

Food and Fuel Microalgae Applications – Insights from the Portuguese Experience

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GOVERNO DE PORTUGAL | MINISTÉRIO DO AMBIENTE, ORDENAMENTO DO TERRITÓRIO E ENERGIA

Portugal

Good conditions for microalgae growth:
- Warm and mild weather (10-25ºC)
- Low rainfall (0-300 L/m^2/month)
- High number of insulation hours (100-350 h/month)
- Large coastal areas, including Madeira and Azores Archipelagos

Associação Portuguesa de Algologia Aplicada

EABA
EUROPEAN ALGAE BIOMASS ASSOCIATION

President: Dr. Vitor Verdelho, A4F

ALGA+

ACOI
Coimbra Collection of Algae

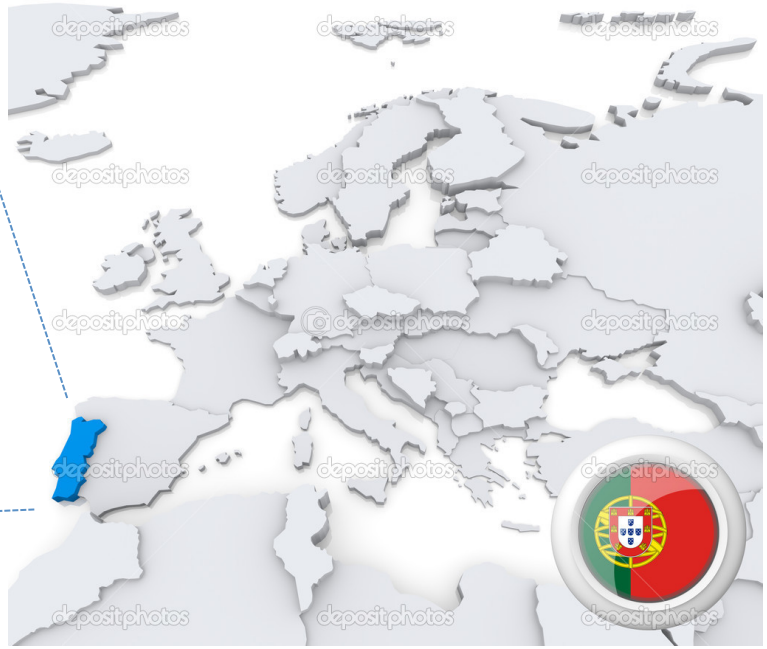
a4f
algae for future

INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa

LNEG

BUGGYPOWER
Microalgae life creators

necton



LNEG (ex-INETI)
Laboratório Nacional de Energia e Geologia

More than 25 years experience in microalgae biotechnology, including:

- Animal Feed (e.g. poultry, aquaculture)
- Food
- Bioactive compounds (e.g. carotenoids, EPA, DHA, SOD)
- Effluent treatment
- CO_2 fixation
- Autotrophic / Heterotrophic bioreactors
- Biofuels (Hydrocarbons, Biodiesel, Bioethanol, $BioH_2$, $BioCH_4$)
- Biorefineries

ESSEM COST Action ES1408
European network for algal-bioproducts (EUALGAE)
Vice-Chair: Dr. Luísa Gouveia (luisa.gouveia@lneg.pt)

Coordinator LNEG
Dr. Alberto Reis
(alberto.reis@lneg.pt)

Microalgae Food Applications
Univ. Lisboa - ISA- LEAF

(*Linking Landscape, Environment, Agriculture and Food*)

INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa

- More than 100 years in Agrarian Sciences Education
- Extensive research experience in Food Science (LEAF – Group IV - **Eco-Novel Food & Feed**)
- Specialists in **Food Rheology and Texture** – Complex food matrixes design and analysis, particularly colloidal food systems – protein/polysaccharide interaction and technological functionality.
- Thorough experience in **novel food product development** (e.g. gluten-free, vegetarian, high-fiber, low calorie)
- **Since 2003 – Research and development of microalgae derived food products**

LEAF
LINKING LANDSCAPE, ENVIRONMENT, AGRICULTURE AND FOOD

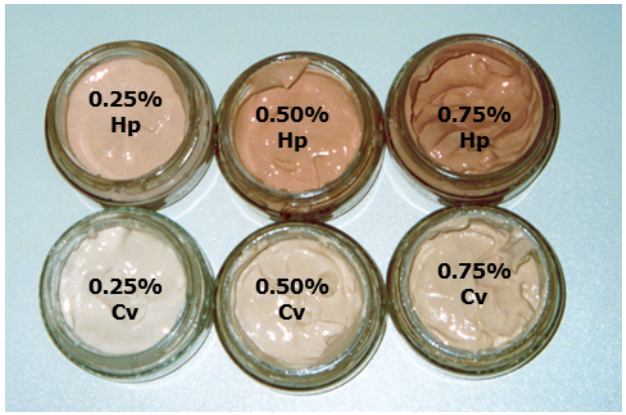
Microalgae Food Applications

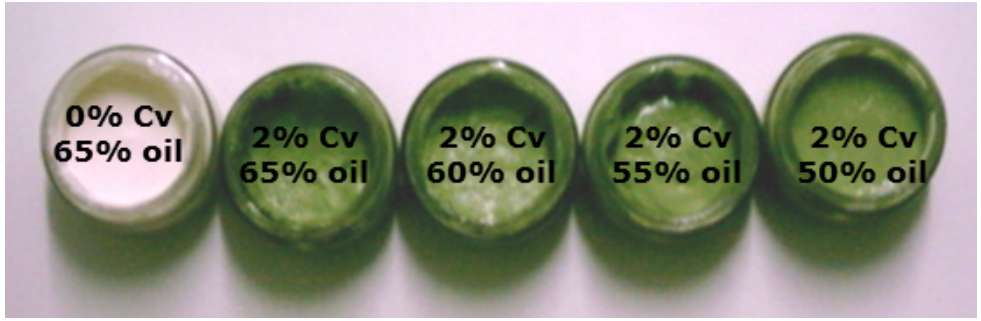
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Project: "Pigments, antioxidants and PUFA's in microalgae based food products – functional implications" **(PTDC/AGR-ALI/65926/2006)**

Instituto PIAGET · LNEG · Instituto Superior de Agronomia, Universidade de Lisboa · ipimar Instituto de Investigação das Pescas e do Mar · Faculdade de Farmácia, Universidade de Lisboa · Universidad de Huelva

Pea protein o/w emulsions **(vegetarian "mayonnaise")**





- Colour and texture stability.
- Enhanced resistance to oxidation (e.g. *Haematococcus*).
- Improvement of the emulsions structural properties - ***"fat mimetic"*** **effect** – lower oil content needed

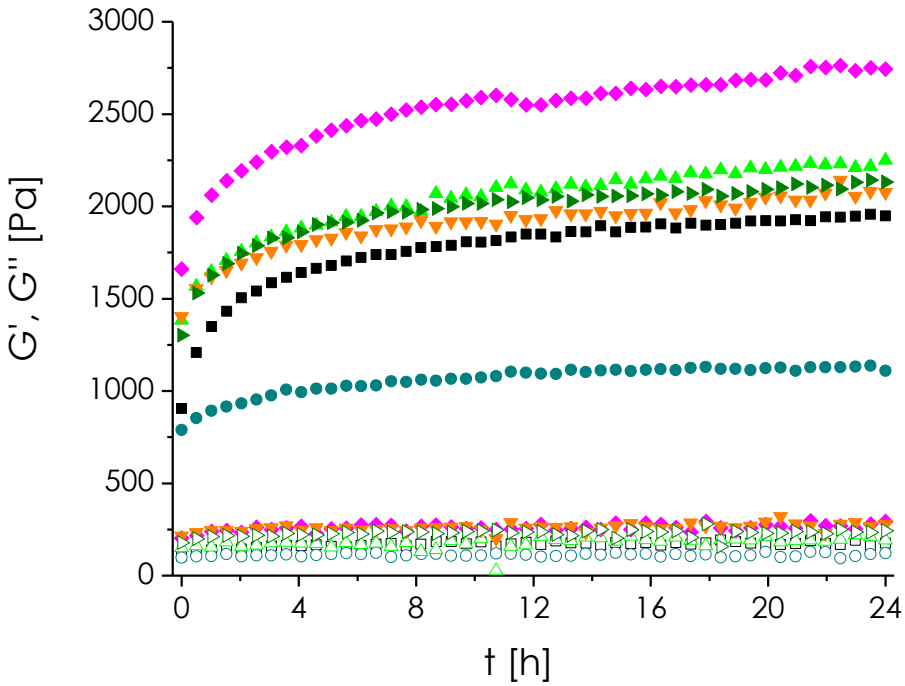
[Raymundo *et al.*, *Food Res Int*, 2005, **38**, 961.]

[Gouveia, *et al*, *Eur Food Res Technol*, 2006, **222**, 362.]

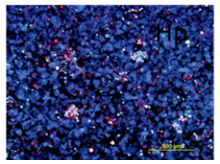
Microalgae Food Applications

Non-dairy vegetarian desserts (pea protein/polysaccharides mixed gels)

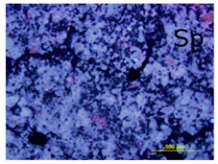
- **Good thermal resistance** (up to 90ºC) - stable colour and carotenoid content
- **Structural effects** – gel setting (e.g. higher T_{gel} at milder thermal processing conditions, avoiding degradation of natural biomolecules



Haematococcus
Structural reinforcement
Higher fat content



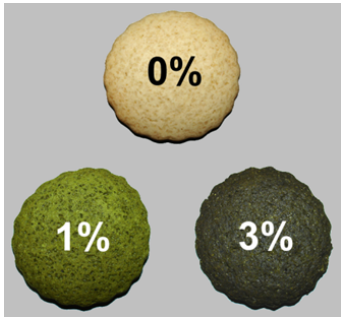
Spirulina
Destabilization process
Competitive interaction



[Gouveia et al (2008) *Nutrition and Food Science*, 38(5)] [Batista *et al* (2008) In *Gums and Stabilisers for the Food Industry 14.* Eds. Williams & Phillips. RSC. pp. 487-94] [Batista *et al* (2011) Food Hydrocolloids 25:817] [Batista *et al* (2012) J Food Eng 110:182] [Batista (2012) PhD Thesis, Universidad de Huelva, España]

Microalgae Food Applications

Biscuits



Pastas

- Both the biscuits and pastas with marine microalga *Isochrysis galbana* biomass presented a high content of PUFA's (EPA+DPA+DHA) – high resistance to termal treatment

[Gouveia *et al* (2007) *Innov Food Sci Emerg Technol* **8**:433] [Gouveia *et al* (2008) *J Sci Food Agric* 88:891]
[Fradique *et al* (2010) *J Sci Food Agric* 90:1656] [Fradique *et al* (2013) *LWT* 50:312]

… Novel products, projects and challenges

ALGA2FUTURE: Production of microalgae for novel food and feed products, using low cost carbon sources.
Norwegian Research Council

BioForsk

Microalgae Functional Foods

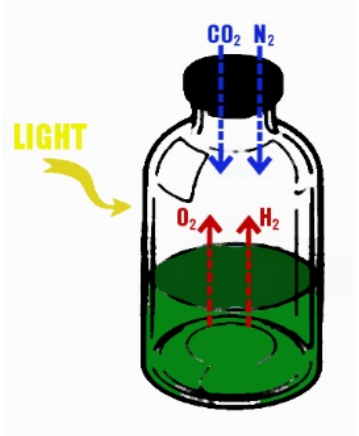
Universidad de Antofagasta
Prof. Pedro Cerezal Mezquita

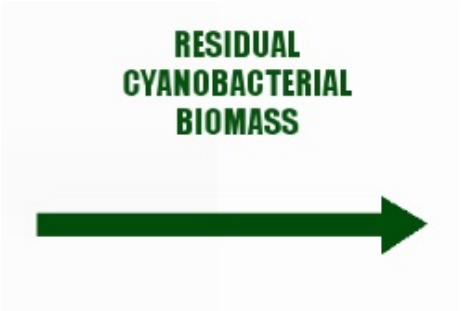
- Development of functional foods from microalgae
- Rheology as a tool for novel foods development
- Development and analysis of pastas (practical)
- Encapsulation of bioactive compounds from microalgae

Microalgae Biofuel Applications
Biorefinery approach

In the last years our team from LNEG-bioenergy group has been exploring several marine and freshwater species for biofuel production within a biorefinery approach, in order to obtain high and low-value co-products using integral biomass maximizing the energy and economical revenue.

Biorefinery - *Anabaena* sp.





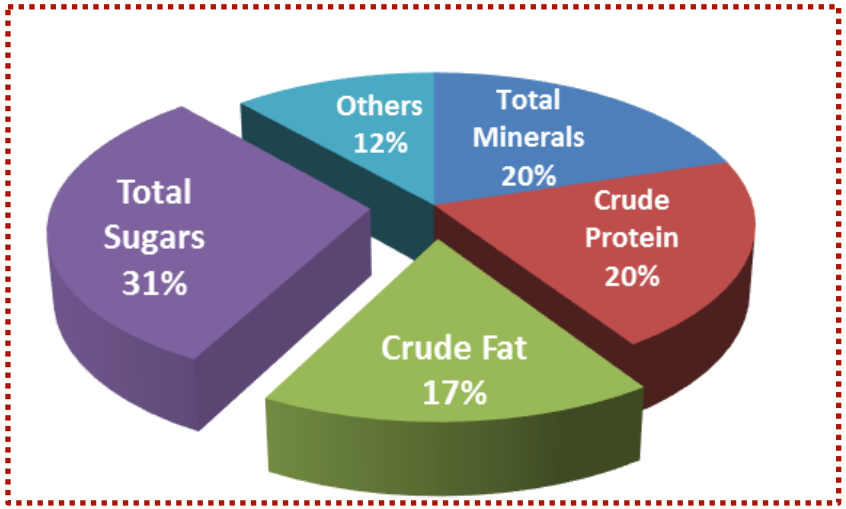
Photoautotrophic H_2 production by *Anabaena* sp.: 0.0128 $kgH_2/kg_{biomass}$

H_2 production by dark fermentation with a strain of the bacteria *Enterobacter aerogenes* bacteria: **↑ 8.1% H_2 yield**

[Ferreira *et al* (2012) *Int J Hydr Energy* **37**:179]

Project *"Biohydrogen production from the cyanobacteria Anabaena sp. and its mutants"* (PTDC/ENR/68457/2006)

Biorefinery *Scenedesmus obliquus*



Alcoholic fermentation ← *Sugar extraction*

Bioethanol

0.19 g EtOH/g $_{alga\ sugar}$

[Miranda et al (2012) Biores Technol 104:342 Miranda et al (2012). Appl Microbiol Biotechnol 96:555]

Transesterification ← *Oil extraction*

Biodiesel

0.16 g biodiesel/g $_{alga}$

[Gouveia & Oliveira (2009) J Ind Microbiol Biotechnol 36:269]

Residual Sc-Oils

346 mL CH_4/g VS_{alga}

Whole biomass

Residual Sc-Sugars

AD Inhibition

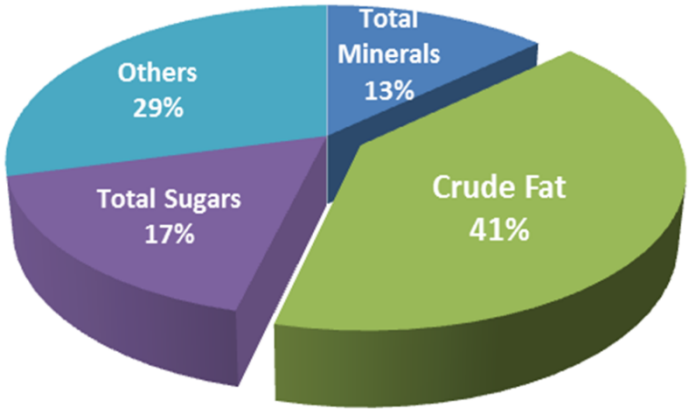
Anaerobic digestion

Biomethane

546 mL CH_4/g VS_{alga}

Project ***"Microalgae as a sustainable raw material for Biofuels Production (Biodiesel, Bioethanol, Bio-H_2 and Biogas)" (PTDC/AAC-AMB/100354/2008)***

Biorefinery Nannochloropsis sp.



Supercritical Fluid Extraction (SFE)
(CO_2 + EtOH (20%), 40ºC, 300 bar)

Oils for biodiesel + added value pigments
100% lipids recovery + 70% pigment recovery

Algal leftovers

Dark fermentation

Enterobacter aerogenes: 30ºC, 220 rpm, 6 h.

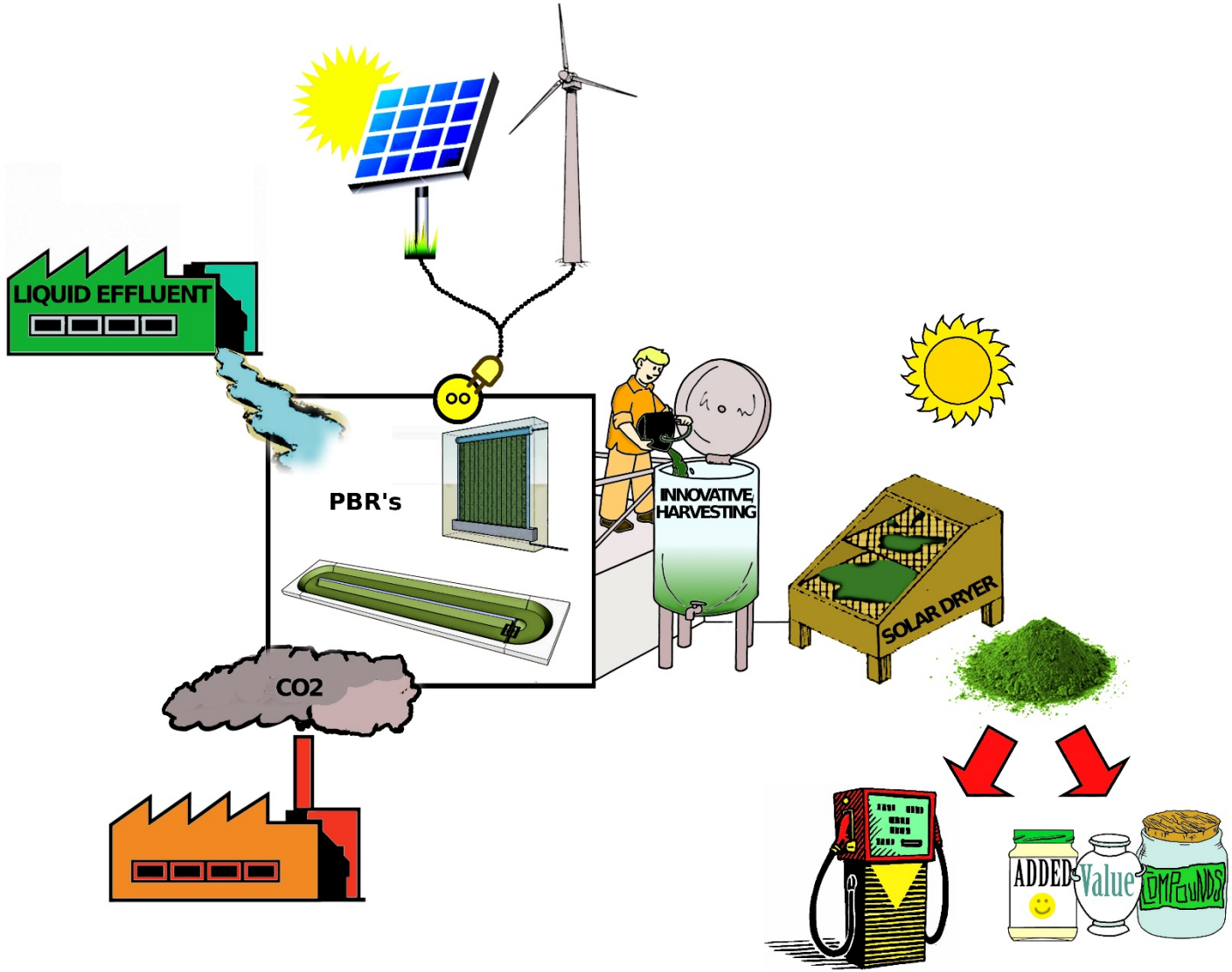
BioH_2 production

60.6 mL H_2/g dry biomass

Best energy/CO_2/economy compromise in comparison to other scenarios
(e.g. Soxhlet extraction, without bioH_2 leftover valorization)

[Nobre *et al* (2013) Biores Technol 135:128; Ferreira *et al* (2013) Biores Technol 138:235]
Project ***"Microalgae as a sustainable raw material for Biofuels Production (Biodiesel, Bioethanol, Bio-H_2 and Biogas)" (PTDC/AAC-AMB/100354/2008)***

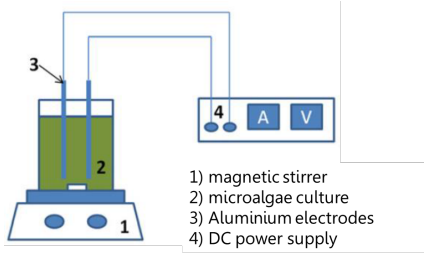
Compromise with sustainability

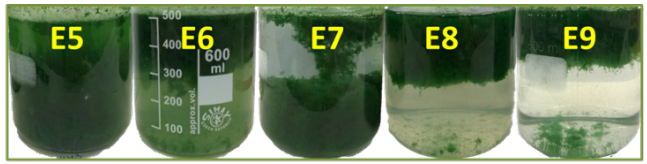


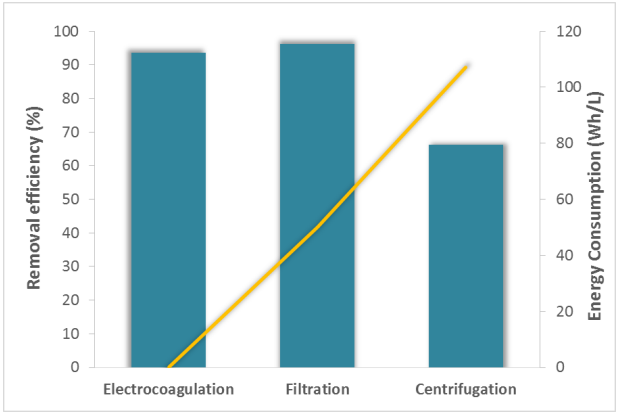
Post-Doctoral Grant *"Produção sustentável de microalgas para biocombustíveis e compostos de alto valor acrescentado, a partir de efluentes líquidos e gasosos com recurso a energias renováveis" (SFRH/BPD/84812/2012)*

Sustainability - alternative harvesting & drying

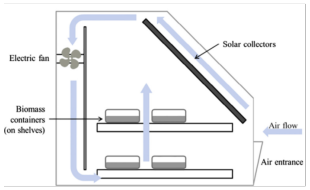
Electrocoagulation

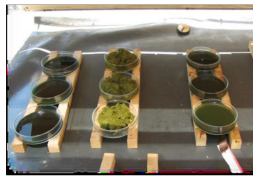


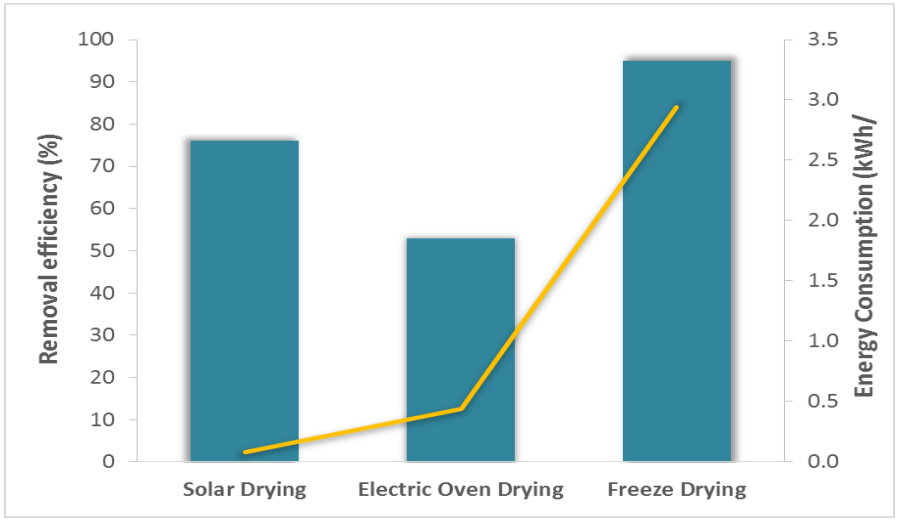




Solar dryer





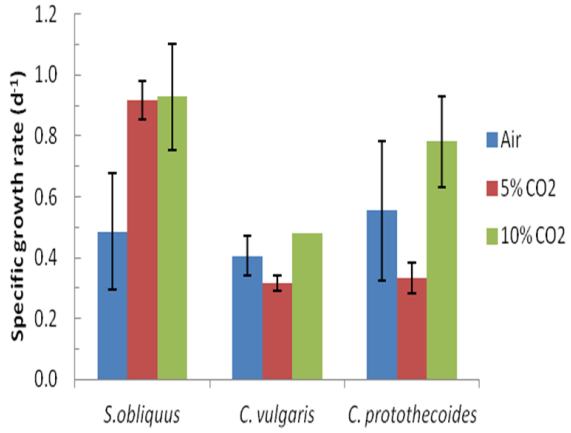


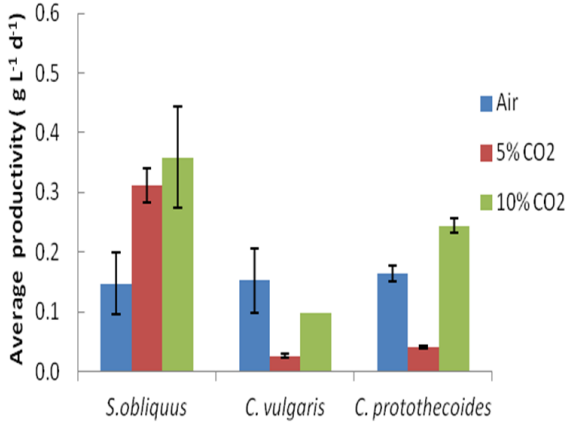
POSTER 6 (Session I, 26Oct):
Low-energy harvesting and drying methods for *Spirulina maxima*: effect on phycocyanin content
AP Batista, AC Monteiro, D Loureiro, L Gouveia, I Sousa

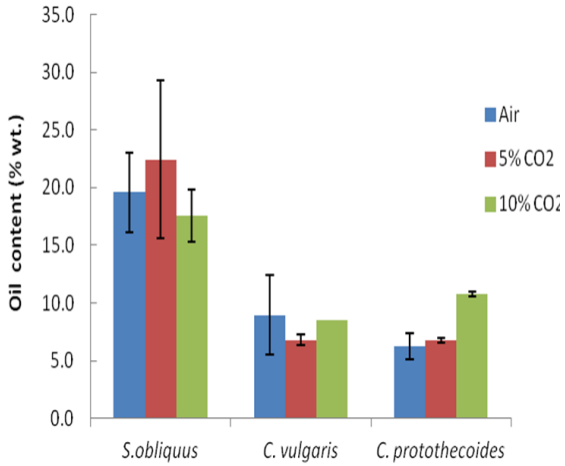
Sustainability - CO_2

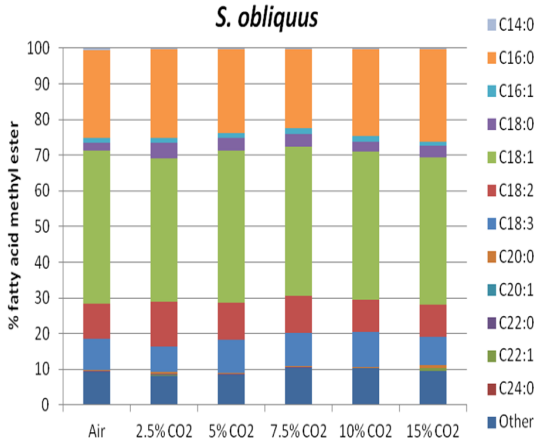
Chlorella vulgaris
Chlorella protothecoides
Scenedesmus obliquus

Great tolerance to high CO_2 levels (up to 15% v/v) with relatively high lipid accumulation (25% w/w) and an adequate fatty acid composition/profile for quality biodiesel production (EN14214)





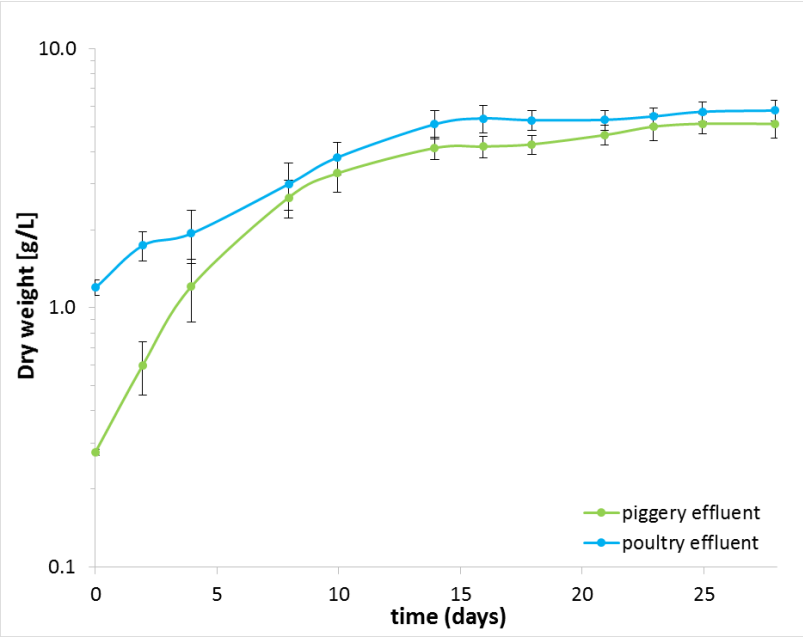




POSTER 15 (Session III, 28Oct):
Carbon dioxide biofixation and lipid accumulation by three green microalgae species at different CO_2 concentrations. J Leonardo, AP Batista, J Manoel, A Reis, P Marques, L Gouveia

Sustainability - Animal Effluents & CO_2

Piggery effluent (diluted at 5% v/v with tap water) - 204 mg/L $NH4^+$
Poultry industrial effluent: raw effluent (without dilution) - 185 mg/L $NH4^+$
5% (v/v) CO_2, 0.6 vvm
Scenedesmus obliquus



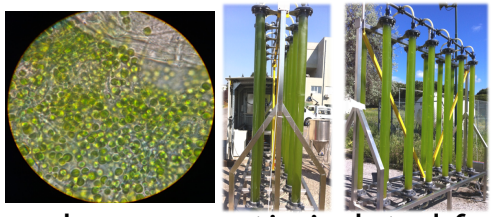
Effluent	NH_4^+ removal (%)	Max. DW (g/L)	Lipid fraction (g/100g)	Total Sugars (g/ 100g)
Piggery	97.4	5.6	**23.3**	23.6
Poultry	98.5	6.1	13.8	**41.4**

Project *"Biosustain - Sustainable mobility: Perspectives for future biofuel production"* (PTDC/EMS-ENE/1839/2012)
Collaboration with a student from Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional (México)

POSTER 16 (Session III, 28Oct):
Bioremediation of piggery effluents using *Scenedesmus obliquus* microalga
AP Batista, V Mirón, B Ribeiro, T Lopes-da-Silva, IP Marques, B Barragán, L Gouveia

Sustainability – Urban Wastewaters

Photobioreactor (microalgae + wastewater)



Microalgae consortia isolated from WW
150 L tubular PBR

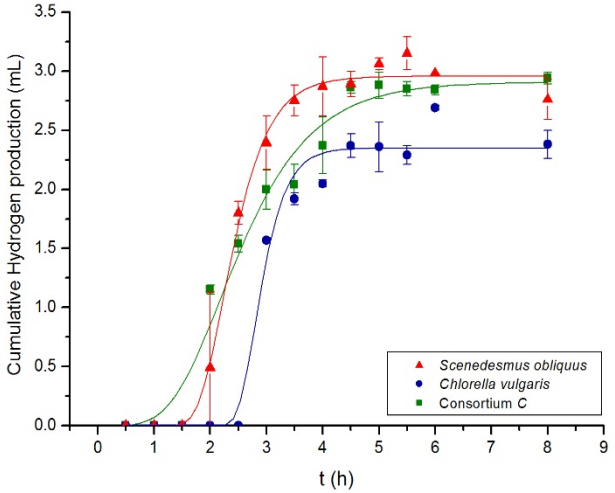
Treated wastewater

P and N removal rates >98%

Algal Biomass

STRESS
Sugar accumulation

Microalgae culture kept under nutritional stress for 2 weeks after nutrient depletion



[Batista *et al* (2015) Biores Technol 184:230]

Bio-energy production

H_2 Dark Fermentation
46.8 mL H_2/g VS_{alga}

LIFE10 ENV/IT/000308

Project *"WW-SIP – From urban wastewater treatment plant to self-sustainable integrated platform for wastewater refinement"* (LIFE10 ENV/IT/000308)

Collaboration with a PhD student from Universidade Federal de Lavras (Brazil)

Sustainability - Beer industry effluents

ERANet LAC

Project ***"GREENBIOREFINERY - Processing of brewery wastes with microalgae for producing valuable compounds"*** (ELAC2014/BEE0357)

Kick-Off: October 2015

UNIVERSIDAD DE ALMERÍA

Coordinator

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GENTE Y PRODUCTOS DE LA MEJOR CALIDAD

Central
Cervejas e Bebidas

Acknowledgements

Research grant SFRH/BPD/84812/2012 (A.P. Batista)
Fundação para a Ciência e Tecnologia for Post-Doc Grants SFRH/BPD/84812/2012, SFRH/BPD/100283/2014 & Projects PTDC/AGR-ALI/65926/2006, PTDC/ENR/68457/2006, PTDC/AAC-AMB/100354/2008 PTDC/EMS-ENE/1839/2012. European Union 7FP For Project LIFE2010ENV/IT/308.

Thank you for your attention!

LNEG
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