG



http://eu-sabana.eu/

SUSTAINABLE ALGAE BIOREFINERY FOR AGRICULTURE AND AQUACULTURE

W2E-WASTE2ENERGY

Está demonstrado que **dejetos orgânicos** lamas, lodos, excreta de produção animal, etc apresentam um potencial significativo para a **geração de energia**

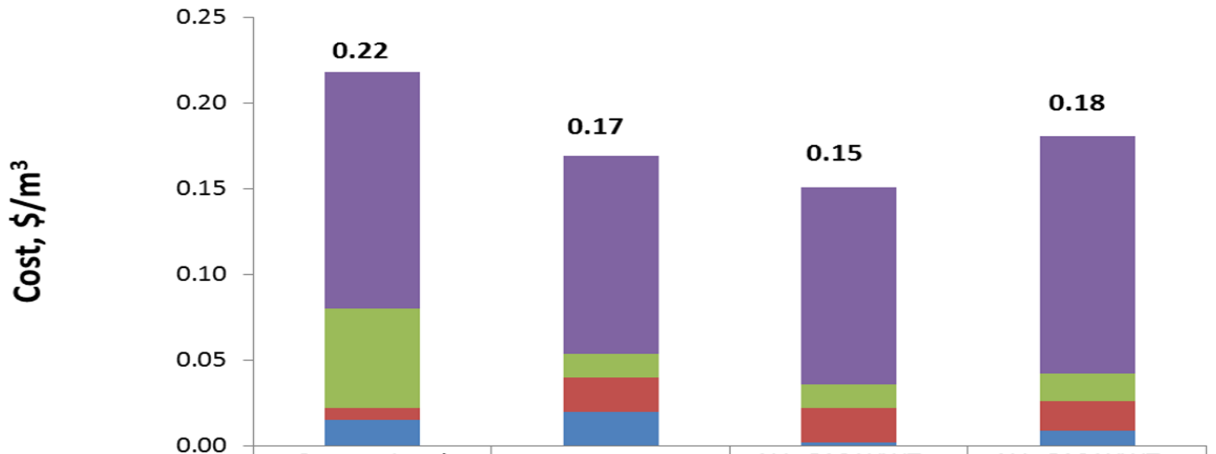
PORQUÊ TRATAR EFLUENTES COM MICROALGAS?

1) Utiliza **consórcios microalgas-bactérias** para **depurar águas** e **CO_2** contido em **gases de combustão** provenientes de indústrias poluidoras ou em **biogás** através de ***upgrading***
2) **Produz-se** até **80 t/ha·ano** de **biomassa valiosa** que pode ser **digerida anaerobiamente** ou **processada termoquimicamente (HTL)** em **biocombustíveis, biometano, combined heat & power (CHP) com produção simultânea de biofertilizantes/bioestimulantes agrícolas, bio-char (bio-alcatrão) para condicionador de solo** e outras aplicações.
3) **Reduz** o **consumo** de **energia até 0.10 kWh/m^3 de água tratada** *versus* **0.50 kWh/m^3 de água tratada em sistemas** de tratamento de água **convencionais**
4) **Recupera azoto/nitrogenio** (**50 g/m^3**) a partir de efluentes (a produção de N fertilizante **requer 10-15 kWh/m^3**).

PORQUÊ TRATAR EFLUENTES COM MICROALGAS?

5) **Minimiza** a **depleção** de **fósforo recuperando-o do efluente (até 10 g/m³)**
6) **Minimiza** as **emissões de gases de efeito estufa (CO_2, NO_x, CH_4, etc.)** em comparação com **sistemas convencionais** de tratamento de efluentes
7) **Respeita a Legislação sobre tratamento de efluentes obtendo-se água que pode ser reutilizada ou descarregada ao ar livre** (ex. Directiva 91/271/EEC)
8) **Produz até 40 t/ha·ano de biofertilizantes/bioestimulantes agrícolas** que podem ser usados na **agricultura** para **melhorar** a sua **sustentabilidade**.

PORQUÊ TRATAR EFLUENTES COM MICROALGAS?



	Conventional WWT	ALL-GAS WWT	ALL-GAS WWT + BIOFERTILIZERS	ALL-GAS WWT + BIOMETHANE
Fixed costs	0.138	0.115	0.115	0.139
Electricity	0.058	0.014	0.014	0.016
Chemicals	0.007	0.020	0.020	0.017
Residues disposal	0.015	0.020	0.002	0.009

Análise comparativa de custos de tratamento de efluentes no âmbito do projeto ALL-GAS em comparação com os processos convencionais (inclui-se diferentes cenáriso de utilização dos produtos finais.

Acien F.G. et al 2017. Economics of microalgae production. In: Microalgae based bioproducts: from feedstock cultivation to end-products. Eds Cristina Gonzalez & Raul Muñoz . Elsevier.

AS MICROALGAS PODEM SER DIGERIDAS ANAEROBIAMENTE PARA PRODUÇÃO DE BIOGÁS

O DIGESTATO da DIGESTÃO ANAERÓBIA PODEM SER CONSUMIDO PARA PRODUÇÃO DE MICROALGAS

CEt CHEMICAL ENGINEERING TRANSACTIONS

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Anaerobic Digestion of pre-treated Microalgae Biomass

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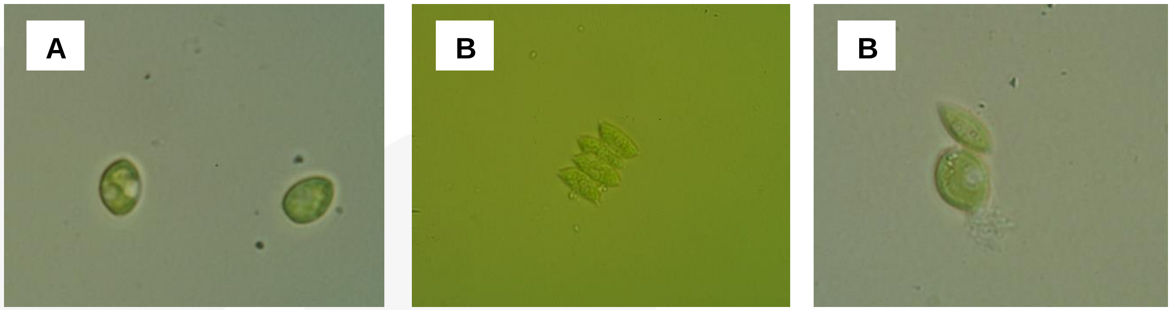
Chlorella vulgaris microalgae biomass was cultivated in brewery secondary effluents and used as a recalcitrant effluent to be valorised energetically by anaerobic digestion process. All previous techniques applied for cellular disruption – autoclave, freeze/heating, ultrasound, microwave - provided either high absorption values and release of reducing sugars in the medium or membrane cells damage, compared to the untreated sample, indicating that the pre-treatment action was effective.
The highest methane production was attained by the autoclave and untreated microalgae assays (samples

ANAEROBIC DIGESTION

LNEG

Microalgas para tratamento de efluentes



A: *Chlorella*, B: *Scenedesmus obliquus*

	$N\text{-}NH_3$ (mg N/L)	Kjeldahl N (mg N/L)	PO_4^{3-} (mg/L)	$P\text{-}PO_4^{3-}$ (mg P/L)	P_2O_5 (mg/L)	COD (mg O_2/L)	pH
Legislation [1]	10	15	-	10	-	150	6 - 9

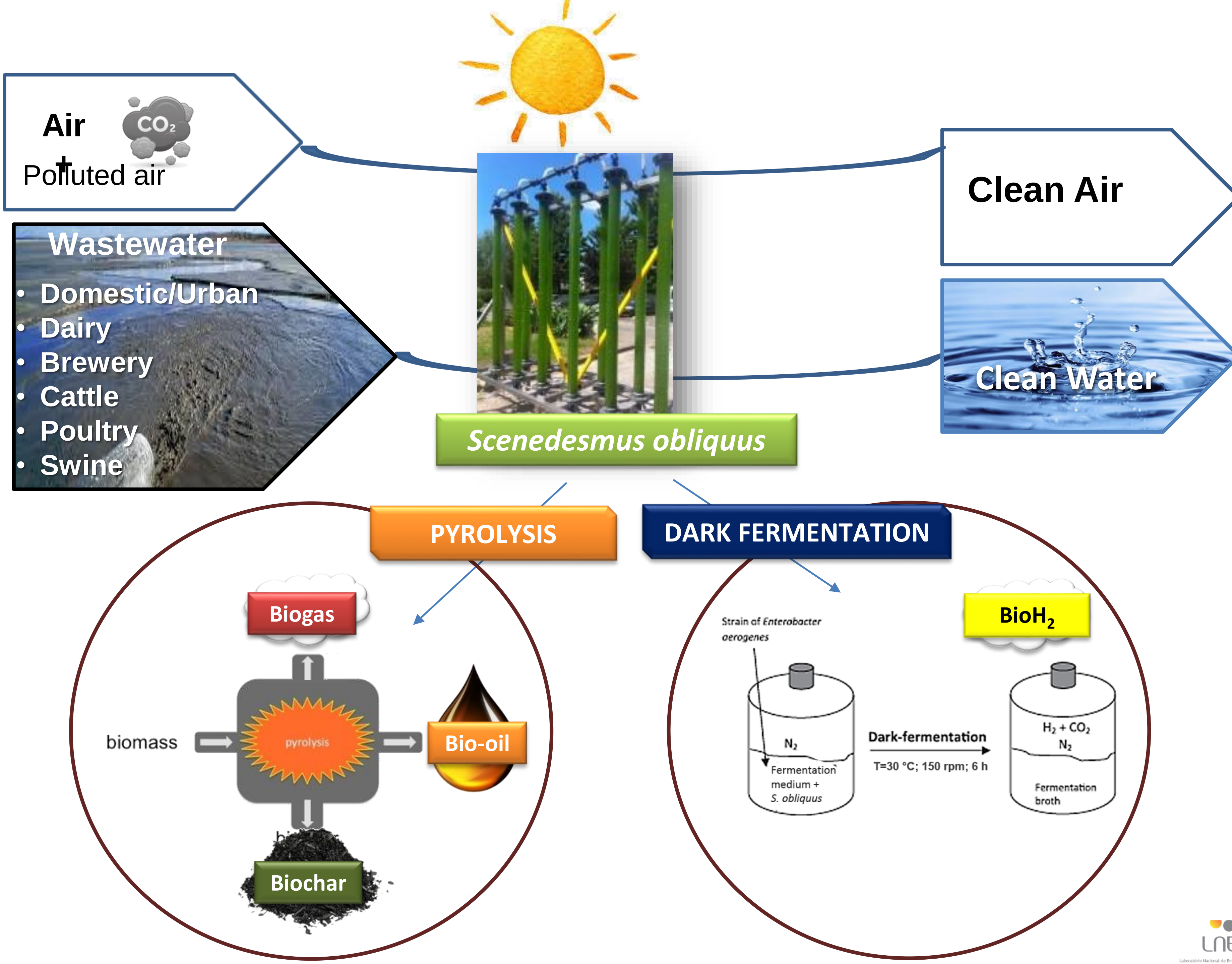
[1] Legislation — Decree-law no. 236/98 (PT)

Efluentes diferentes testados com sucesso:

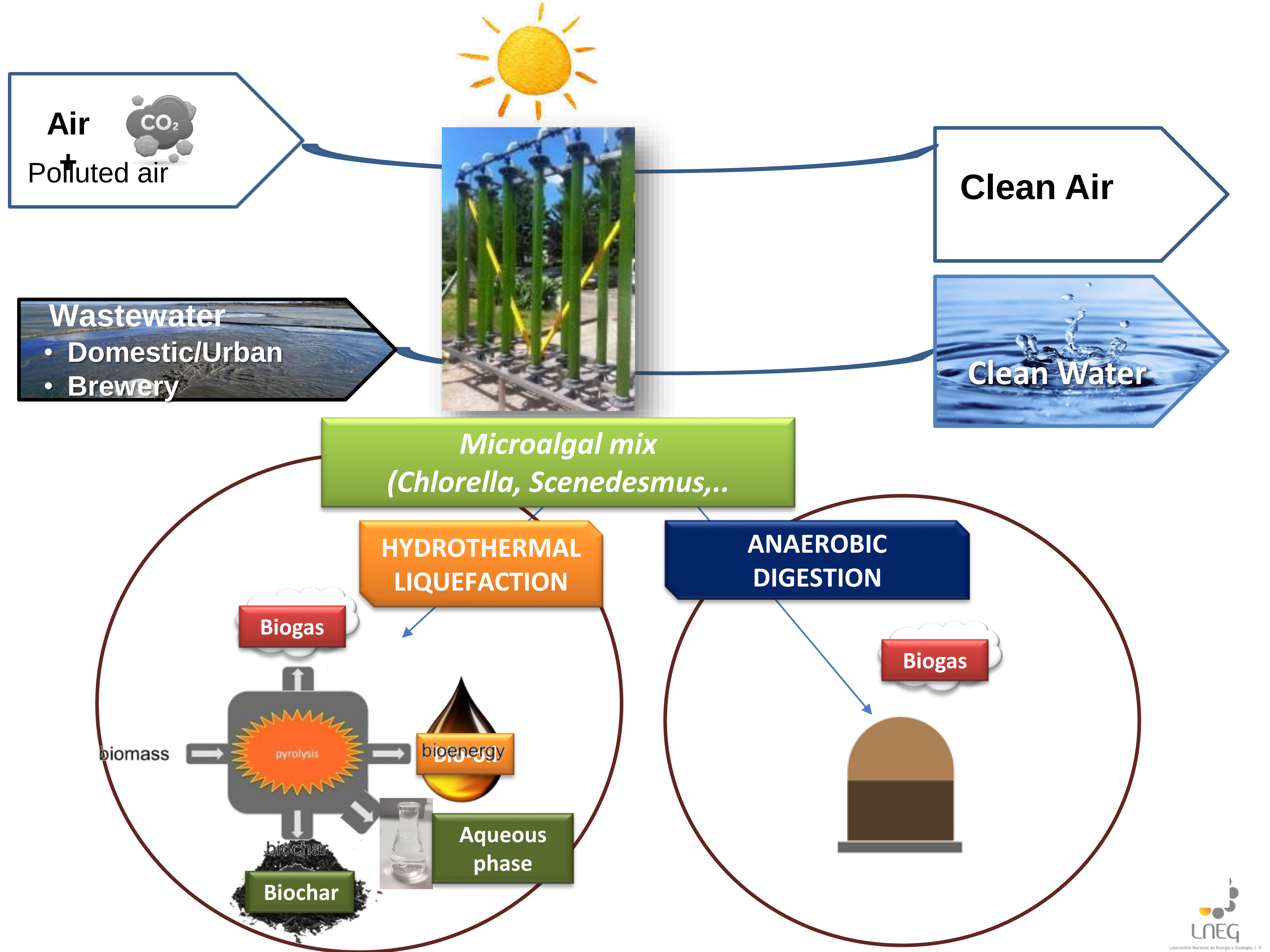
- Urbano/doméstico
- Indústria lacticínios
- Indústria cervejeira
- Gado de leite
- Suinicultura
- Avicultura (aviários)

Tempos médios de retenção hidráulica <3 dias !

Cumpre a atual legislação: Diretiva UWWT, DL 236/98, outras…



Air
CO_2
+
Polluted air
Wastewater
• Domestic/Urban
• Dairy
• Brewery
• Cattle
• Poultry
• Swine
Clean Air
Clean Water
Scenedesmus obliquus
PYROLYSIS
DARK FERMENTATION
Biogas
biomass
pyrolysis
Bio-oil
Biochar
BioH$_2$
Strain of Enterobacter aerogenes
N_2
Fermentation medium + S. obliquus
Dark-fermentation
T=30 °C; 150 rpm; 6 h
$H_2 + CO_2$
N_2
Fermentation broth

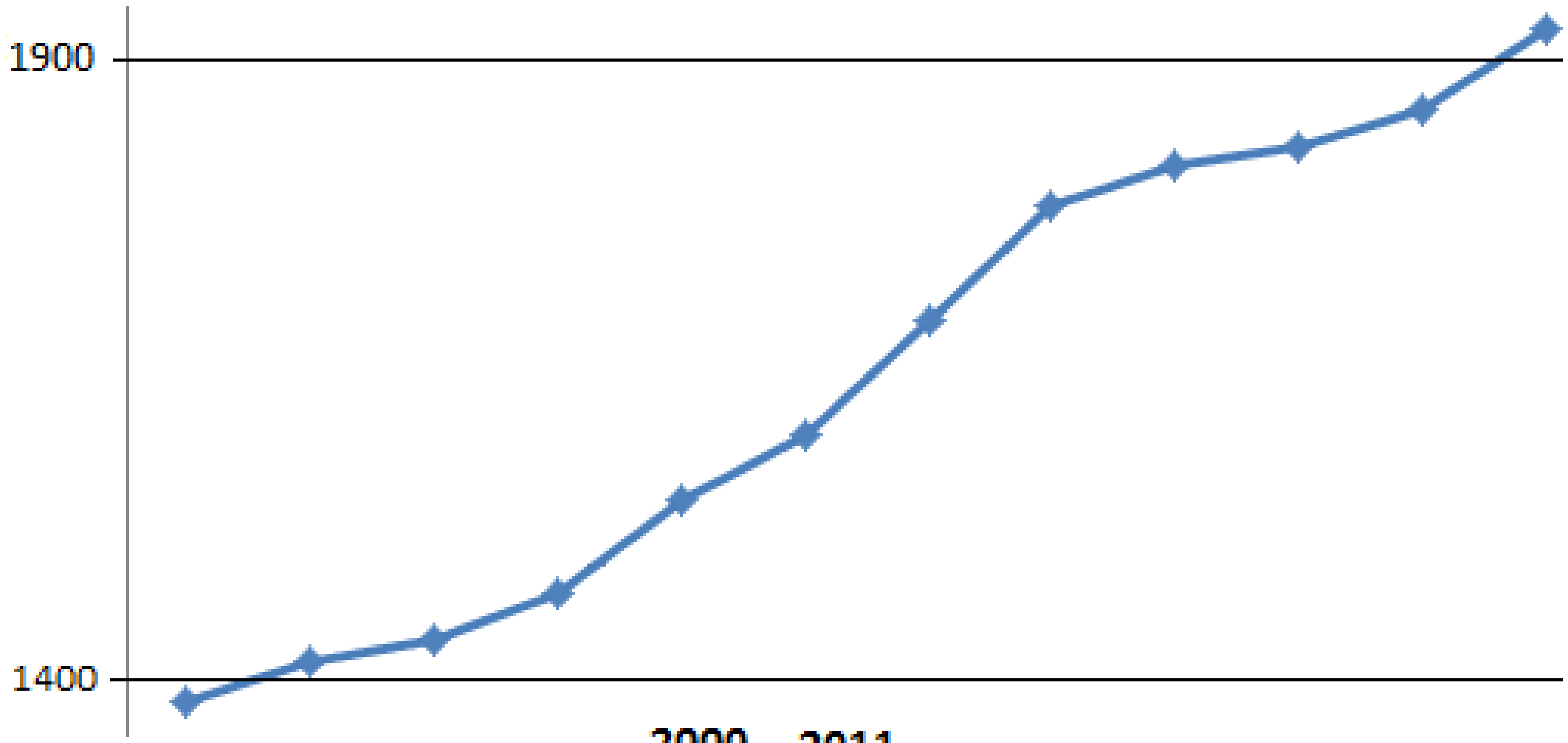

Air
CO_2
Polluted air
Clean Air
Wastewater
• Domestic/Urban
• Brewery
Clean Water
Microalgal mix
(Chlorella, Scenedesmus,..
HYDROTHERMAL
LIQUEFACTION
ANAEROBIC
DIGESTION
Biogas
biomass
pyrolysis
bioenergy
Bio-oil
biochar
Biochar
Aqueous
phase
Biogas
LNEG

Beer is the **3rd** most popular beverage
after **water** and **tea**

LNEG
Laboratório Nacional de Energia e Geologia, I. P.

World Beer Production

Millions of hectoliters



2000 - 2011

Source of Data: Barth-Haas Group

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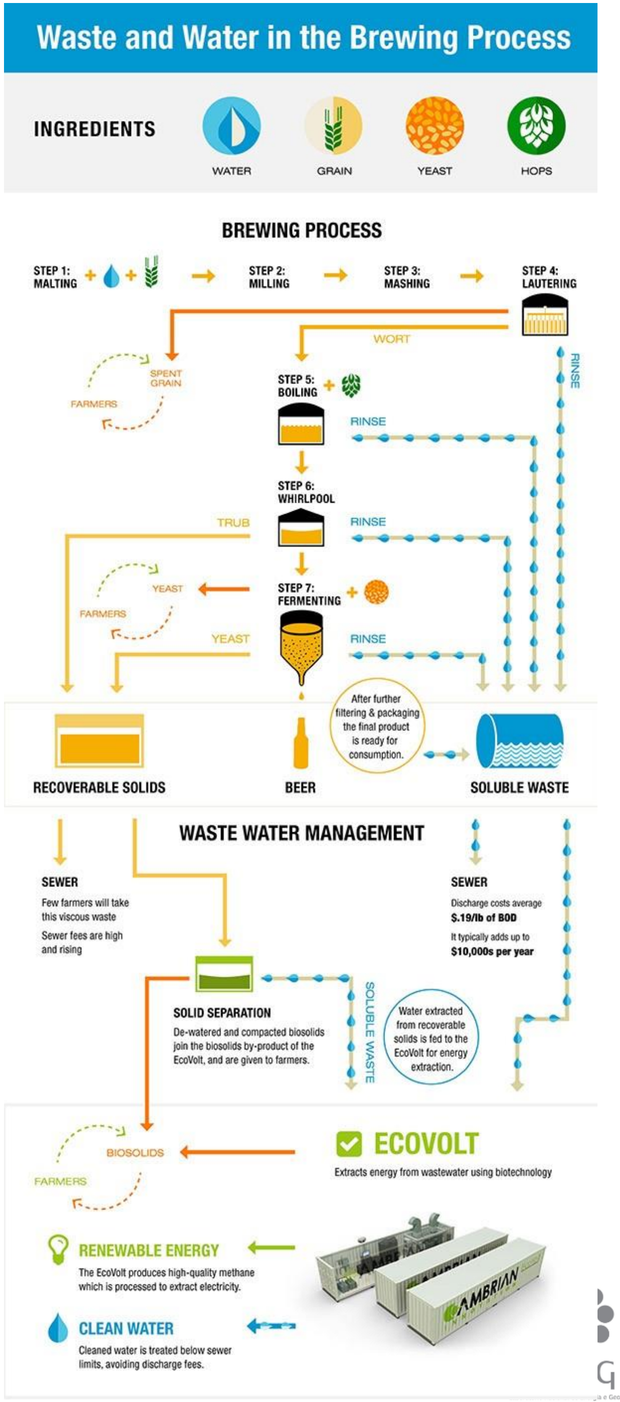
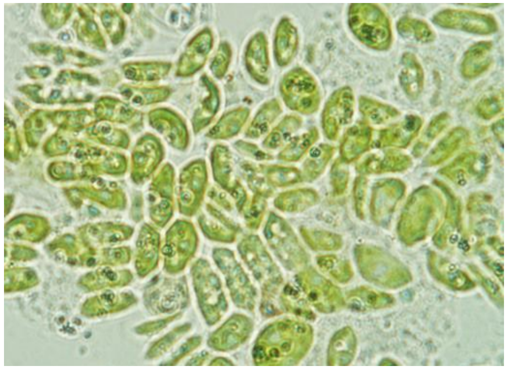
wastewater is one of the **most significant waste products** of **brewery** operations

approximately **3 to 10 liters** of **waste effluent** is generated **per liter of beer produced** in breweries





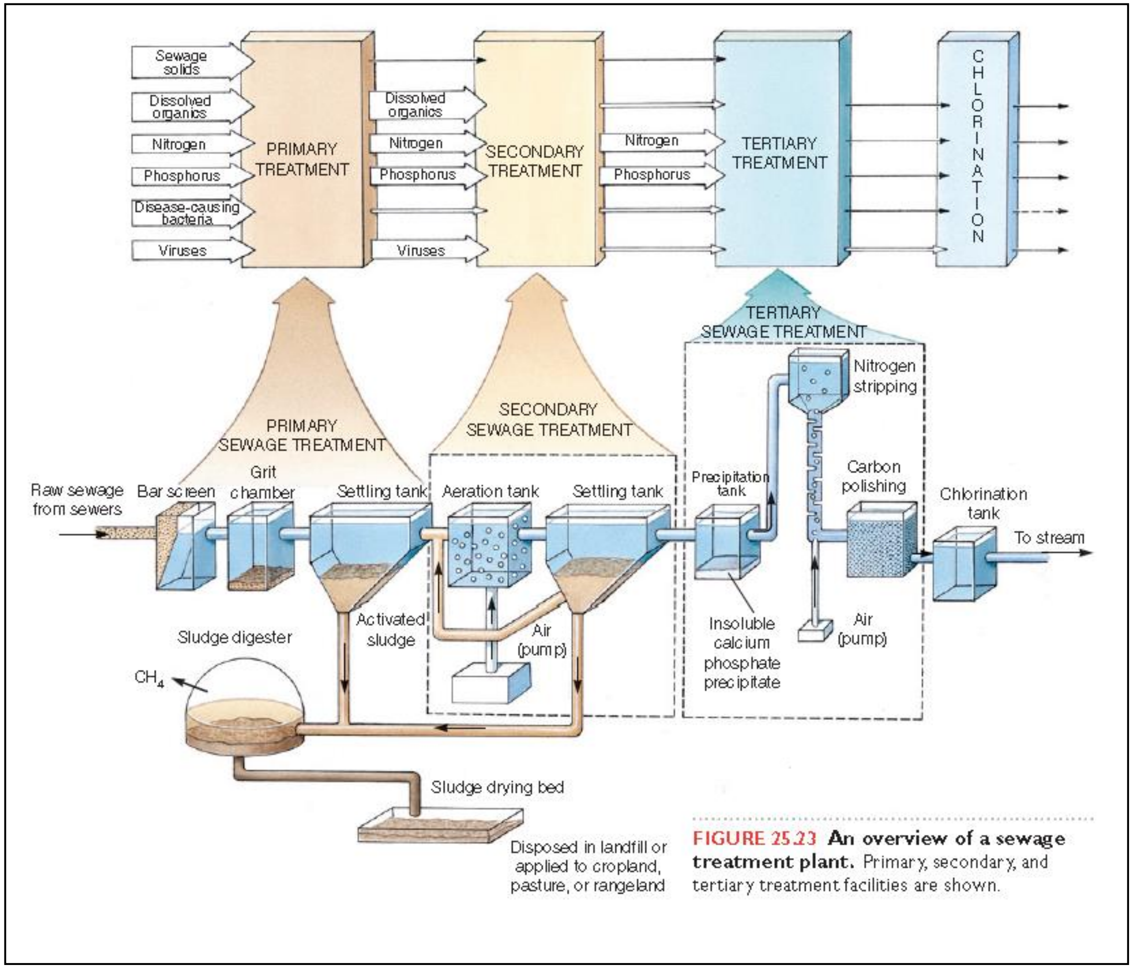
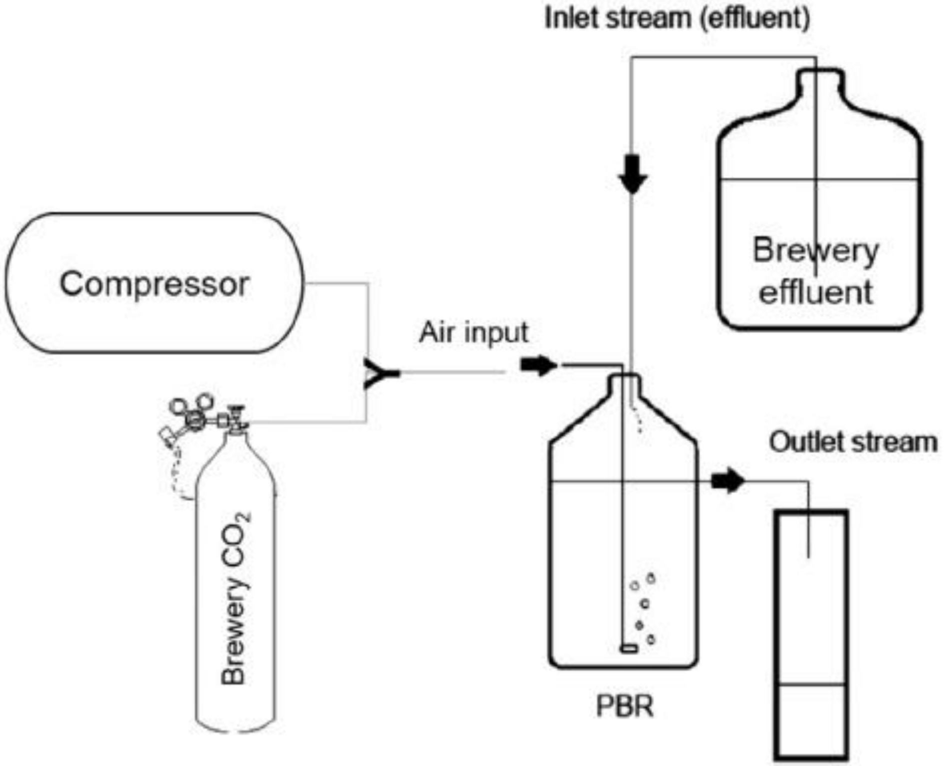


FIGURE 25.23 **An overview of a sewage treatment plant.** Primary, secondary, and tertiary treatment facilities are shown.

Microalgae treat successfully brewery **primary** and **secondary WW**

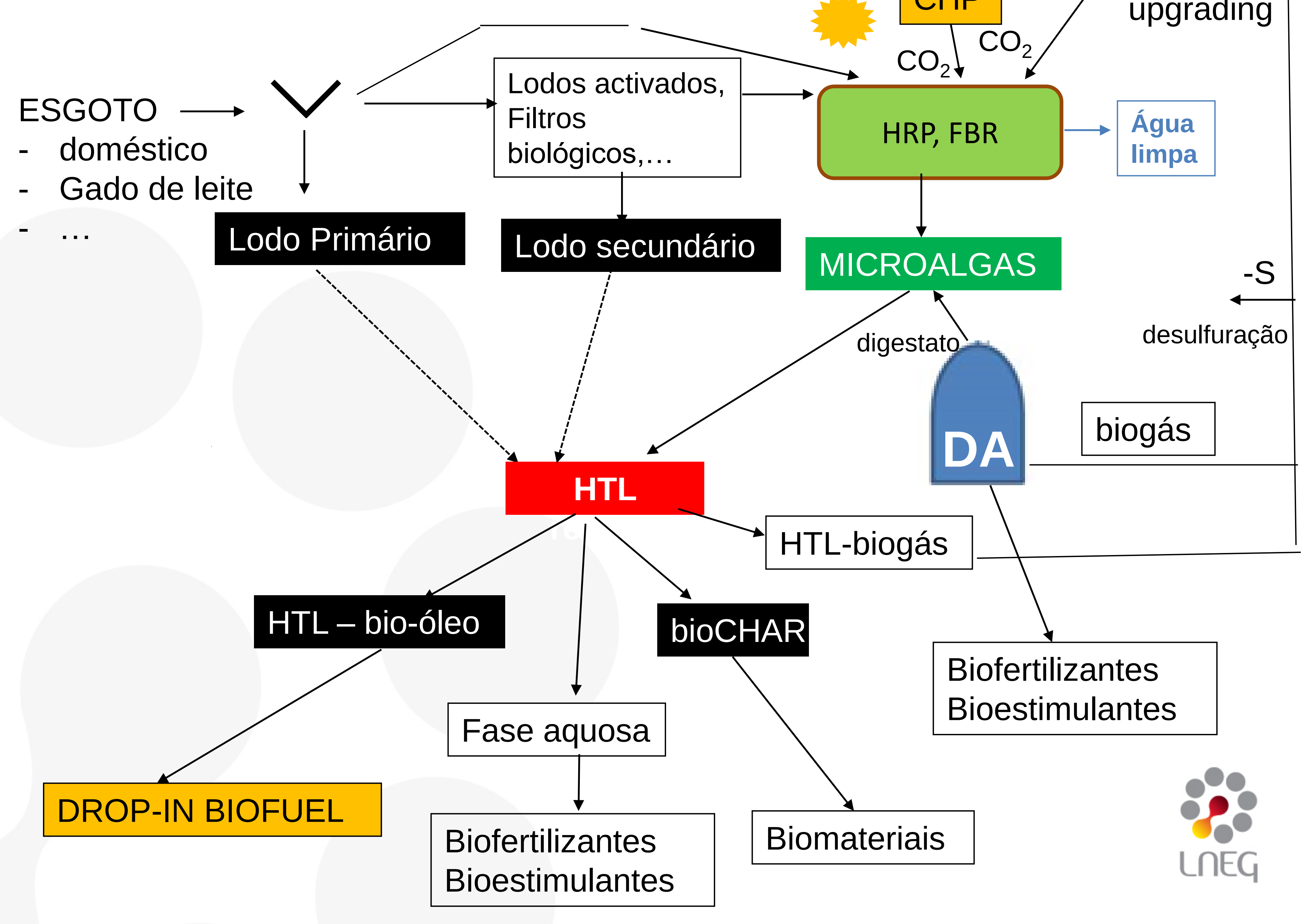


Maximum removal efficiency achieved after biological treatment with *Scenedesmus obliquus*, grown in brewery wastewater with and without CO_2 supplementation.

HRT (d)	D (d^{-1})	Maximum removal efficiency (%)							
		$N\text{-}NH_3$		TKN		P		COD	
		No CO_2	10% (v/v) CO_2	No CO_2	10% (v/v) CO_2	No CO_2	10% (v/v) CO_2	No CO_2	10% (v/v) CO_2
2.1	0.48	67	71	65	73	14	6	57	56
3.5	**0.29**	**87**	**91**	**76**	**89**	**23**	**22**	**74**	**62**
5.3	0.19	91	86	59	85	17	22	66	61
6.5	0.15	96	81	76	81	26	18	66	58
8.7	0.11	97	91	76	81	9	27	55	56
10.4	0.10	97	93	76	89	13	41	66	50

The bold values refer to the highest removal efficiency, thus was the chosen HRT and Dilution rate.

Tratamento Esgotos



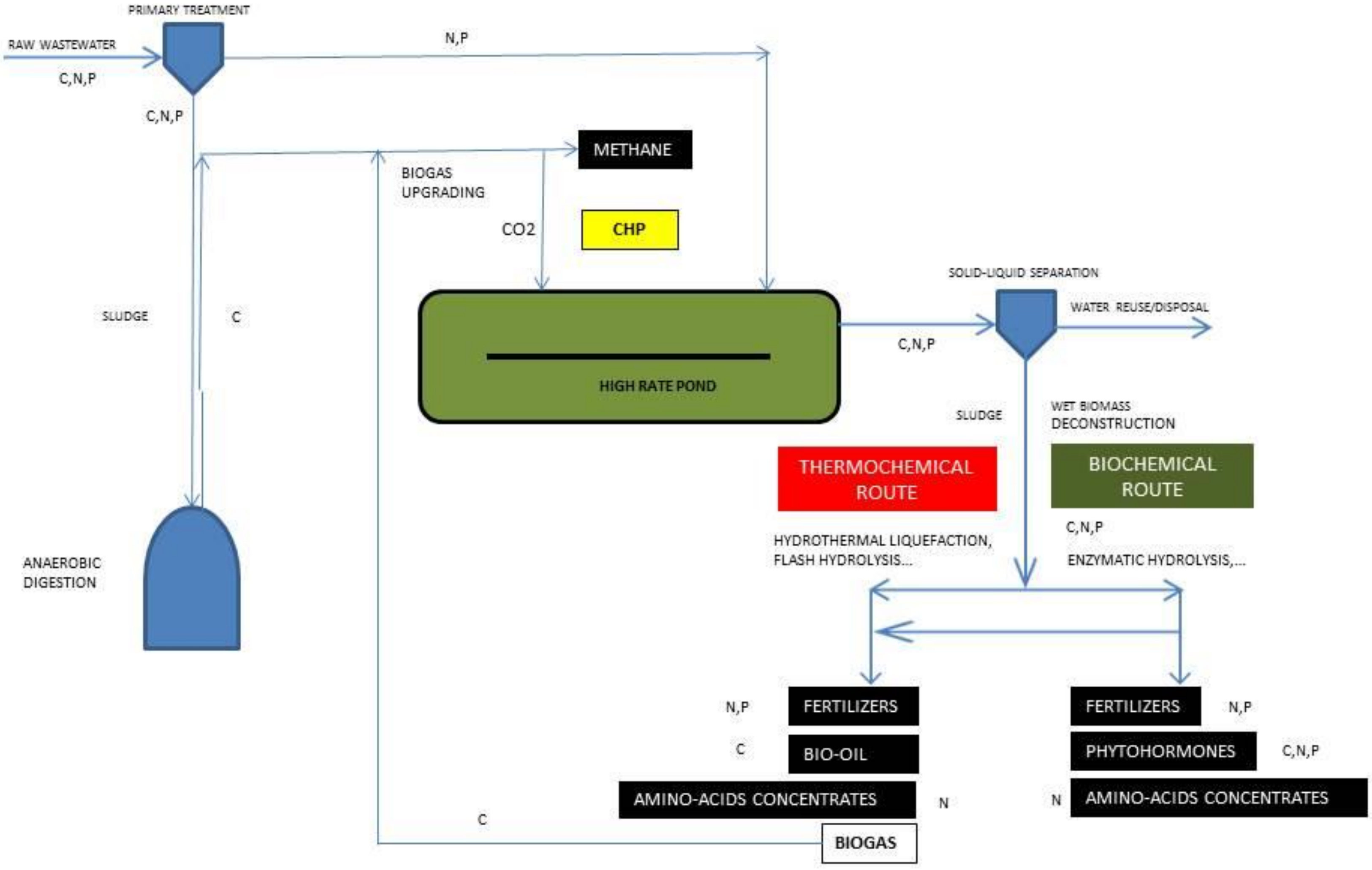
EXPECTED OUTPUTS

EU-28; Reference load: 496 Million population equivalent (p.e.);

Raw urban wastewater (WW) generation per population equivalents (p.e.) per year (m^3)	54.75
Kg microalgal biomass to be produced /m^3 raw WW	1
Kg SST/m^3 raw WW	0.6
Kg Sludge generation (microalgae+TSS)/m^3 raw WW	1.6
Kg Sludge generation (microalgae+TSS)/ per population equivalents (p.e.) per year	87.6
Sludge generation (EU-28)/year	4.3 Mton
Bio-oil production (EU-28)/year	2.82 Mton
Drop-in fuel production (EU-28)/year	1.84 Mton
Drop-in fuel production (EU-28)year	1.89 Mm^3

>1% share

Gross inland consumption of energy within the EU-28 in 2014 was **1 606 million ton** oil equivalent (Mtoe) (Source: EUROSTAT)



PRIMARY TREATMENT
RAW WASTEWATER
C,N,P
N,P
C,N,P
METHANE
BIOGAS
UPGRADING
CO2
CHP
SLUDGE
C
SOLID-LIQUID SEPARATION
WATER REUSE/DISPOSAL
C,N,P
HIGH RATE POND
SLUDGE
WET BIOMASS
DECONSTRUCTION
THERMOCHEMICAL ROUTE
BIOCHEMICAL ROUTE
C,N,P
ANAEROBIC
DIGESTION
HYDROTHERMAL LIQUEFACTION,
FLASH HYDROLYSIS...
ENZYMATIC HYDROLYSIS,...
N,P
FERTILIZERS
C
BIO-OIL
AMINO-ACIDS CONCENTRATES
N
C
BIOGAS
FERTILIZERS
N,P
PHYTOHORMONES
C,N,P
N
AMINO-ACIDS CONCENTRATES

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Hydrothermal liquefaction of biomass produced from domestic sewage treatment in high-rate ponds

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ABSTRACT

This study evaluates the application of biomass produced from the treatment of domestic sewage in high-rate ponds (HRPs) as feedstock for the production of bio-oil *via* hydrothermal liquefaction (HTL). The effects of reaction time, temperature, and biomass/water ratio on the yield of bio-oil were assessed. In addition, a balance of carbon and nitrogen among the products (bio-oil, aqueous phase, solid residue, and gas) was carried out, in order to evaluate the quality of the bio-oil and possibilities for increasing value from the byproducts. In a 15-min operation at 300 °C with biomass/water ratio of 1/10 ($w.w^{-1}$), the bio-oil yield was of 44.4% (Dry Ash Free - daf-basis). Under every condition tested, the solid residue was the most abundant byproduct, mostly due to the high ash content in the biomass. The minimum nitrogen recovery in the bio-oil was 57%, obtained in the operation at 275 °C, which is considered the main disadvantage of the process. The use of biomass directly after its production may result in an excessive consumption of energy due to the high water content. However, the need for drying is reduced when compared to other microalgal-based bioenergy production processes, potentially achieving a positive energy balance in the HTL.

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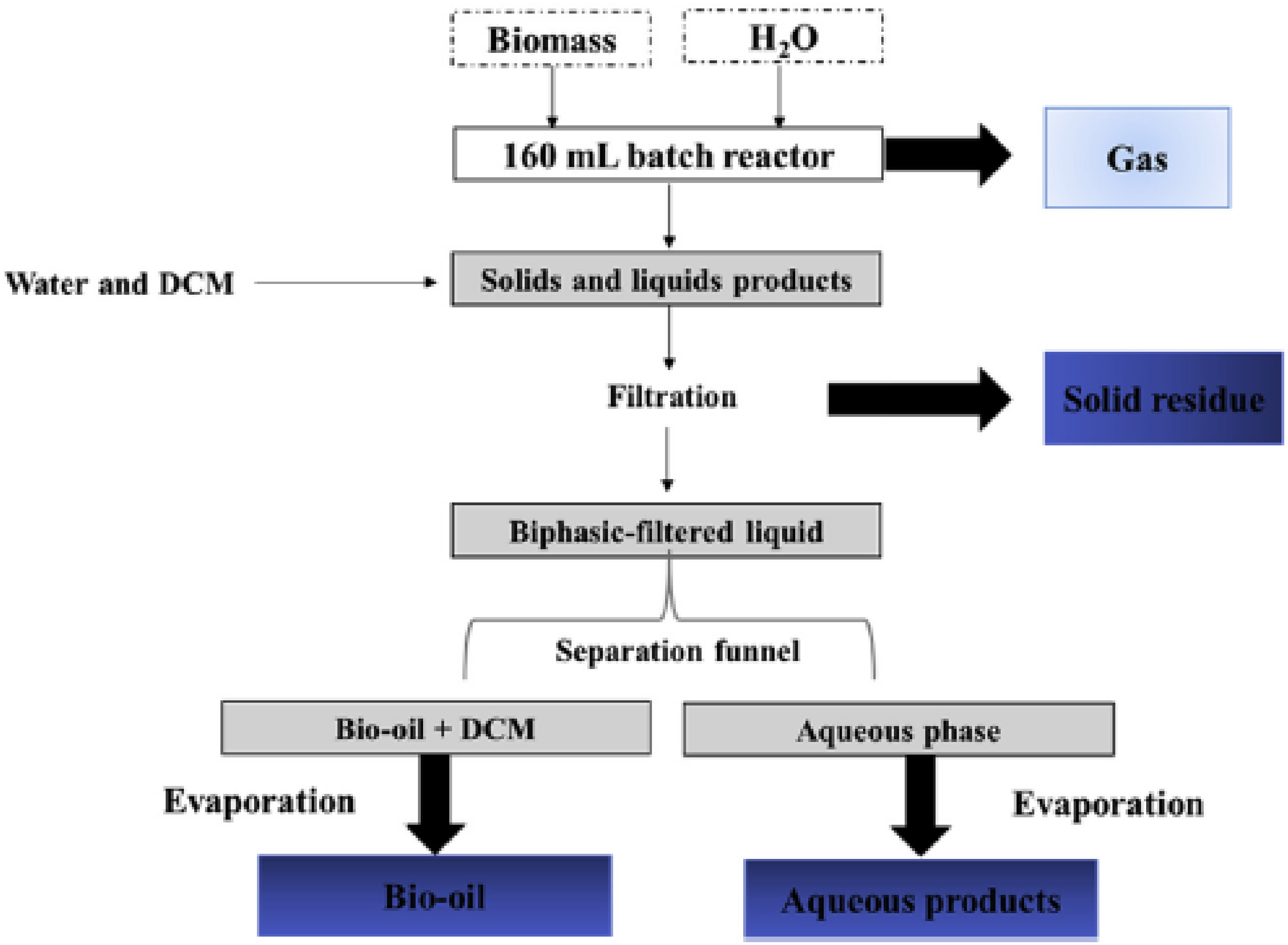
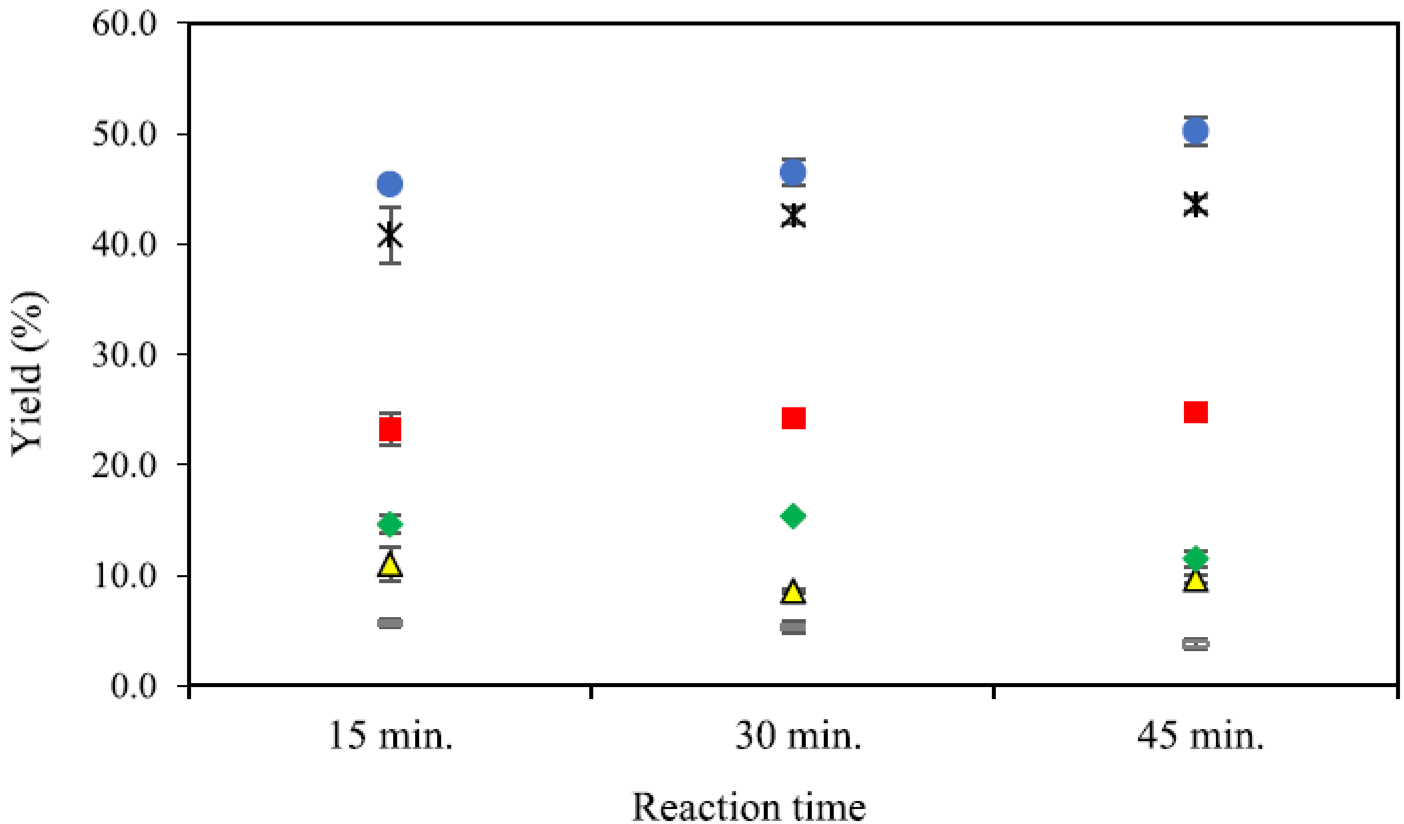


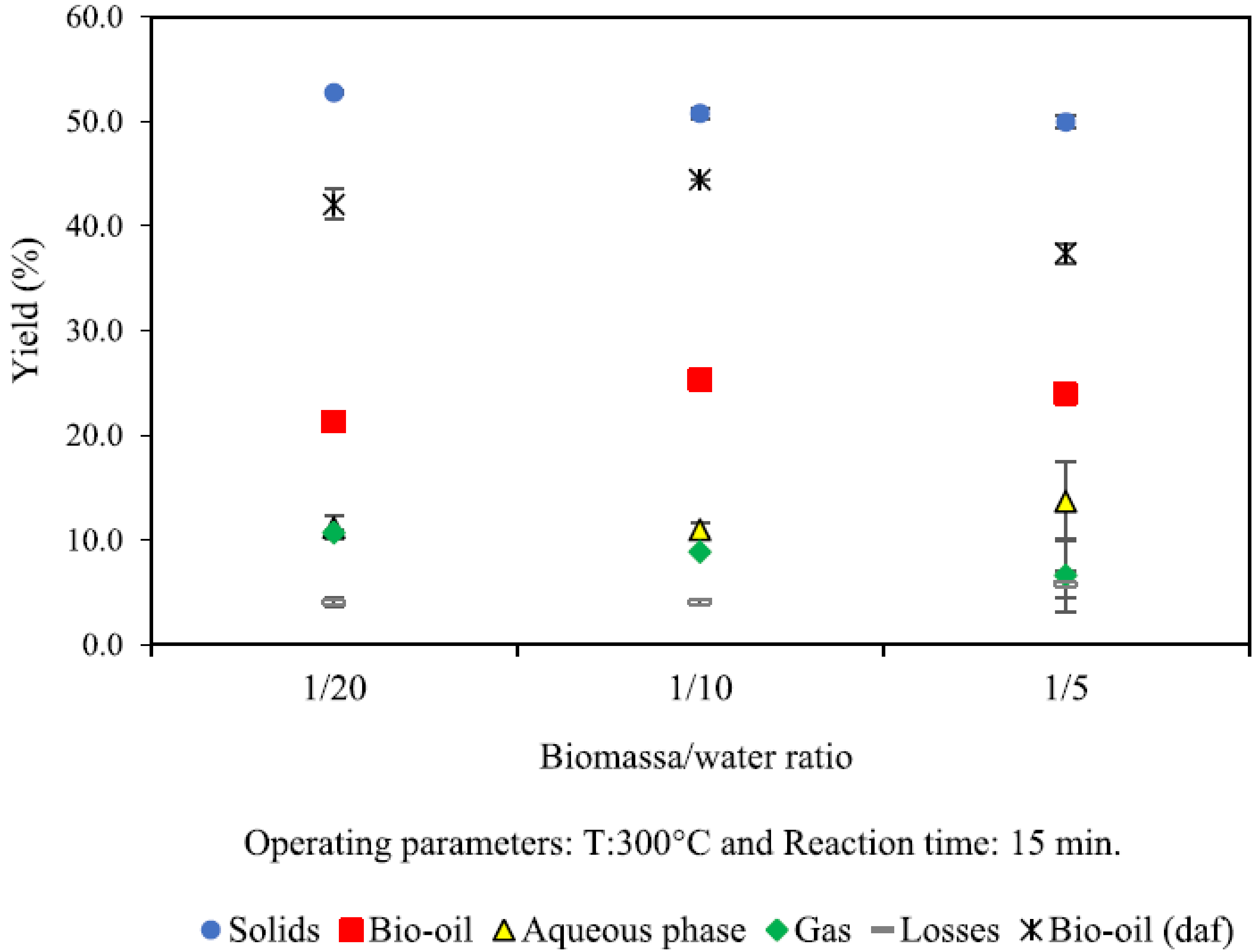
Processes for separation of the HTL products.



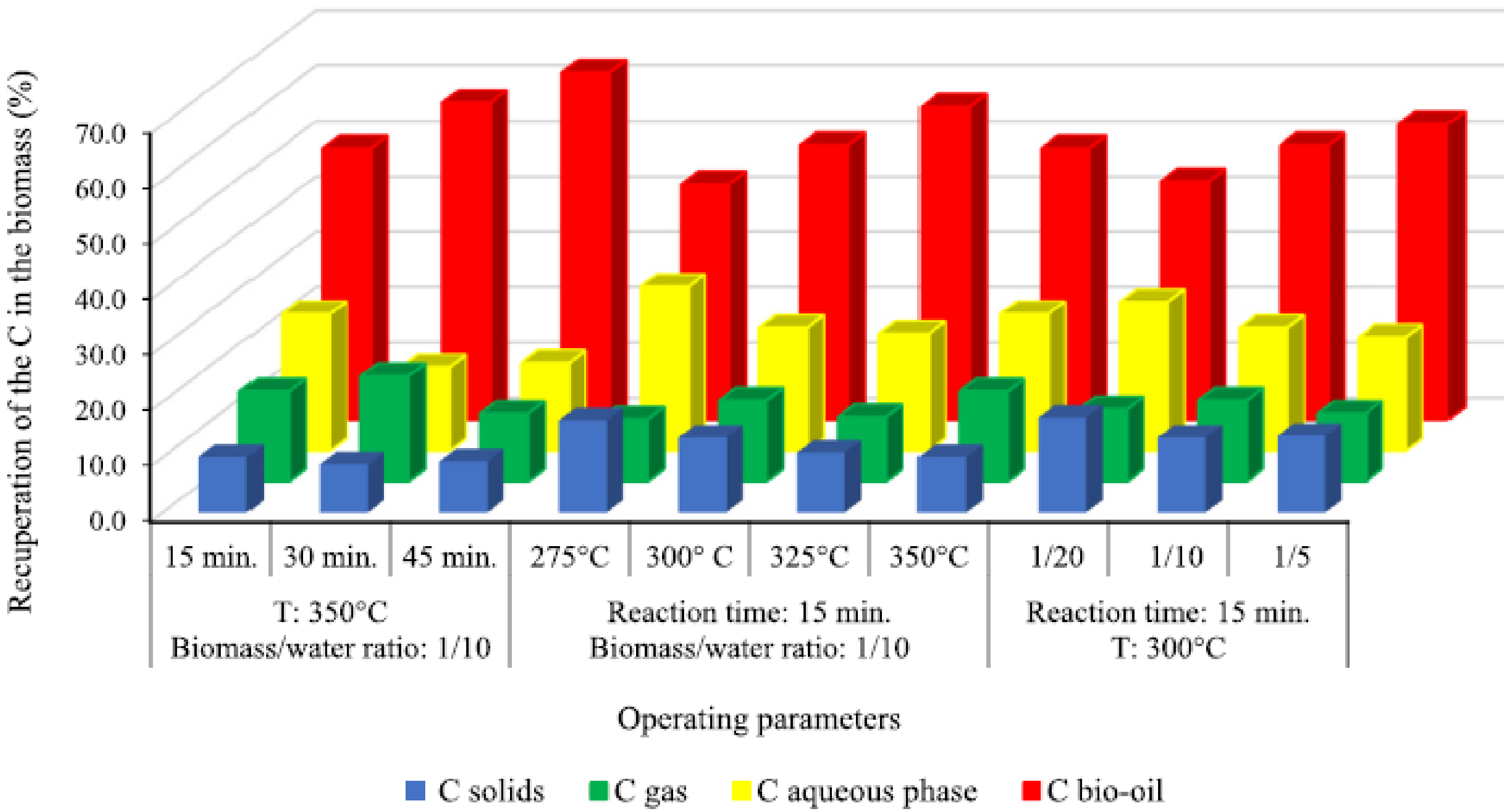
Operating parameters: T:350°C and biomass/water ratio: 1/10

● Solids ■ Bio-oil △ Aqueous phase ◆ Gas ▭ Losses ✱ Bio-oil (daf)

daf=dry ashfree basis



daf=dry ashfree basis



. Balance of C in the biomass among the HTL products.

ECR= CONSUMED ENERGY / RECOVERED ENERGY

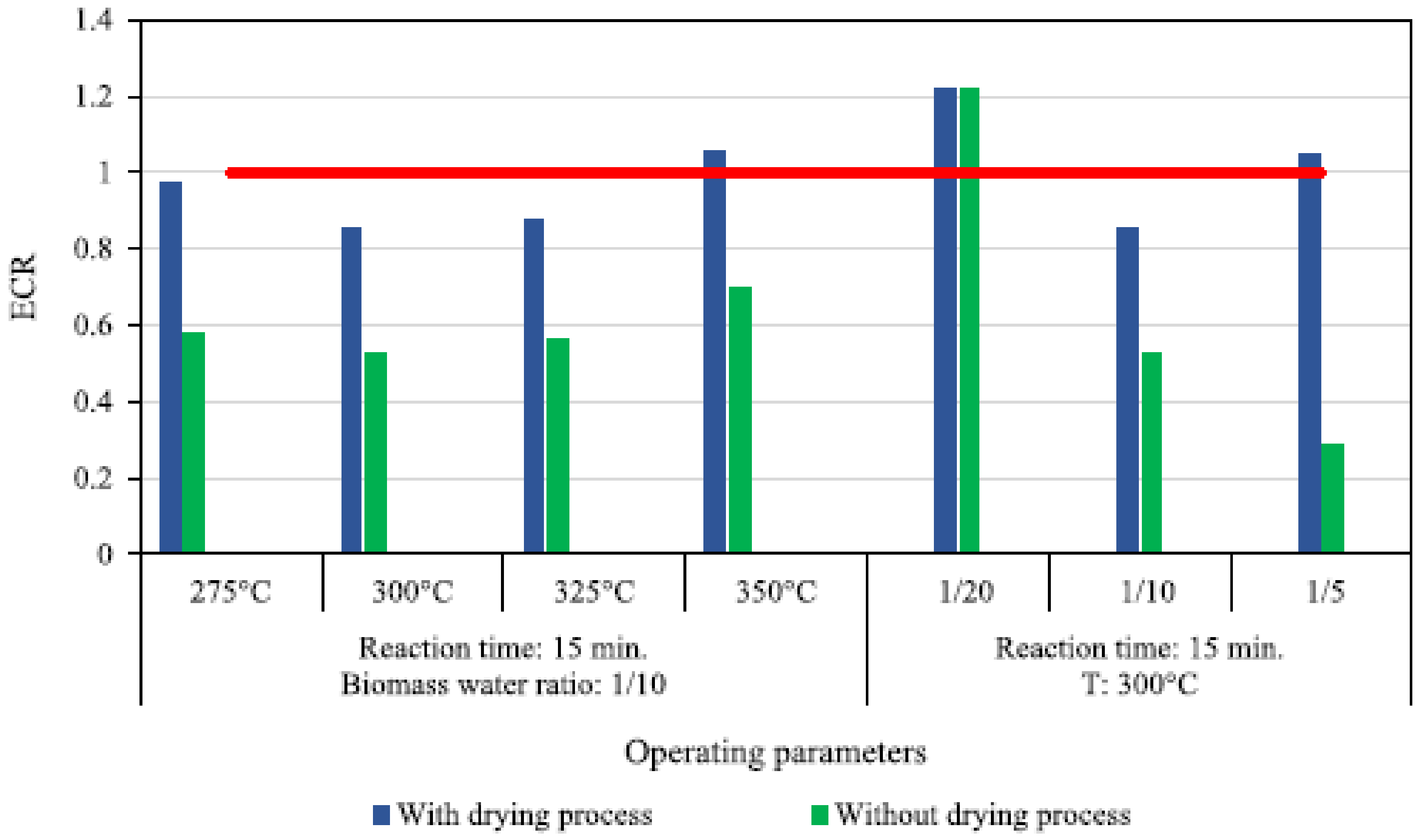


Fig. 7. Energy consumption ratio for the conditions assessed in the HTL.

HURDLES

ARE BIOFUELS FROM MICROALGAE TRULY GREEN?

NER NET ENERGY RATIO = CONSUMED ENERGY / PRODUCED ENERGY

PROCESS	GASOIL	BIODIESEL SOYA	BIODIESEL ALGAE	BIODIESEL ALGAE +BIOGAS	BIOETHANOL SUGARCANE
NER	0.19	1.64	0.93	0.35	0.12

Batan *et al.*, 2010; Oliveira *et al.*, 2012;

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Obrigado pela vossa atenção!

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