Life cycle assessment of biomethane from wastewater algae

The All-Gas approach

Biorefineries

Microalgae session

Dr.-Ing. Daniel Maga

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Germany

Department: Resources and Innovation Management

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SEVENTH FRAMEWORK PROGRAMME

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Content

- **The All-Gas project**
- Goal and scope of the life cycle assessment
- Results and discussion
- Conclusions

1
2
3
4

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»Industrial scale demonstration of sustainable algae cultures for biofuel production« – The All-Gas Approach

Objectives

- Large demonstration plant: Farming area 10 hectares
- Full industrial plant: from biomass production to fuel processing and fleet demonstration
- To use only carbon from non-fossil fuel sources for growth supplementation (CO_2 from biogas and biosolid combustion)
- To achieve yields > 90 t of algal biomass $ha^{-1}*yr.^{-1}$ ($25*g*m^{-2}*d^{-1}$)
- To make use of the wastewater nutrients for algal growth

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All-Gas Pilot Plant in Chiclana de la Frontera

- 10 ha open ponds supplied with pre-treated wastewater
- Production of biogas
  - by upflow anaerobic sludge blanket (UASB) and
  - by anaerobic digester
- Upgrading of biogas to biomethane as fuel

Photo of the All-Gas pilot plant

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1
2
3
4

Life cycle assessment methodology

Common methodology of the Algae Cluster:
http://www.algaecluster.eu/

3 case LCA studies

- All-Gas
- InteSusAl
- BIOFAT

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Unified approach to Life Cycle Assessment between three unique algae biofuel facilities ☆

Tom Bradley [a,*], Daniel Maga [b], Sara Antón [c]

[a] UK National Renewable Energy Centre, United Kingdom
[b] Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Germany
[c] Abengoa Bioenergy S.A., Spain

HIGHLIGHTS

- Description of the Algae Cluster, a set of three European Commission funded algae biofuel demonstration facilities.
- Discussion of various issues within the LCA of algae biofuels with regard to the methodologies used.
- Development of a common LCA methodology for the comparison of three different algae biofuel demonstration facilities.

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ABSTRACT

The Algae Cluster is a group of three European Commission funded projects, each building a different demonstration algae biofuel facility up to 10 hectares in size. Each project is carrying out an independent Life Cycle Assessment (LCA) to understand the various environmental impacts of the biofuel production.

A major issue with LCA is that there is a high flexibility on defining metrics such as the boundary conditions, functional unit and impact categories. The LCA practitioners for these three projects have agreed upon a harmonised approach, with the intention of ensuring the projects are comparable. This paper details the logic behind this approach, and shares it with the community.

The purpose of this paper is to introduce the three algae demonstration projects and to present a harmonized methodology for LCA of algae biofuels. With this, work by different researchers may be compared more effectively, making it easier to measure the effectiveness of different strategies in algal biofuels with regard to sustainability.

1. Introduction

1.1. Algae biofuels

Algae based biofuels are one of many options to allow society to move to a low carbon society [1], which is necessary to reduce future levels of anthropogenic climate change. However, as with anything, the production of biofuels from an algae feedstock also goes along with environmental impacts. Life Cycle Assessment (LCA) is the most accepted method to quantify these impacts and thus provide options for reducing identified environmental impacts. This paper introduces three unique algae demonstration facilities, and describes the unifying of the LCA approach for these facilities.

Within the literature there are various good discussions on the differences in LCA methodologies, and the associated difficulties these cause, such as [2,3], including system boundaries, co-product allocation methods, electrical energy sourcing, and life cycle inventory data. An example of the differences caused by these inconsistencies is described in [4], where it is noted how the climate change impact results in the literature vary from 0.75 $kgCO_{2eq}$/MJ [5] to 5.34 $kgCO_{2eq}$/MJ [6] (with many studies producing figures between these extremes).

Due to these differences between studies, meta-analysis techniques have been developed such as the Meta-Model of Algae Bio-Energy Life Cycles (MABEL) discussed in [7]. This model adapts previous LCA studies to align the methodologies. Similar meta-models exist for biofuels, such as the Energy and Resources Group

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* Corresponding author at: UK National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ, United Kingdom and Institute for Sustainability (NIRES), Newcastle University, Newcastle, Tyne & Wear NE1 7RU, United Kingdom. Tel.: +44 (0)1670 357685.
E-mail address: tom.bradley@narecde.co.uk (T. Bradley).

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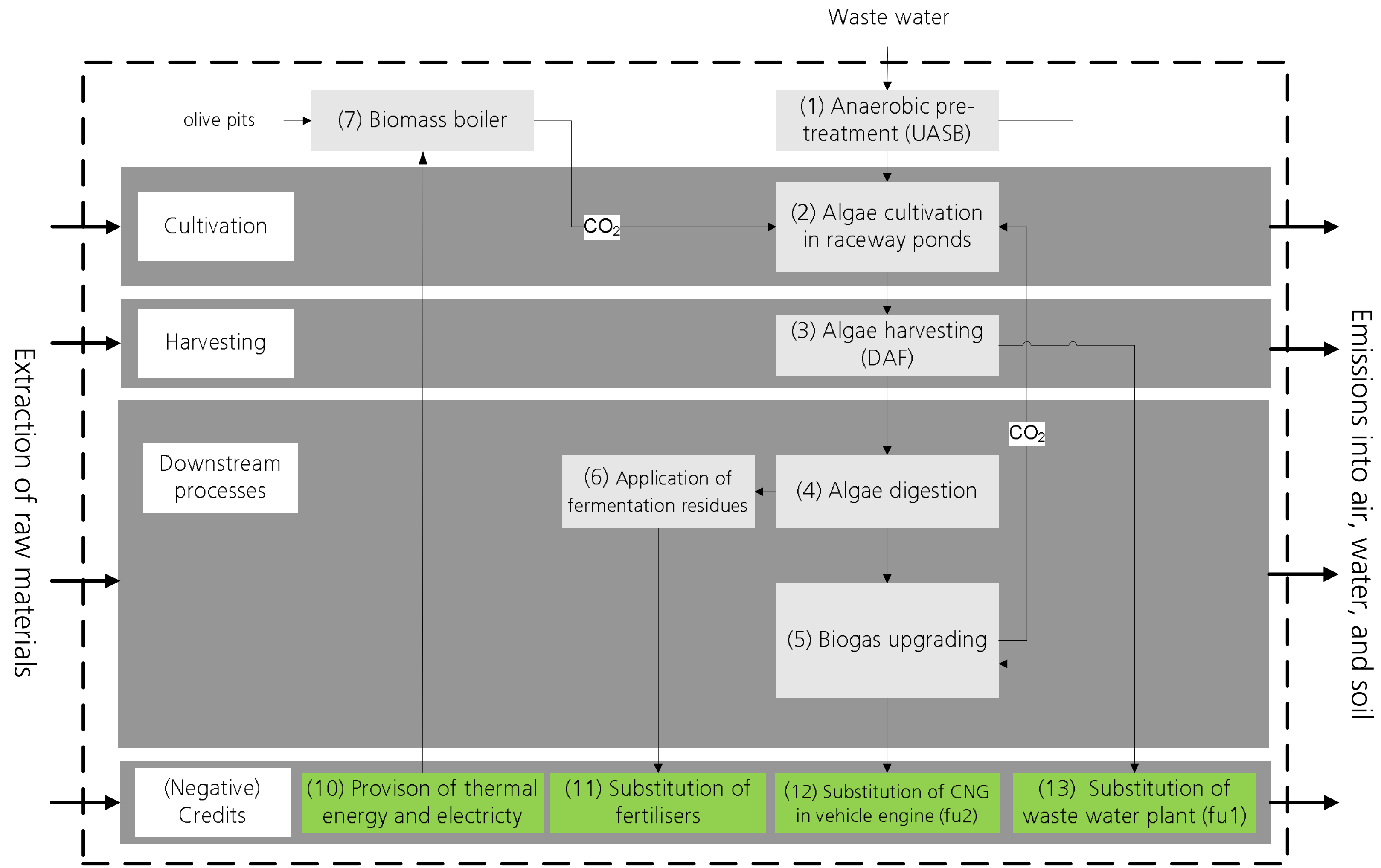
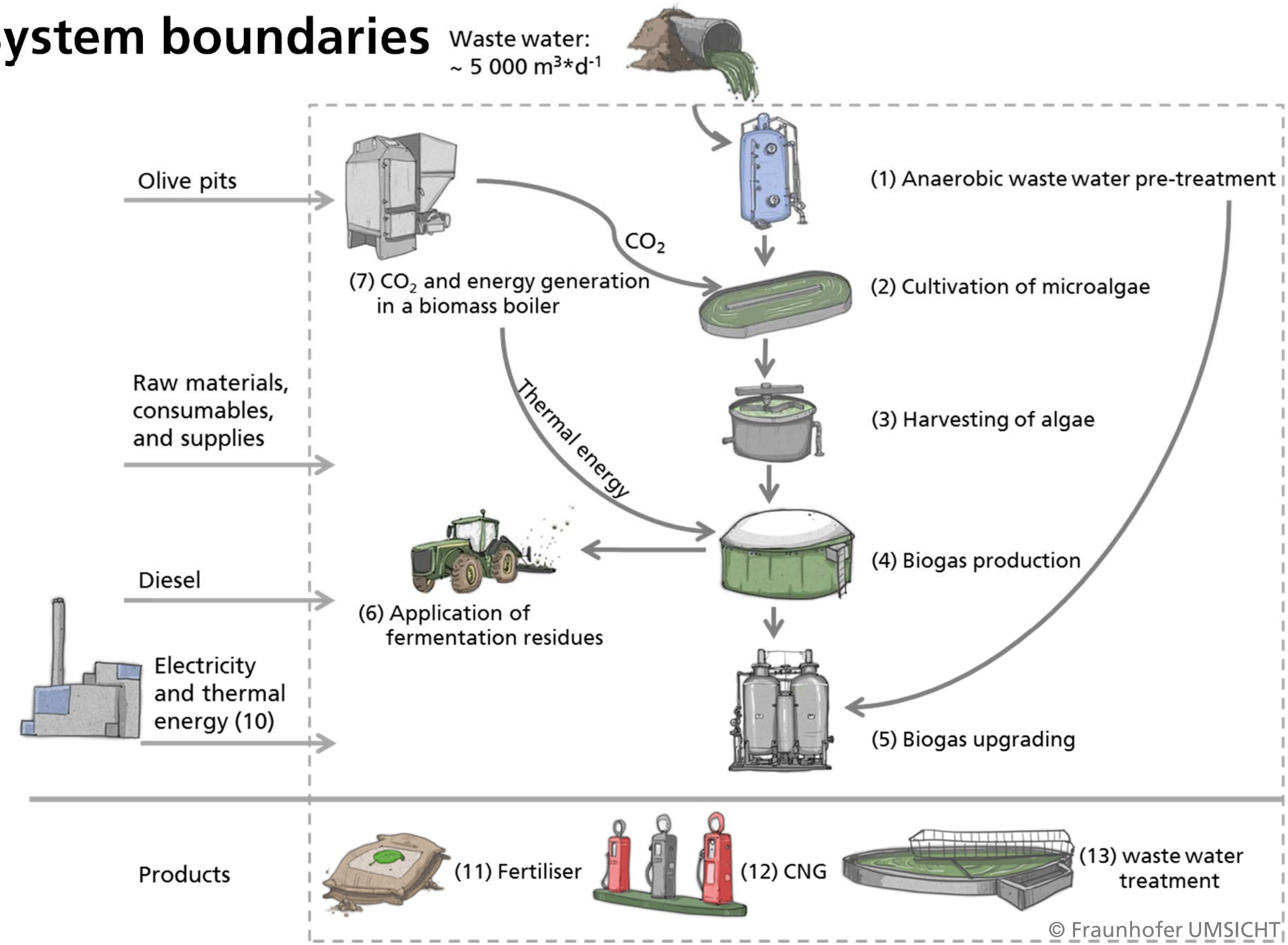
System boundaries and functional unit



Functional units (FU): FU1: 1 m^3 of treated waste water,
FU2: 1 MJ fuel in car engine

System boundaries



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Reference system: Conventional waste water treatment

- European average waste water treatment plant (10 000 - 50 000 per-capita-equivalents)
  - Anaerobic digestion of prim. and sec. sludge
  - 100 % anaerobic sludge to incineration
- Today, in small cities in Spain oxidation ditches are installed that perform worse
  - Higher electricity consumption
  - Sewage sludge to field
  - Higher nitrous oxide emissions

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Content

1
2
3
4

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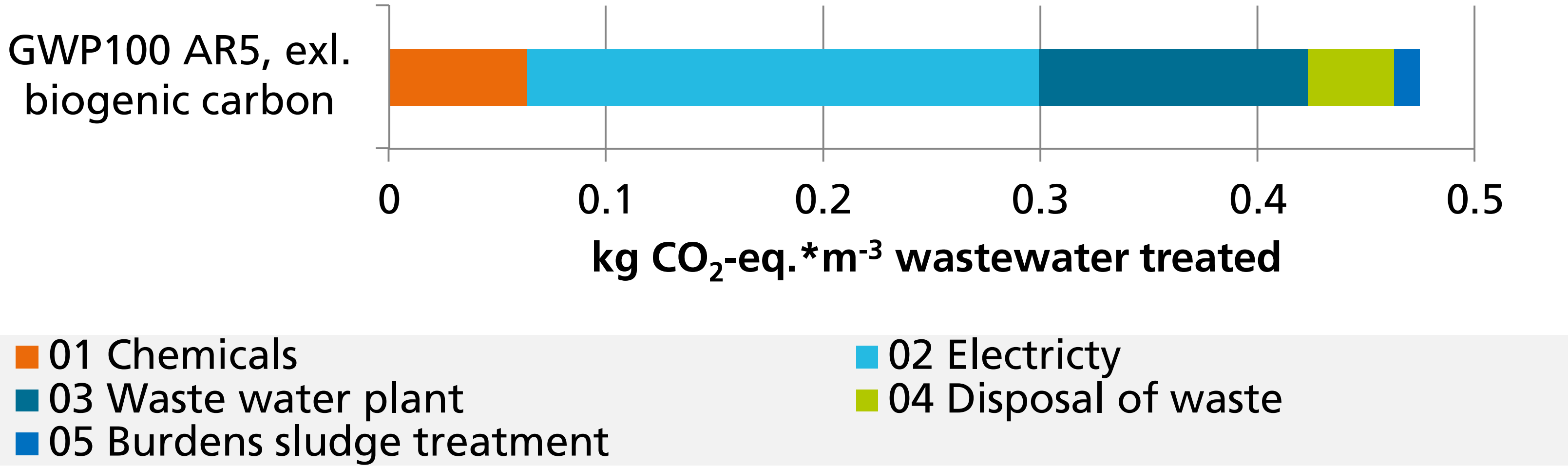
Carbon Footprint of reference waste water treatment

- 0.47 kg CO_2-eq.*m^{-3} of treated wastewater



- Main greenhouse gas (GHG) emissions can be traced back to the electricity demand of the WWT plant
  - total: 0.60 kWh*m^{-3}
  - net 0.49 kWh*m^{-3}

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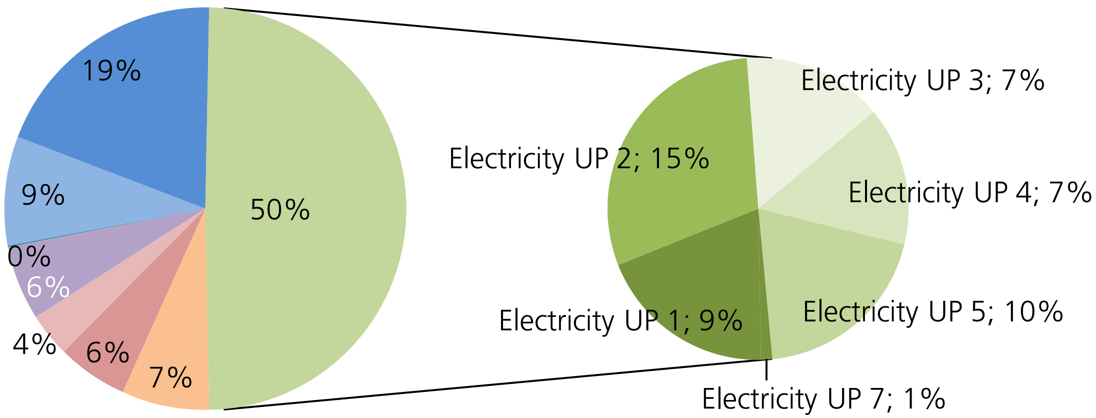
All-Gas: Distribution of primary energy demand (CED)



Total CED: 33 188 MJ*d^{-1}

- CED caused by electricity generation (green)

Indirect primary energy demand

- UP1: Anaerobic waste water pre-treatment
- UP2: Cultivation of microalgae
- UP3: Harvesting of algae
- UP4: Biogas production from algal biomass
- UP5: Biogas upgrading and provision at service station
- UP6: Application of fermentation residues on the field
- UP7: CO2 and energy generation in a biomass boiler

- Approx. 50 % of CED can be traced back to the electricity

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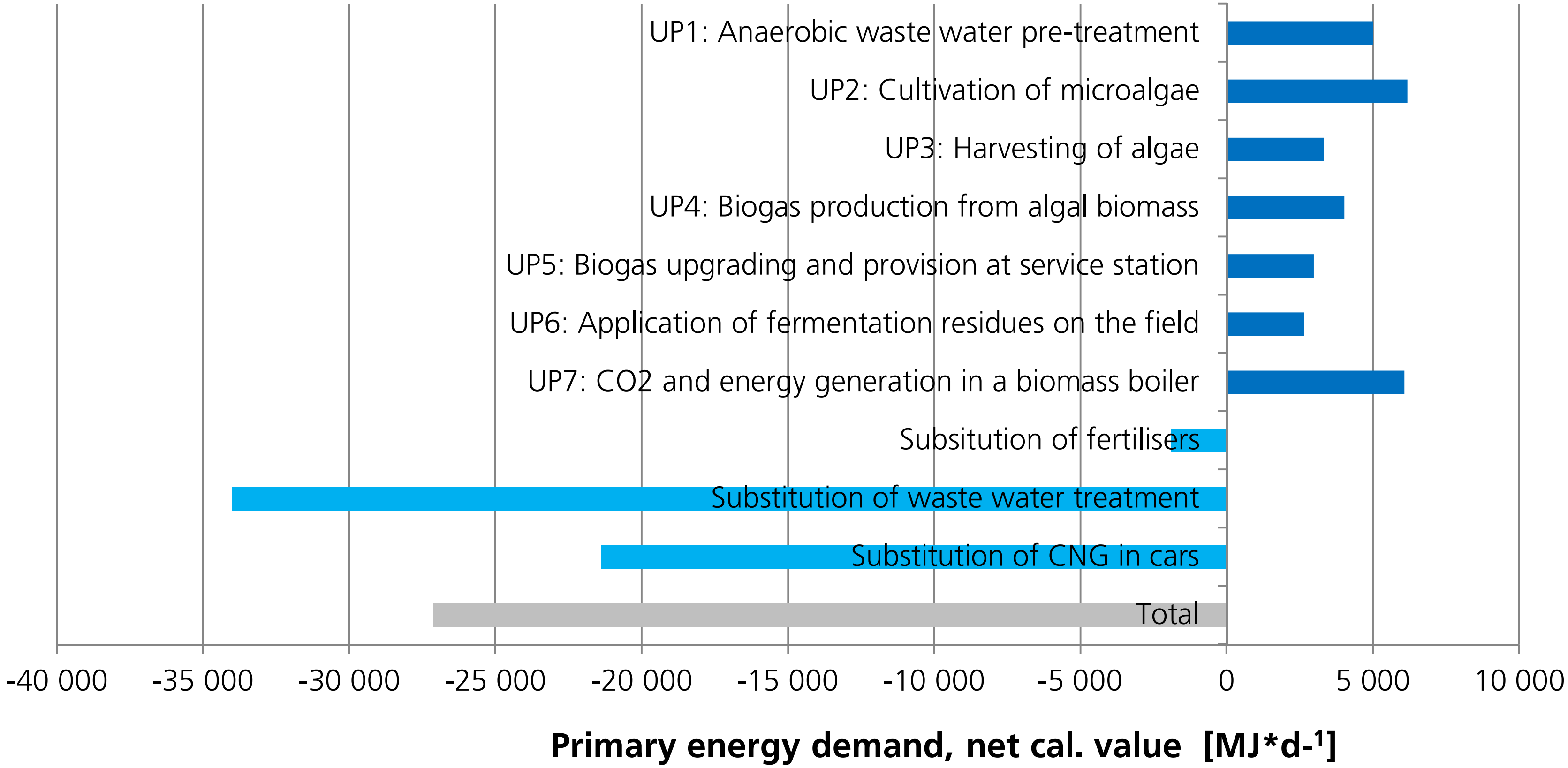
Energy balance of All-Gas (10 ha, 5 000 m^3*d^{-1})



- Credits for waste water treatment, fermentation residues, and compressed natural gas (CNG) in cars allow primary energy savings of approx. 27 000 $MJ*d^{-1}$

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Does the system provide more usable energy than it consumes? - Energy Return On Investment (EROI)

- EROI: Relation of primary energy supplied to primary energy used in supply process

$$EROI_{BM} = \frac{EC_{BM} + EC_{CP}}{E_{BM}} = \frac{LHV_{BM} * \rho_{BM} + EC_{CP}}{E_{BM}} = 1.9$$

EC_{BM}: energy content of biomethane

EC_{CP}: is the primary energy of the co-products fertilizer and water purification

E_{BM}: direct and indirect energy required to produce biomethane

→ The system produces two times more usable energy than it consumes

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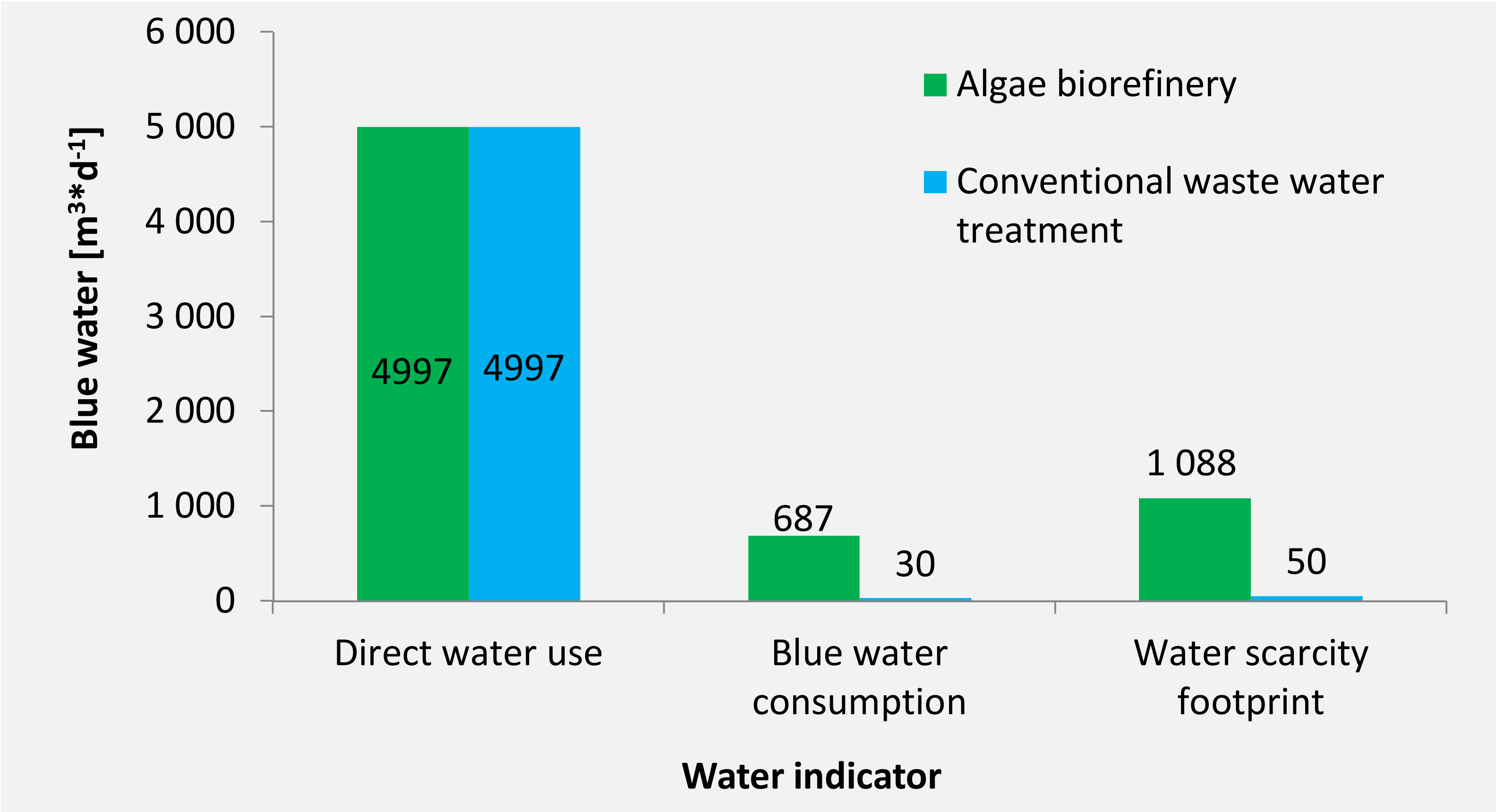
Water footprint

Water use, water consumption, and water scarcity footprint



- Algae biorefinery has a higher water scarcity footprint
- But in both cases treated waste water might go to the sea

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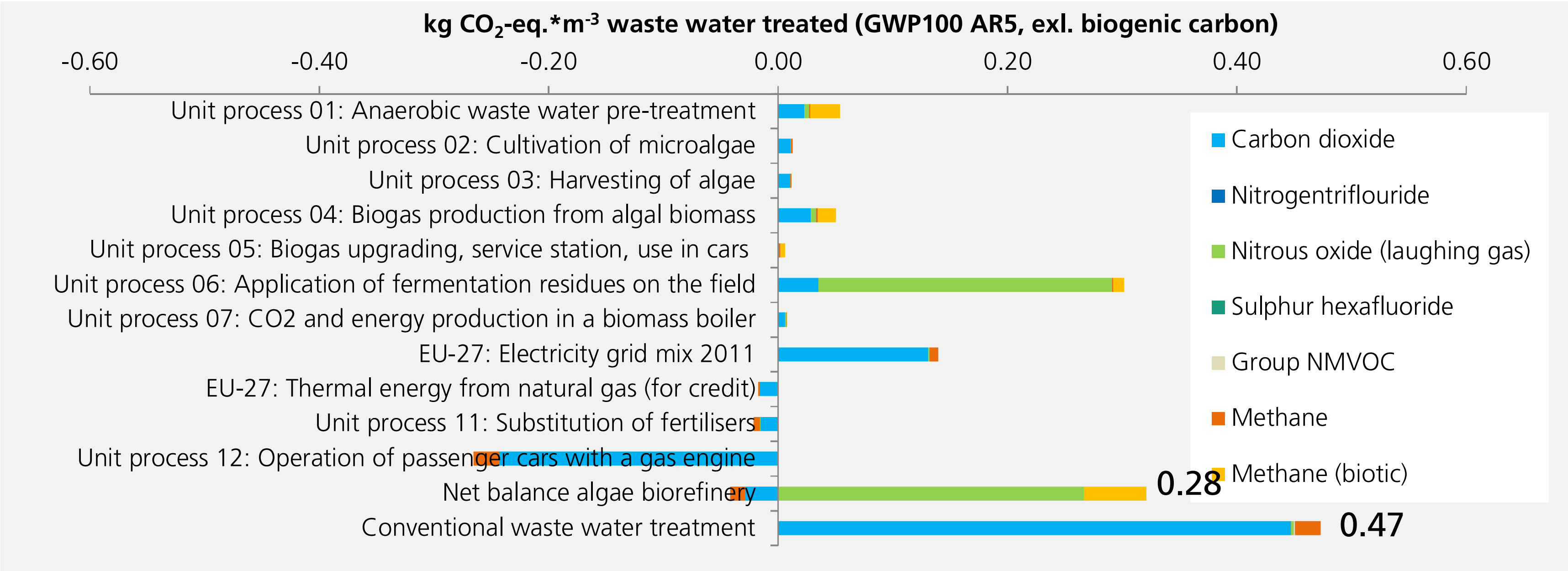
Does the All-Gas approach contribute to climate protection? Carbon Footprint of 1 m^3 treated waste water



- All-Gas approach allows approx. 40 % GHG savings compared to conventional waste water treatment
- N_2O strongly influences the GHG balance (application of fermentation residues on the field)

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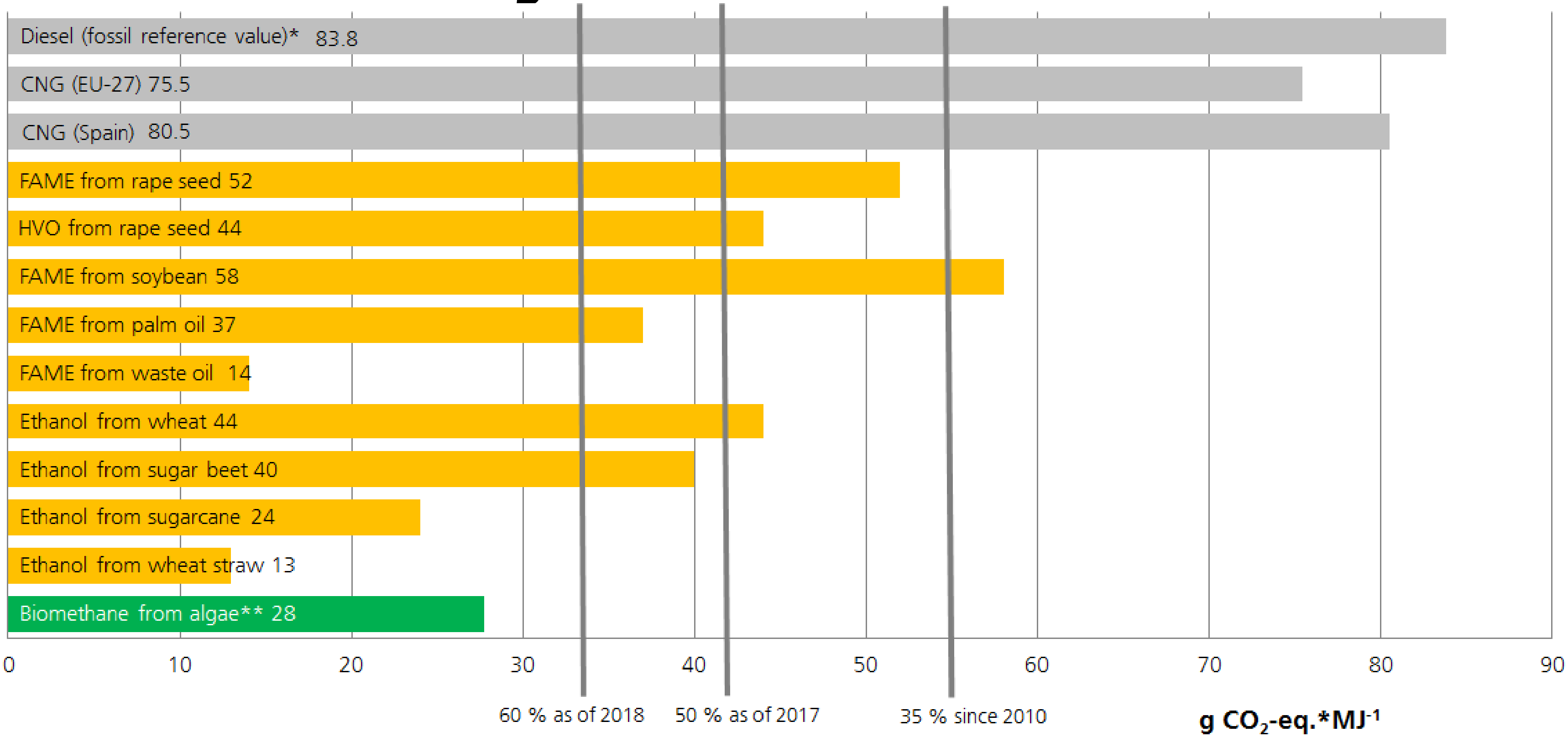
Comparison of green house gas (GHG) emissions of biomethane from algae to other fuels



* EU standard value (RED annex V); fossil reference value refers to diesel

** Biomethane from algae biorefinery: credits are given for waste water purification and for the application of fermentation residues on the field, GWP100: IPCC (2007)

- Biomethane from algae allows GHG savings of more than 60 %
- Different calculation approach (system expansion)!

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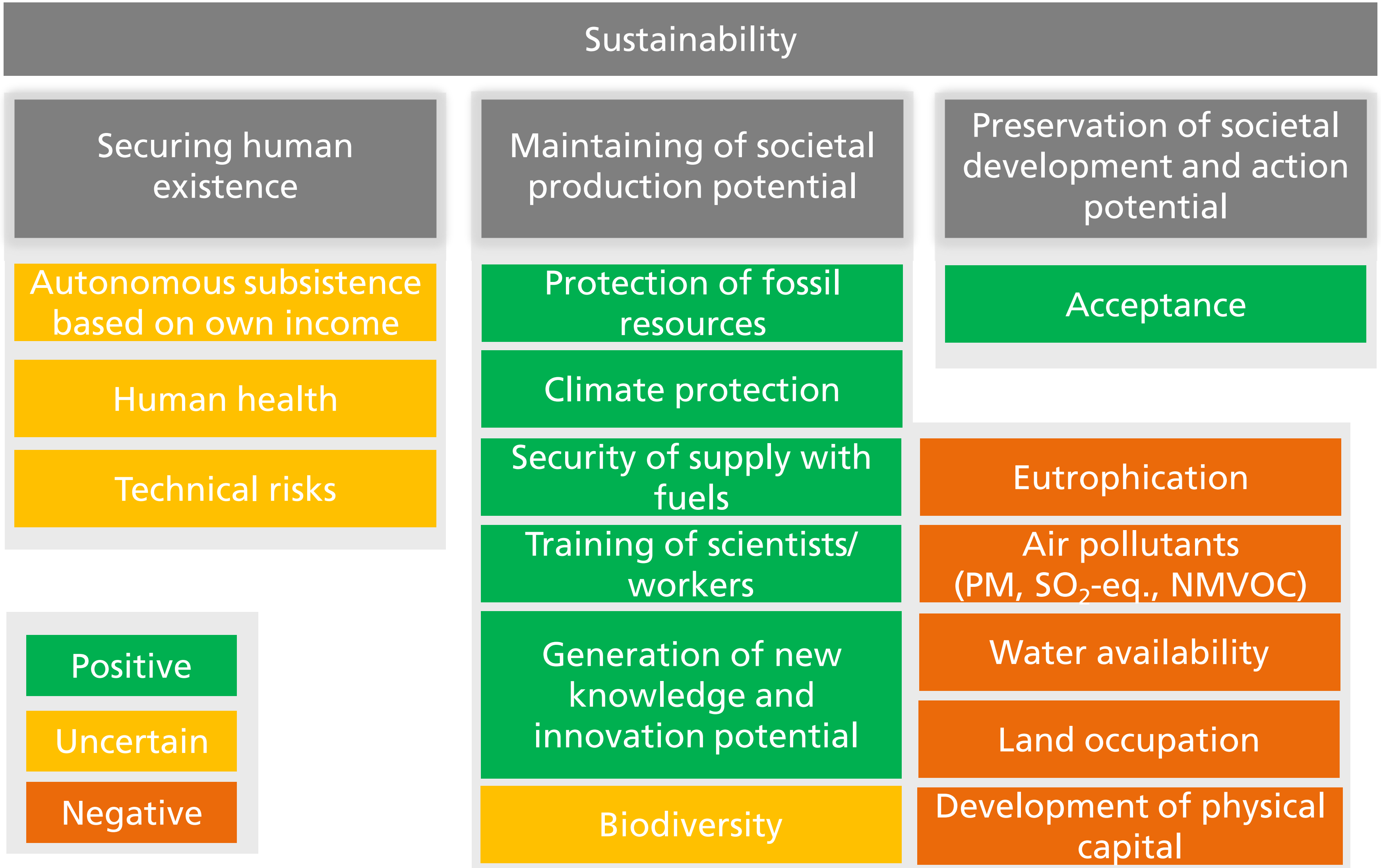
1
2
3
4

Summary of potential impacts of the algae biorefinery



Final conclusions

- Demonstration plant is still under development
- Algae biorefinery has already now proved to be an attractive alternative to conventional waste water treatment
- The approach allows the expansion of biofuels and contributes to the conservation of fossil energy carriers and to climate protection
- Environmental friendly management of fermentation residues (nutrients) is needed → high potential to further improve the overall performance
- Future products from algae might have a positive influence, too

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PhD Thesis

- Entire sustainability assessment was published in the PhD thesis
- Will be available at the homepage of the University of Bochum and in Fraunhofer Publica: http://publica.fraunhofer.de/dokumente/N-364431.html
- ISBN: 978-3-87468-355-7


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Contact

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Thanks for your attention!

Contact:
Fraunhofer UMSICHT
Department: Resources and Innovation Management
Osterfelder Strasse 3
46047 Oberhausen
Germany
Email: daniel.maga@umsicht.fraunhofer.de
Internet: http://www.umsicht.fraunhofer.de

Dr.-Ing. Daniel Maga
Telephone: +49 208-8598-1191
E-mail: daniel.maga@umsicht.fraunhofer.de

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