The Nottingham Algae Biorefinery (NAB)

EnAlgae Symposium

Kortrijk

18/9/2014

Steve Skill
• What commercially viable biomolecules can we characterise and extract from the algae?
• Can we grow the algae and extract the biomolecules economically?
• Does the consumer want whatever we find?
• Whole supply chain consideration - Can we develop a carbon negative ingredient supply chain?
Microalgae Products and Applications

- Anti-oxidants
- Anti-inflammatory
- Anti-tumour
- Anti-microbial
- Sunscreens & Cosmetics
- Pharmaceuticals
- Nutraceuticals
- Flavours and fragrance
- Biodiesel
- Bioethanol
- Hydrogen
- Methane
- Bioplastics
- Materials science
- Ceramics
- Adhesives
- Bioremediation
- Waste water treatment
- Contamination remediation
- Bulk chemicals
- Building block chemicals
- High value bioactives
- CO₂ capture
- Sunscreens & Cosmetics
- Pharmaceuticals
- Nutraceuticals
- Flavours and fragrance
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- Bioplastics
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- Waste water treatment
- Contamination remediation
- Bulk chemicals
- Building block chemicals
- High value bioactives
- CO₂ capture
CCIF Project £2.1m – Steve Skill PI

- Optimising Yield
- Molecular Biology
- Biomass production and harvesting

- Chemistry
- Photophysiology
- Stress Response
- Modelling
- Biosynthesis

- Power Station Engineers and Consultants

- Health and Beauty Retailer
- Formulator and Manufacturer
- Healthcare provider

- Product Identification
- Product Extraction
- Downstream Processing
- Healthcare and Personal care
- Ingredient Production

Technology Strategy Board
Driving Innovation
Which microalgal strain?

Screening programme lead to the selection of a ROBUST cyanobacteria (CX68)

- Auto-flocculation
- Thermophilic
- Robust
- Monoalgal culture
- Storage
- Freshwater strain
- Wild type produces potentially valuable metabolites
- Di-azotrophe
- Prokaryote
2008-2013 Microalgal Biorefinery with Carbon Capture

Hot flue gases from Boots’ Power Station → 16 m³ PBR → Harvesting (Passive) → Ball Milling → Tangential flow filtration → Cosmetic Bioactive Extract

- Low CO2 Flue gas
- Nutrients N, P
- 14% Solids
- Protein (Hair care)

Process Design: Steve Skill
Microbes: Autoflocculating Thermophilic Cyanobacteria
Company: Boots, Cognis (BASF)
Location: Nottingham, UK.

PBR- Photobioreactor
15MW Power Station

Flue gas duct

Direct carbon capture PBR

16,000 litre photobioreactor (PBR)
Productivity: 0.3-0.9g/l/day
Energy use: 20-70W/m³
Patent: Apparatus for the treatment of fluid streams and method for conducting the same.
S. Skill 2009
Nottingham Algae Biorefinery Process Diagram
Continuous Operation Process Control Logic

1. Runtime on?
   - YES: Culture Levels high?
     - YES: Open Harvest valve
       - NO: Close Harvest valve
     - NO: OD above Set level?
       - YES: Close Dilution valve
         - NO: Open Dilution valve
       - NO: Close Nutrient valve
         - NO: Open Nutrient valve
       - YES: Heatx temp at Set level?
         - YES: Heatx pump on
           - NO: Heatx pump off
         - NO: PH above Set level?
           - YES: Close CO2 valve
             - NO: Open CO2 valve
           - NO: PH above Set level?
             - YES: Data logged
               - YES: End
                 - NO: Delay 1sec
                 - NO: End
Product R&D Focus

- Antioxidants
- UV Protection (Suntan lotions)
- Anti inflammatotry
- Anti ageing
- Protein Hydrolysates (hair care)
**Table 1**
Comparison of the energy consumption of the algal cell disruption system used in this study* against data from literature.

<table>
<thead>
<tr>
<th>Organism</th>
<th>Cell disruption equipment</th>
<th>Energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Haematococcus pluvialis</em> [31]</td>
<td>Pulverizer</td>
<td>3.5 kWh/kg (dry wt)</td>
</tr>
<tr>
<td><em>Chlorella vulgaris</em> [9]</td>
<td>Bead mill</td>
<td>2.82 kWh for 77% extraction or 7.51 kWh for 85% extraction/kg (dry wt)</td>
</tr>
<tr>
<td><em>Nannochloris oculata</em> [32]</td>
<td>High pressure homogenizer</td>
<td>11 kWh using 10% (w/v) suspension</td>
</tr>
<tr>
<td><em>CX68</em></td>
<td>Ball mill</td>
<td>1.87 kWh/kg (dry wt)</td>
</tr>
</tbody>
</table>

**Table 2**
The surface area of the grinding media and stress energy calculated using Eq. (1) for the various process conditions used in the pilot scale ball mill experiments.

<table>
<thead>
<tr>
<th>Type</th>
<th>Bead size (mm)</th>
<th>No of beads</th>
<th>Kinetic energy (kg m² s⁻²)</th>
<th>Surface area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per collision</td>
<td>Total</td>
</tr>
<tr>
<td>Zirconia</td>
<td>0.8–1.0</td>
<td>1,254,812</td>
<td>4.03E–08</td>
<td>0.025</td>
</tr>
<tr>
<td>Zirconia</td>
<td>2.0–2.4</td>
<td>82,402</td>
<td>5.88E–07</td>
<td>0.024</td>
</tr>
<tr>
<td>Glass</td>
<td>2.0–2.4</td>
<td>139,232</td>
<td>3.87E–07</td>
<td>0.027</td>
</tr>
<tr>
<td>Glass</td>
<td>0.8–1.0</td>
<td>2,033,661</td>
<td>2.64E–08</td>
<td>0.027</td>
</tr>
</tbody>
</table>

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*Note: *The energy consumption values are based on the experimental data provided in the study. The surface area calculations are based on the equations given in the study.
Multi-stage-stage biorefinery fractionation process using low energy ball mills.

- Harvest
- Passive settling
- Ball Mill 1
- Passive settling
- Ball Mill 2
- Passive settling

14% solids

Extra-cellular Extract
- Sunscreen
- Anti-inflammatory
- Anti-oxidants (Anti-ageing)

Lysate
- Anti-oxidants
- Carotenoids
- Natural colours

Further Fractionation
(Crossflow filtration)

Protein
Hair Care
Efficacy testing

• A suite of bioassays and analytical protocols have been employed to validate the cosmetic efficacy of extracts recovered from the biomass including; Antioxidant, Lipid peroxidation, anti-inflammatory, UVA & UVB protection and antimicrobial potential.
Biocrude oil production and nutrient recovery from CX68

Nutrient recycling of aqueous phase for microalgae cultivation from the hydrothermal liquefaction process
Biller, P; Ross, AB; Skill, SC; Lea-Langton, A; Balasundaram, B; Hall, C; Riley, R; Llewellyn, CA. 2012 Nutrient recycling of aqueous phase for microalgae cultivation from the hydrothermal liquefaction process. Algal Research, 1. 70 - 76.
Investigation of the presence of the biomacromolecule algaenan in cyanobacteria; Implications on kerogen formation.

Patrick Biller, Andrew B. Ross, Stephen Skill

ABSTRACT
Algaenan has been suggested to be one of the main precursors and contributors to kerogen deposits. Its aliphatic structure has been shown in a variety of microalgae strains. Algaenan is a non-hydrolysable and insoluble biomolecule with a very high molecular weight. There is considerable uncertainty about the formation and preservation of algaenan which led to the current kerogen formation and the implications on the global carbon cycle. We aim to prove our current hypothesis - that the cyanobacteria CX68 may synthesise a similar resistant biomacromolecule to algaenan of green algae. This could explain some of the discrepancies in the published literature concerning algaenan. The two microalgae Pseudochoricystis ellipsoidea and Scenedesmus obliquus as well as the cyanobacteria were subjected to harsh solvent extraction and hydrolysis steps to obtain the in-soluble and non-hydrolysable macromolecule algaenan. The residues from all three strains were analysed by Pyrolysis-GC-MS and Solid-state NMR. The analysis revealed that the strain CX68 indeed contains algaenan or a resistant biomacromolecule very similar, exhibiting the characteristic aliphatic structure diagnostic to algaenan. Due to the robust nature of CX 68 compared to the Eukaryotes to prevail extreme environments such as freezing, thawing, desiccation and overheating conditions which were prevalent in primeval earth, it could have significantly contributed to kerogen formation and the global carbon cycle.
Developing a platform for sustainable chemical production

CO$_2$ and sunlight as feedstocks

Metabolic engineering

Engineering microalgae for sustainable chemicals

Sustainable Chemicals

CX68 Prokaryote Genome Sequenced
Transformation protocols
Pathways for manipulation?
Towards the development of a platform for sustainable chemical production

The Nottingham Microalgae Biorefinery

• Robust production and biorefinery system
• Downstream processing
• Molecular tool kit for Cx68
• Metabolic engineering
• Synthetic pathways
• Sustainable chemical production
Low Energy Flue Gas Contacting Photobioreactor

Robust Modified Cyanobacteria Producing Propane and Elevated Levels of Natural Sunscreen Compounds (MAAs)

Cosmetic Ingredients
- Natural Sunscreens (MAAs), Pharmaceutical extracts
- Anti-inflammatory Compounds
- Wound healing extracts

Downstream Processing
Ball Milling
Controlled Lysis
Nano-filtration

Future Project
PML EnAlgae Team

Carole Llewellyn
Dan White

Thank you.. Steve Skill s.c.skill@swansea.ac.uk