

The Big Algal *open* Experiment

The Idea

Microalgae are tremendously diverse, inhabiting almost every biome of the planet. Estimates suggest that there are over 50,000 microalgal species¹, representing a rich resource for industrial biotechnology and an immense library of biosynthetic components which can be unlocked with synthetic biology.

Despite this promise, the potential of these “tiny plants” remains unrealised due to a lack of knowledge on how to predictably cultivate microalgae and benefit from this biodiversity. While algae could play a role as a crop of the future, this needs to be enabled by building up a mass of data and know-how (UK Roadmap for Algal Technologies, 2013). For example, popular and scientific search engines like Google, Web-of-Science and PubMed give hundreds/thousands time more results when “plant” is search instead of “algae” and “microalgae” (**figure1**).

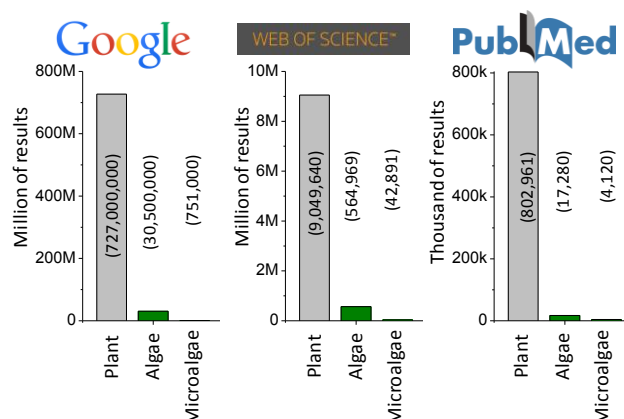


Figure 1. Result given by searching for “plant”, “algae” and “microalgae” in popular and scientific search engines like Google, Web-of-Science and PubMed (retrieved on June 2015).

This project aims to create the tools needed for a citizen science project called “Big Algae open Experiment”. The experiment aims to enhance our knowledge of microalgae by inviting universities and citizen scientists to participate in an open-source data collection experiment on outdoor microalgal growth. During the experiment, certain algal species will be selected and systematically tested in several locations across the entire UK. The tools and activity that we are planning to use to execute the project are displayed in the **figure 2**.

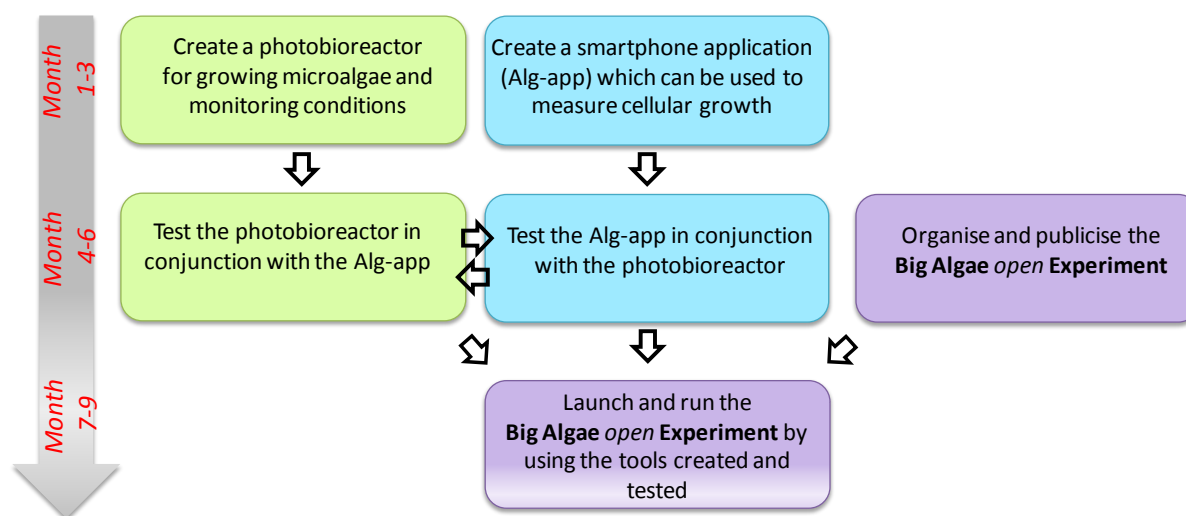


Figure 2. Diagram of the tools (i.e., photo-bio-reactor and smartphone app) and activity (i.e., The Big open Algae Experiment) planned for implementing this project and respective timeline.

Who We Are

Dr Brenda Parker, Biochemical Engineering, UCL: Brenda has worked on applied phycology for the past 5 years, primarily on downstream processing of algae and bioremediation². Along with designers at Wayward Plants, she created the algaegarden, an exhibit selected for the Metis International Festival in Quebec. Brenda was supported by a Public Engagement Award from the SGM for her algae installations for Secret Cinema and FARM:shop in London. She currently holds a Churchill fellowship on bioremediation.

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Dr Paolo Bombelli, Biochemistry, University of Cambridge: Paolo has a multidisciplinary background with specific interests in energy conversion, photosynthesis and electrochemistry. Since 2007 he has been pioneering the development of algal solar panels known as Bio Photo Voltaic (BPV) systems³, featured in national and international press. He is currently a postdoctoral fellow in the Department of Biochemistry at Cambridge with the title of “algal electrician”.

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Dr James Lawrence, Biochemical Engineering, UCL: James is a Teaching Fellow in Biochemical Engineering and his research focuses on the design and fabrication of small-scale tools for bioprocesses development⁴. James works extensively with UCL’s Institute of Making, where he has developed expertise on a range of ‘making’ tools, including 3D printers and laser cutters. He is currently part of Lego2Nano, an international project with the aim of redesigning scientific tools (such as atomic force microscopes) to reduce their cost and make them accessible for schools and citizen scientists.

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Marc Jones, Computational and Systems Biology, John Innes Centre: Marc is a PhD student working in the group of Prof. Richard Morris at the John Innes Centre, Norwich. Previously, Marc studied Systems Biology at the University of Cambridge, during which time he was exposed to a wide range of computational techniques and their application to biological problems. Since moving to Norwich Marc has been working on the flowering time regulatory network in the crop plant *Brassica napus*, applying experimental and computational approaches to transfer knowledge from *Arabidopsis thaliana* to a more economically important plant species. As the Webmaster for the JIC Student Voice Committee, Marc has been given a number of opportunities to develop his web programming skills. In particular, he updated the website and rewrote the online registration system for a Norwich and Cambridge student symposium (<http://nocass.org/>).

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Implementation

This project was conceived out of a genuine research need: investment in the algal biotechnologies will require solid data for algal growth. The amount of data available is severely lacking, and calculations of algal productivity are often based on controlled experiments in specialist labs with few replicates and indicators of robustness.

The concept of Big Algae open Experiment is to invite universities and citizen scientists to participate in a month-long data collection experiment on outdoor microalgal growth conducted in small, self-built photo-bio-reactors. Data collected during this time (2-4 weeks) will inevitably contain variation, but productivity can be established within certain confidence

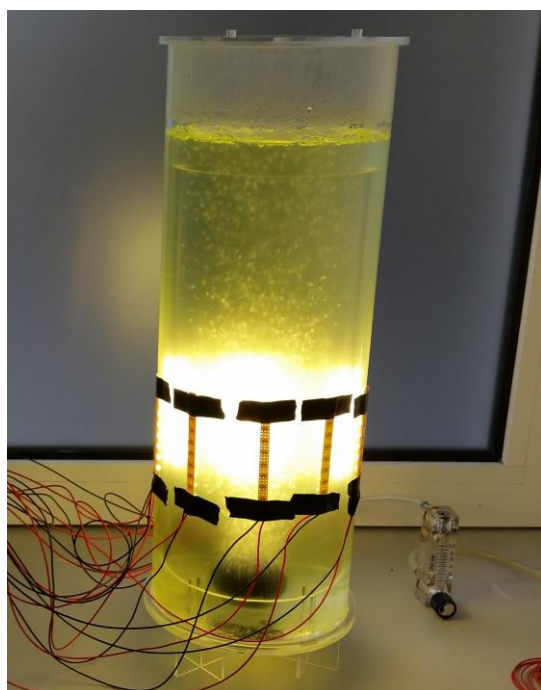
limits by ensuring that all participants have access to the same tools for cell culture and monitoring.

At the end of the Experiment, data will be pooled and analysed to give a greater depth of understanding on algal productivity.

With the support of OpenPlant we plan to do the following actions:

1) To create an open source, simple and robust photo-bio-reactor

The photo-bio-reactor being developed for the Experiment is designed to be inexpensive, easy to build and simple to use. The current prototype (shown in **figure 3**) is an airlift-type reactor built from readily available materials, using an aquarium pump for sparging of air. Parts for the reactor were produced using a laser-cutter, a widely-available 'maker' tool. The designs for the parts and instructions for assembly will be distributed to participants in the



Experiment (and the wider world) via maker community websites such as Thingiverse.

(<https://www.thingiverse.com/>)

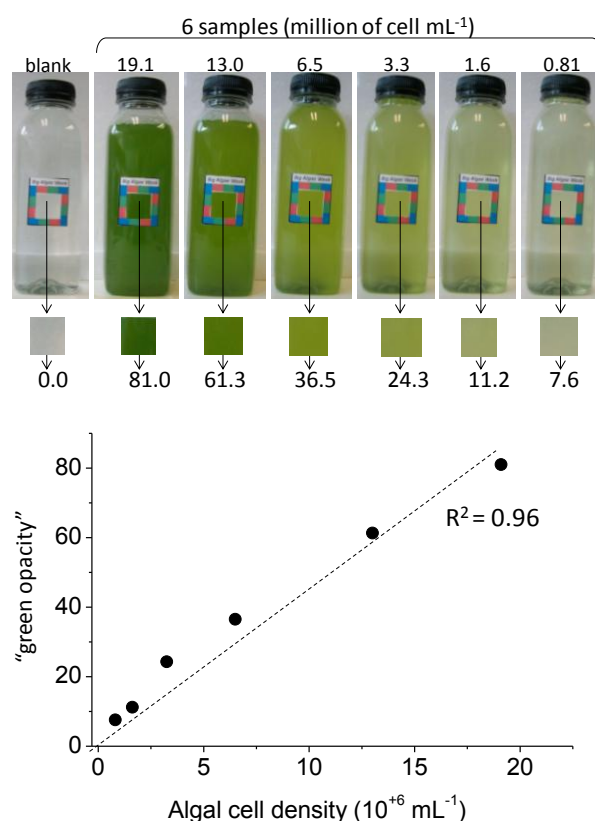
Although the basic design does not feature any lighting or monitoring and control systems, these can be realised with a relatively basic understanding of electronics and programming, again using readily available components and control boards such as the Arduino or Raspberry Pi. We have already tested the construction and use of a cheap light jacket and of an Arduino-based temperature and light monitoring system. Instructions for building and running these systems will be included in the designs as optional extra features for those participants that want to use them.

Figure 3. Prototype of the photo-bio-reactor, including the optional light jacket

2) To create a smartphone application (Alg-app) for the Big Algae open Experiment.

The suite of sensors incorporated into modern smartphones, as well as their ubiquity, presents many new possibilities for citizen science⁵, with recent work demonstrating that smartphones are capable of reliable and accurate colorimetric analysis⁶. The Alg-app will be used to provide a standardized and reproducible method of algal density measurement for all participants in Big Algae open Experiment. Participants will be required to attach a calibration window to the photo-bio-reactor that they construct. The Alg-app will make use of the phone's camera to image this calibration window and, through use of an open source computer vision library⁷, estimate algal density in the photo-bio-reactor, normalizing for variations in lighting conditions (we have already tested this method – **figure 4**). The Alg-app will be web based, providing cross-platform compatibility and flexibility for the users; if the users do not own a smartphone, for example, the web application will still be functional to them by taking pictures with a common digital camera.

The Alg-app will be made entirely with open source libraries and technologies and itself be open source. This will allow other scientists to modify the Alg-app for their own needs. The use of open source libraries will also reduce the cost of development, such that the only costs incurred will be the server costs of hosting and running the Alg-app. Development of



the algal density estimation algorithm will be performed in close collaboration with experimental scientists familiar with working with algae to ensure accuracy and reliability. Algorithm development will take place during autumn 2015, with the web based Alg-app interface developed and tested during winter 2015 and spring 2016 to ensure stability prior to Big Algae open Experiment taking place in the summer of 2016. Amazon Web Services will be used to provide a scalable host for the Alg-app to accommodate large numbers of concurrent users, reducing the possibility of technical problems.

Figure 4. Preliminary data developed to test photos taken with the phone's camera can be used to estimate the algal density in the photo-bio-reactor and or see-through vessels (e.g., plastic bottle). Example of calibration curve.

3) Organise the Big Algae open Experiment

The Big Algae open Experiment will operate as a hub-and-spoke model, where we will ask universities to sign up for the project and recruit partner schools or community groups. They will run the same experiment, and this will provide a mechanism for outreach such as visits to the lab or careers talks from researchers. At the end of the month data will be uploaded to our portal and analysed. We can then make correlations between environmental conditions and biomass growth. Via open-source platforms we will make the data set publicly available for other researchers.

The tools developed during this project (photo-bio-reactor and Alg-app) will permit to run the Big Algae open Experiment. The activity will be organized as follow:

- During Autumn 2015 academic UK's phycologists and plant physiologists will be introduced and invited to take part in the Big Algae open Experiment. The scientist will be also invited to team up with a local school. Contextually, the idea of Big Algae open Experiment will be introduced to schools via the events run at SAP, Fascination of Plants and Big Biology Day.
- During Spring 2016 the identified teams will be instructed for creating the tools needed to run the Big Algae open Experiment. The teams will need to provide the resources for construction the photo-bio-reactor and run the experiment.
- During Summer 2016 the Big Algae open Experiment will take place.

Benefits and outcomes

Upon completion, this project will have two tangible outcomes (a bioreactor and a smartphone app) which can be shared with the scientific community, as well as wider interest groups such as schools and biohacking labs. The legacy of the project will also be a pool of opensource information which will enable further development of these components for new applications.

For algal research to make progress, an interdisciplinary approach is essential, and this is reflected in our team. Our project promotes interactions between synthetic biologists and biochemists based in Cambridge, engineers based at UCL and computational biologists at the JIC Norwich.

We see that this project is timely, as the opportunities for synthetic biology in algal host strain grows. Microalgae and cyanobacteria are becoming increasingly attractive cell factories and increasing research efforts from the synthetic biology approach have been made in recent years to modify those organisms for various biotechnological applications⁸. In future, research from institutes such as OpenPlant will enable the photosynthetic machinery to be altered, for example resulting in carbohydrate and lipid⁶ engineering to increase quality and yield, or via engineered pathways for the metabolic production of high level biomolecules⁷. By creating a robust, cost-effective and well-characterised photo-bio-reactor we will foster the implementation of all those biotechnological applications on algal “platform”.

The OpenPlant laboratories based in Norwich and Cambridge could both benefit from the tools developed within this project. We are proposing to offer to install 3 photo-bio-reactors in each lab as stable facility. These prototypes will stay permanently (subject to space availability) and will facilitate the develop of synthetic biology by using algal material as cellular platforms.

In addition, by creating a complete open source platform we could provide a benefit for: Schools: we provide a new ways of teaching core concepts related to phycology, as well as introducing the concept of synthetic biology and OpenPlant system. This also serves as a means of exposing students to careers in research via the university partnerships. For biohackers and other groups: this project creates a way of cultivating algae or participating in citizen science and empowers them to contribute to meaningful research.

The link between Universities (Cambridge, UCL and JIC) could also promote the sharing of own expertise (e.g. Cambridge and JIC Syn-Bio and UCL bioprocessing) for the mutual benefit. The wider algal community in academia and industry can use and access the data generated by the project via publications. It can also serve as baseline data for comparison.

The blueprints for the photo-bio-reactor, the Alg-app and the data generated by using those tools will be distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

The responsibility for disposing biological and plastic materials will be up to the individual users. All users of the website would need to agree to the “terms and conditions/code of conduct” before downloading materials and instructions.

Sponsor for the research and cost centre

Professor Chris Howe
Department of Biochemistry
University of Cambridge
Cost-code: PHDT

Budget

Create the photo-bio-reactor & consumables

Materials for 3D printing / polycarbonate: £1000
Off-the-shelf parts (e.g. aquarium pumps): £250
Sensors, Arduino control boards and general electronic components: £600
Algae strains, reagents and consumables for cell culture: £600
Design costs for user interface: £450

Alg-app

Design and development the Alg-app will be done “in-house” at no cost: £0
Alg-app hosting and server costs: £300 per year

Travel

Budget for traveling and testing the tools: £300
Budget for educational workshop and bioreactor prototype testing workshops: £500

Big Algae open Experiment

Budget to generate material templates: £1000

External contribution

Seed funding from UCL Biochemical Engineering Outreach for bioreactor parts: £250

In kind support:

UCL Dept of Biochemical Engineering and University of Cambridge: access to labs / supervision of student developers and staff time. JIC Norwich: access to computer and staff time. Institute of Making for access to 3D printing. Outdoor testing and validation will be performed by UCL and the Algal Innovation Centre in Cambridge.

References

- [1] Guiry MD (2012) How many species of algae are there? *Journal of Phycology*, doi: 10.1111/j.1529-8817.2012.01222.x
- [2] Horst I, Parker BM, Dennis JS, Howe CJ, Scott SA, Smith AG (2012) Treatment of *Phaeodactylum tricornutum* cells with papain facilitates lipid extraction. *Journal of Biotechnology*, doi: org/10.1016/j.jbiotec.2012.06.033
- [3] McCormick AJ, Bombelli P, Bradley RW, Thorne R, Wenzel T, Howe CJ (2015) Biophotovoltaics: oxygenic photosynthetic organisms in the world of bioelectrochemical systems. *Energy Environ. Sci.*, doi: 10.1039/C4EE03875D
- [4] Lawrence J, O'Sullivan B, Lye GJ, Wohlgemuth R, Szita N (2013) Microfluidic multi-input reactor for biocatalytic synthesis using transketolase. *Journal of Molecular Catalysis B: Enzymatic*, doi: 10.1016/j.molcatb.2013.05.016
- [5] Smith ZJ, Espenson CK, Rahimzadeh AR, Gryshuk M, Molinaro A, Wachsmann-Hogiu S (2011) Cell-phone-based platform for biomedical device. *PloS One*, doi: org/10.1371/journal.pone.0017150
- [6] Yetisen AK, Martinez-Hurtado JL, Garcia-Melendrez A, da Cruz Vasconcellos F, Lowe CR (2014) A smartphone algorithm with inter-phone repeatability for the analysis of colorimetric tests. *Sensors and Actuators B: Chemical*, doi: org/10.1016/j.snb.2014.01.077
- [7] Bradski G (2000) The OpenCV Library. *Dr. Dobb's Journal of Software Tools*
- [8] Wang B, Wang J, Zhang W, Meldrum DR (2012) Application of synthetic biology in cyanobacteria and algae. *Microbiol.*, doi: org/10.3389/fmicb.2012.00344