UNIVERSITY OF CAMBRIDGE

Dept of Plant Sciences

Algal bioenergy: what we need is more biology and less hype

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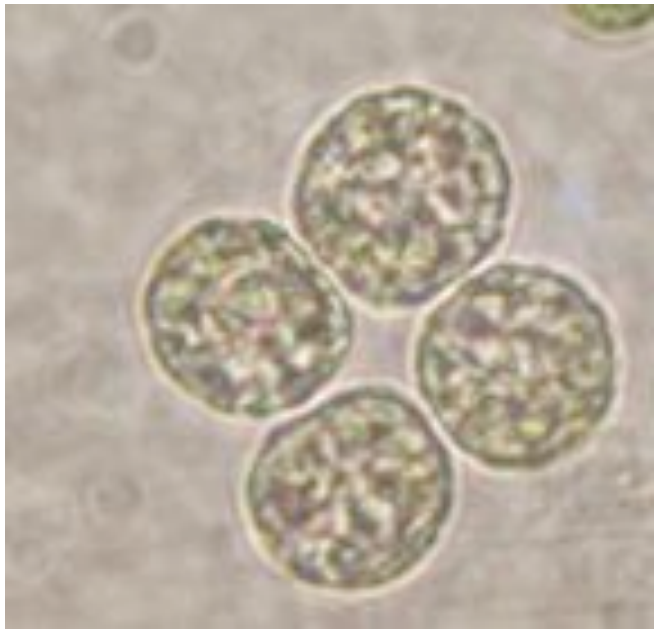
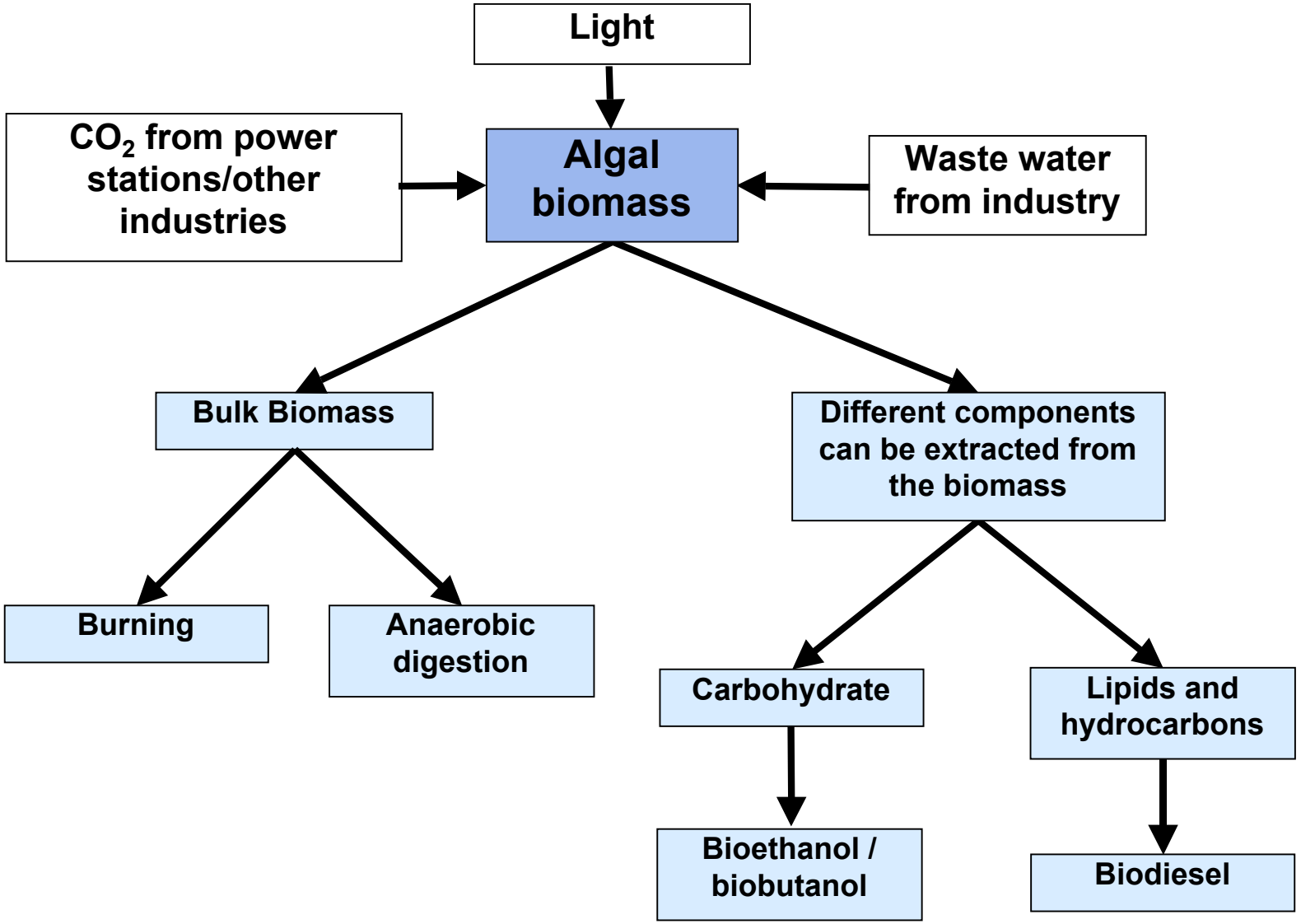
Exploitation of algae

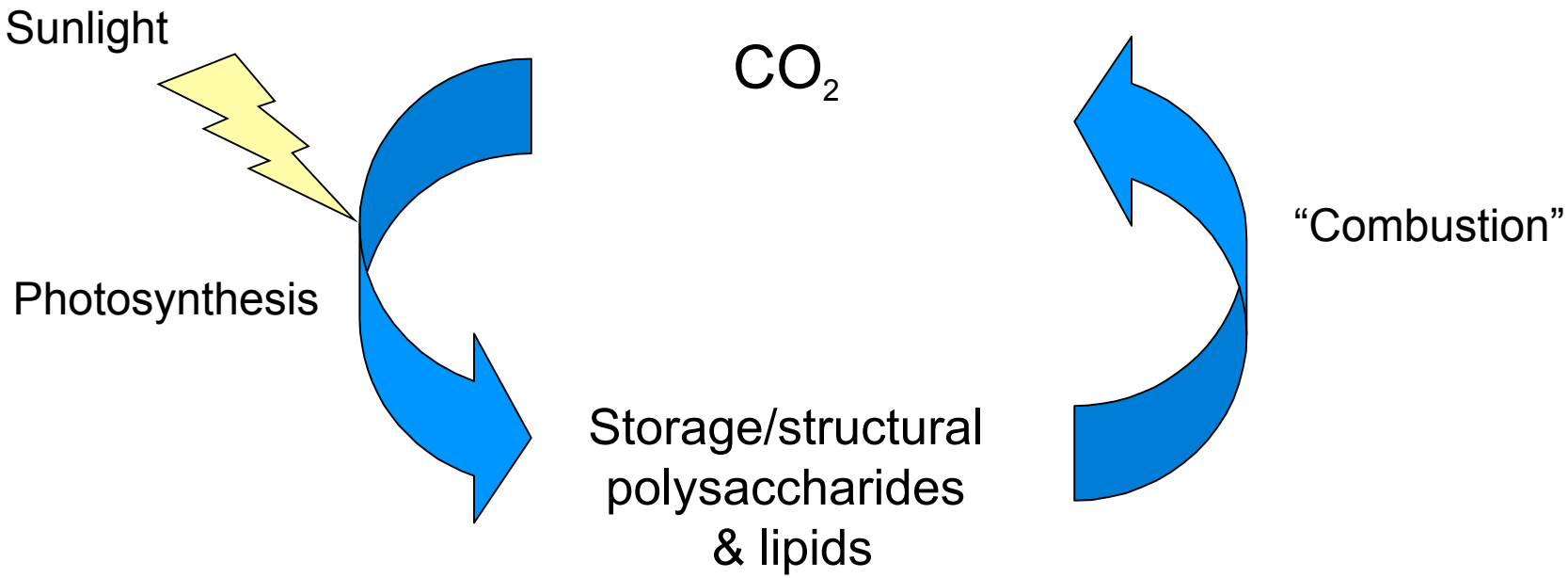
- As a source of biofuel feedstock, and CO_2 capture
- Barriers to commercialisation
- How studying algal biology might help
- Vitamin metabolism as example



Algae as a source of biofuel feedstock



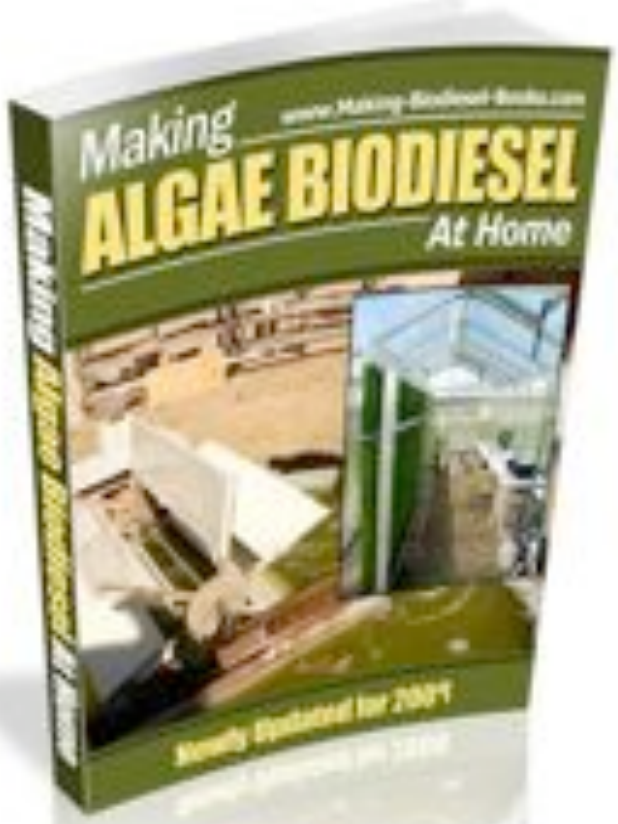
Use of biomass is theoretically carbon neutral



- But not CO_2 *sequestration*, unless biomass is stored
- Burying, or biochar?

It’s easy, isnt it?

http://www.making-biodiesel-books.com/algae-biodiesel.html

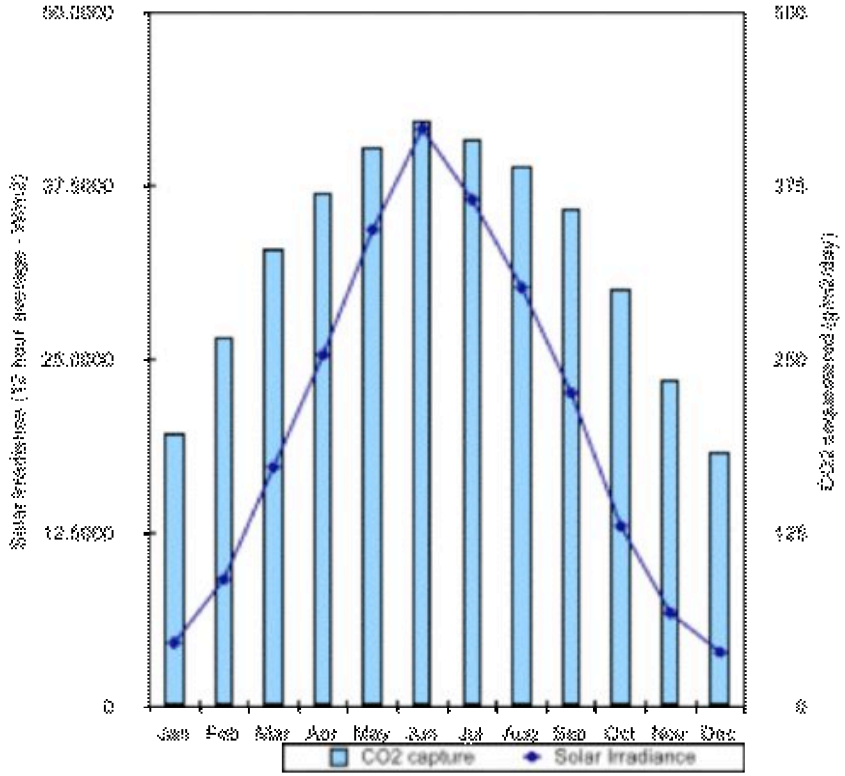


Click here to get started right now with Making Algae Biodiesel at Home!

eBook JUST $99.99

CO_2 capture by algae

- *Chlorella vulgaris,* modelled for UK
  - Efficient at low light intensity
  - Growth in winter limited by temperature



- Under these conditions current strains of *Chlorella vulgaris*
  - could incorporate ~100 te/ha of CO_2 per year
  - 100 ha needed to fix 1% of 100 MW power station CO_2

Algal biodiesel production

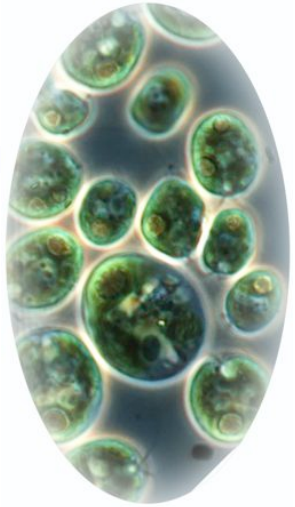
- Current productivity:
  Raceway culture (open, shallow, pumped systems): 10 – 50 te/ha/y
  Oil content ~25%

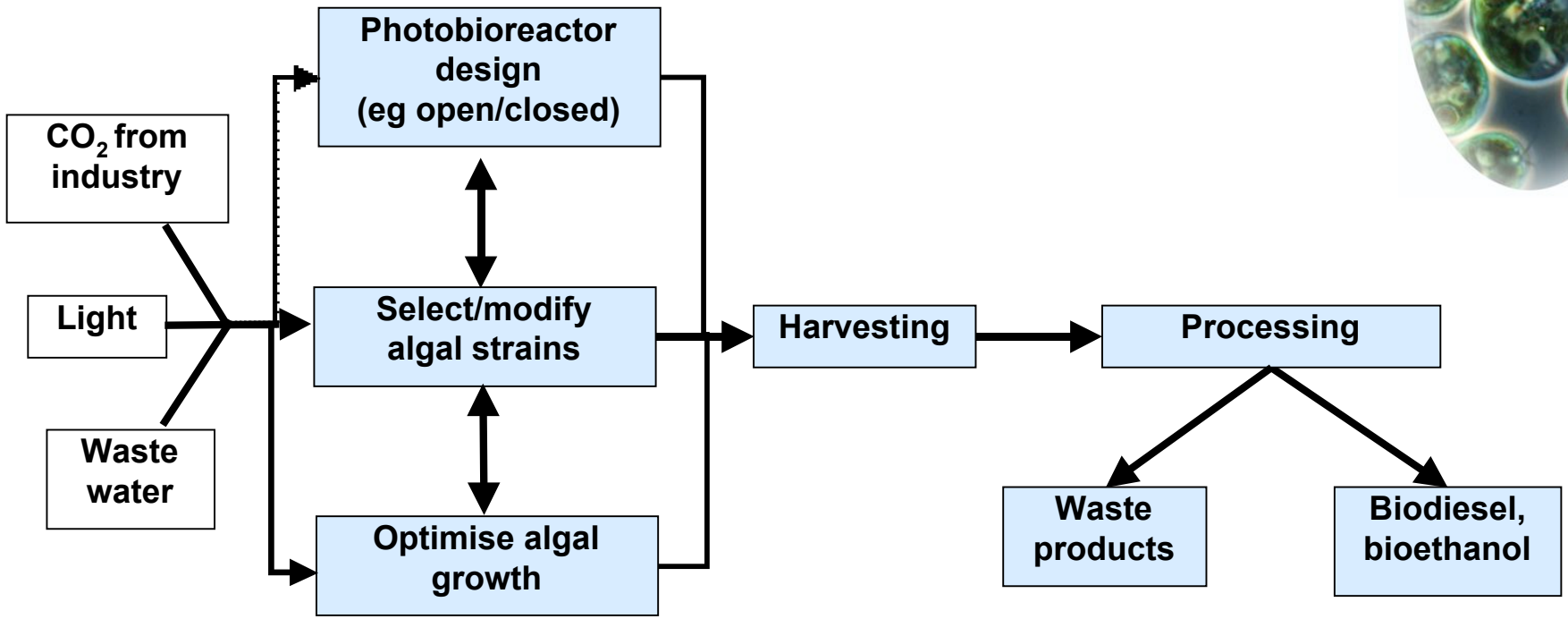
Crop	Oil production
Chlorella vulgaris	10 te/ha/y
Oilseed rape	1.5 te/ha/y
Jatropha	2.4 te/ha/y

- Annual UK transport fuel is 60 Mte, 40% diesel

- To replace this with algal biodiesel would need 2.4 Mha (10% of UK land area)

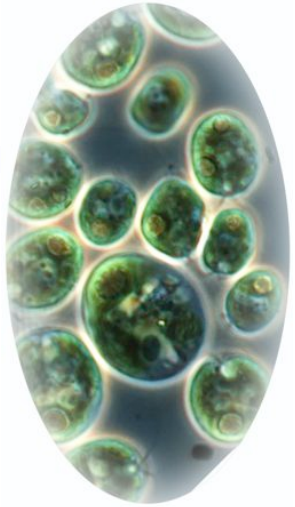
Potential algal biofuel ‘pipeline’

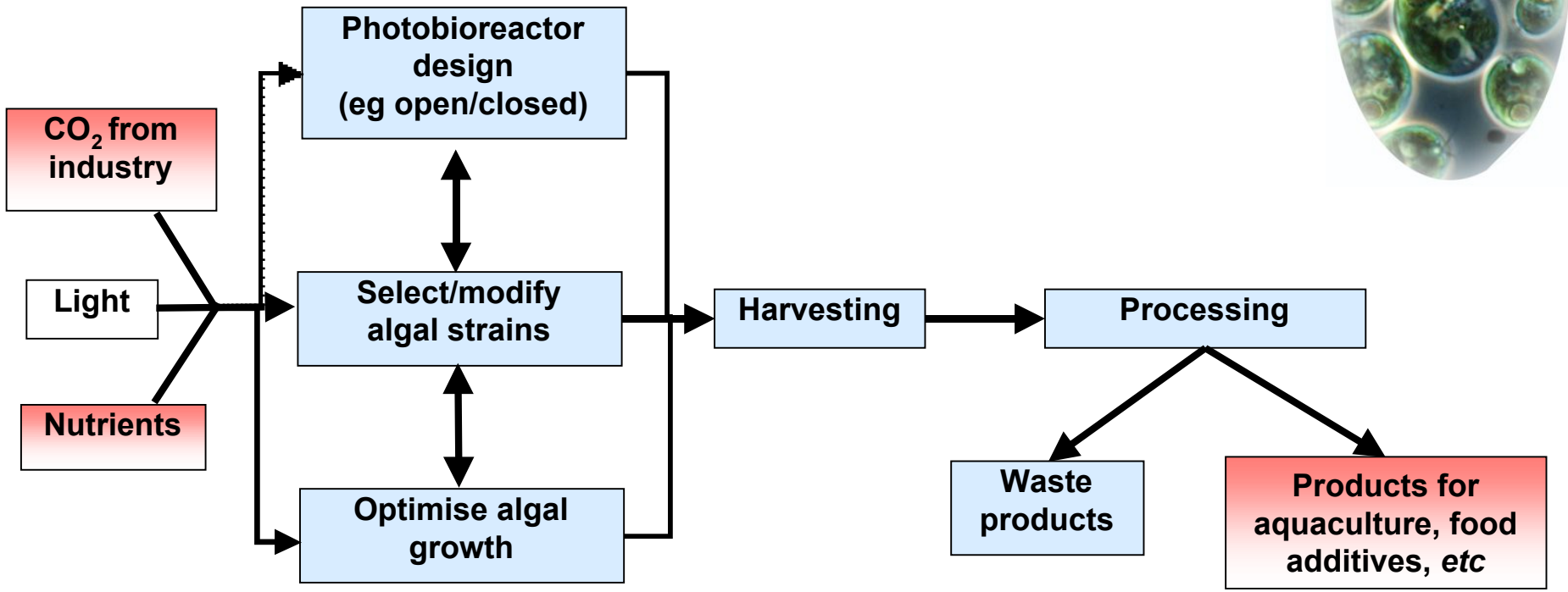




- Life cycle analysis indicates that more energy to obtain fuel than is produced from fuel

Current commercial algal production

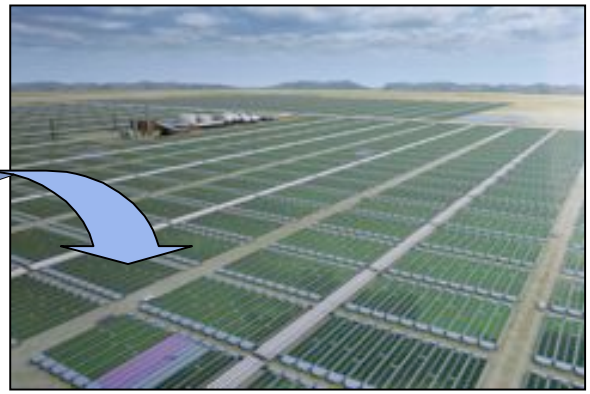




- High value products mean few constraints on cost or energy requirements

Constraints for commercialisation of algal biofuels

Solix "algal farm", from
Popular Science, July 2007



- Algal strain identification
  over 300,000 species to choose from
- Closed versus open photobioreactors
  costs of manufacture and operation
  contamination
- Algal physiology
  biomass production, lipid production, high value products
- Harvesting, processing, waste products
- Fuel characteristics
- Public acceptance

Strategies to tackle algal bioenergy challenges

Level 1: instal algal bioreactor/pond and monitor progress

Level 2: consider constraints holistically, design experiments to test various solutions

Level 3: fundamental studies of algal biology and engineering design to provide generic information/solutions

Algal Bioenergy Consortium

UNIVERSITY OF CAMBRIDGE

Chris Howe
Algal and cyanobacterial photosynthesis

John Dennis & Stuart Scott
Chemical engineering and bioprocessing
Gasification and sustainable engineering

Adrian Fisher
Electrochemistry; photovoltaic devices

Alison Smith
Algal molecular biology; regulation of metabolism

UCL

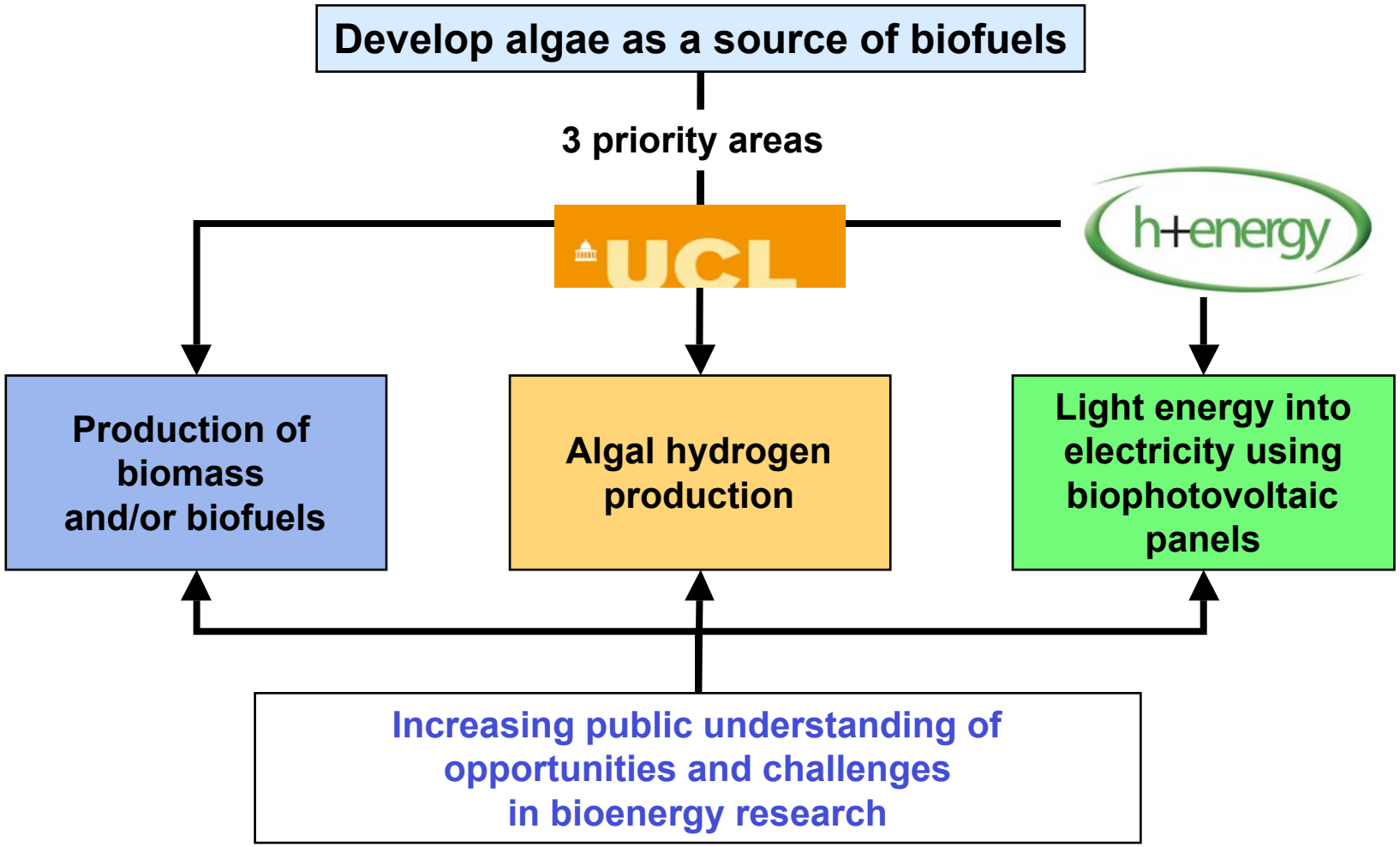
Saul Purton
Algal molecular biology

ROTHAMSTED RESEARCH

Johnathan Napier
Lipid metabolism and metabolic engineering

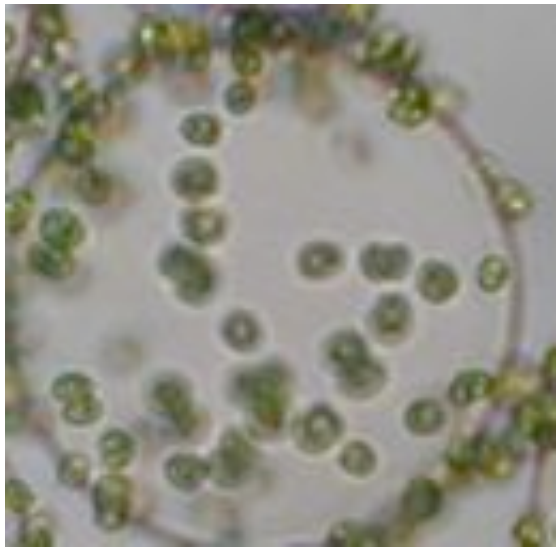
http://bioenergy.cam.ac.uk/abc.html

Strategic aims of the Algal Bioenergy Consortium

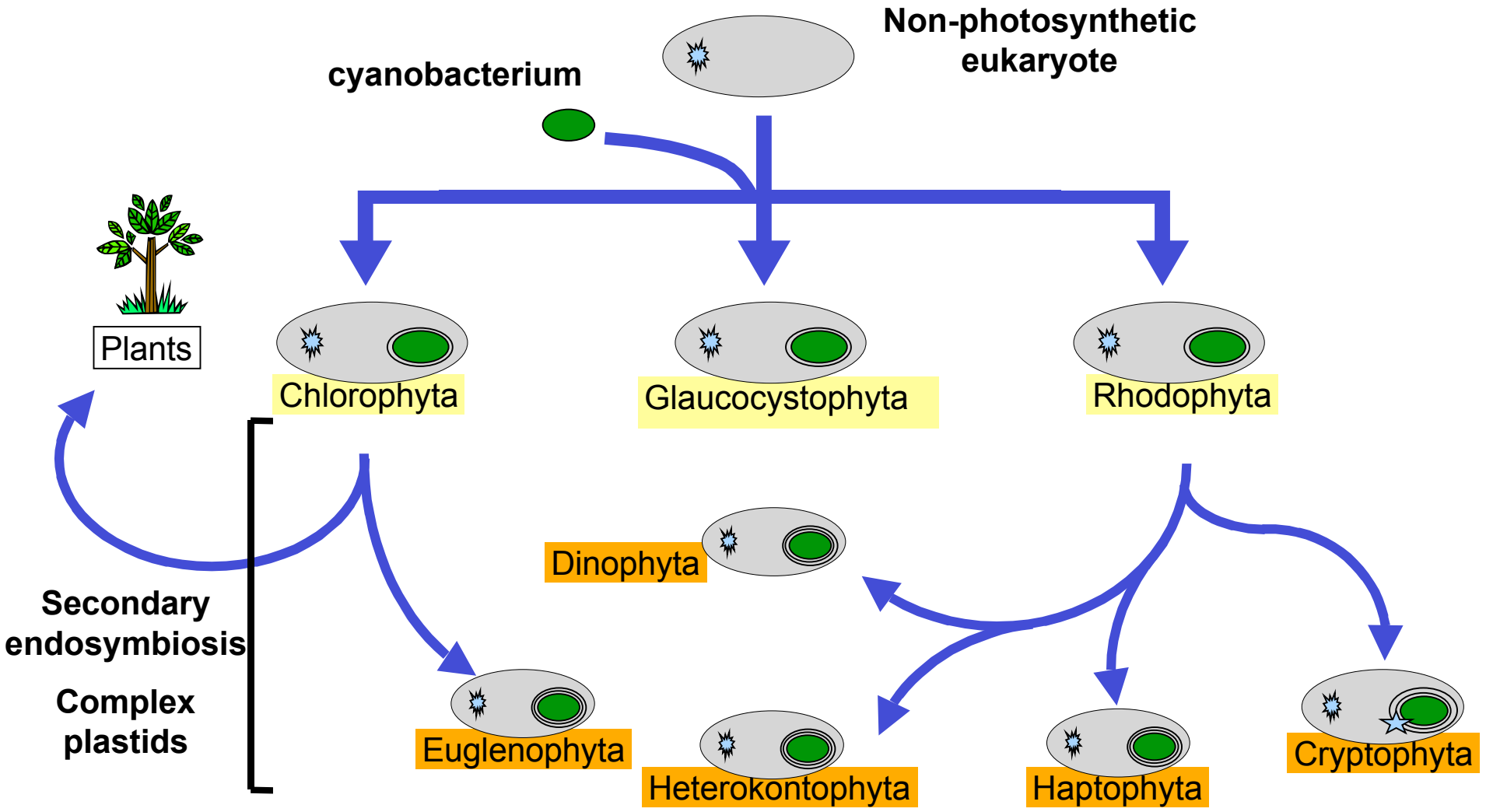


Areas in which studying algal biology might help

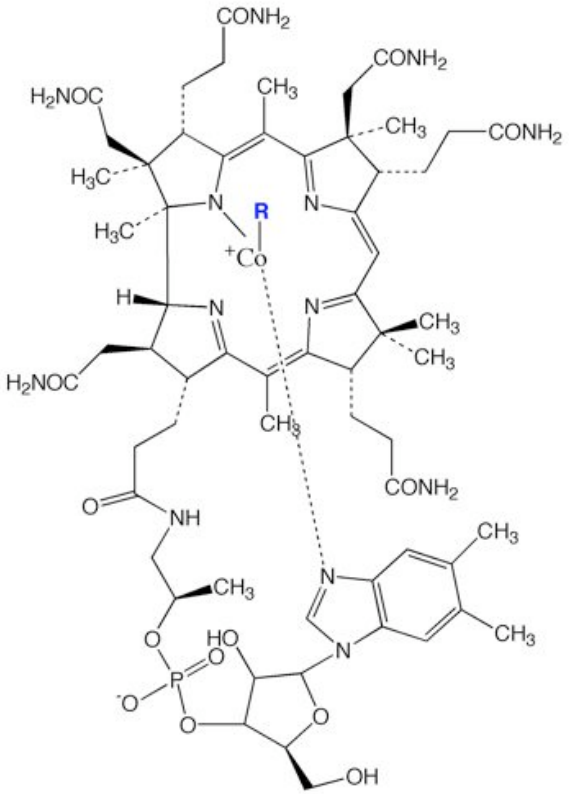
- Different uses of algae to pump-prime industry
- Taxonomy & systematics
- Knowledge of algal community biology
- Leverage from genomics



Algal kingdom is extremely diverse



Vitamin B_{12} (cobalamin)



R = upper axial ligand of CN, Me, or 5'deoxyadenosyl

- Most complex single primary metabolite
  - in animals cofactor for methionine synthase & methylmalonyl coA mutase
  - deficiency causes pernicious anaemia
- Higher plants do not contain cobalamin
  - strict vegetarians at risk of deficiency
  - many algal species contain high levels

Porphyra blade

Vitamin B_{12} requirements of algae

Phylum	Total Species Assessed	Require Cobalamin	Do not require cobalamin
Chlorophyta	158	46	112
Glaucocystophyta	1	1	0
Rhodophyta	13	12	1
Cryptophyta	7	6	1
Dinophyta	30	26	4
Euglenophyta	15	13	2
Eustigamatophyta	1	0	1
Haptophyta	18	12	6
Heterokontophyta	88	51	37
TOTAL	**331**	**167**	**164**

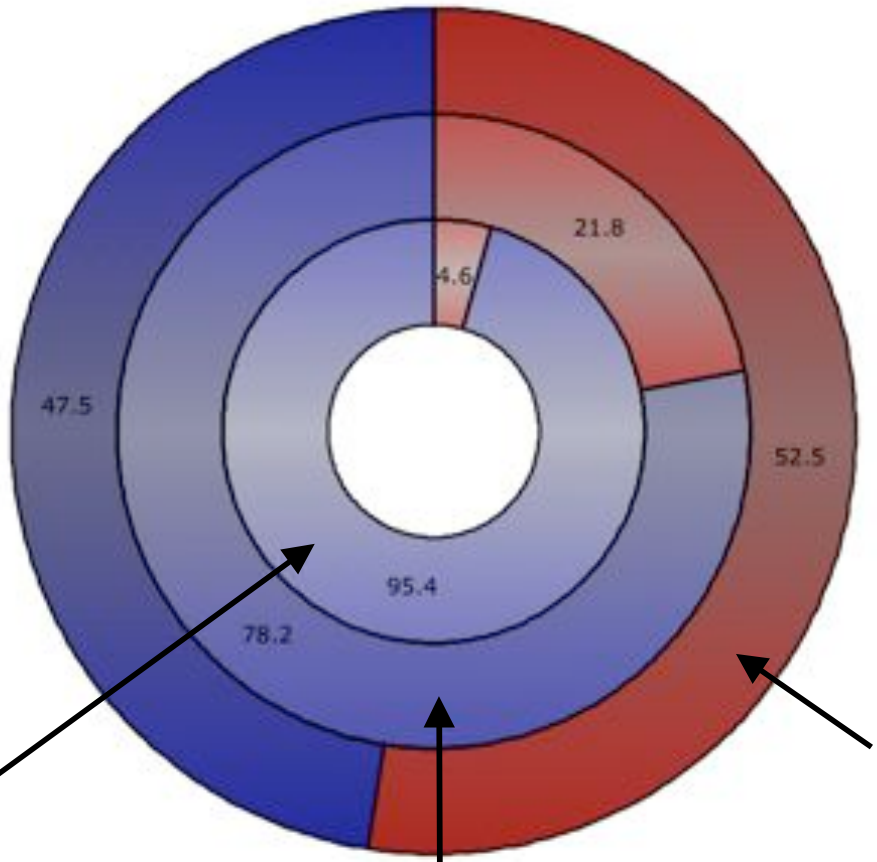
- Non-requirers do not contain vitamin B_{12}

Croft et al (2005) Nature 438: 90-93

Algae require other vitamins too

Do not require a vitamin

Require one or more vitamins



Biotin

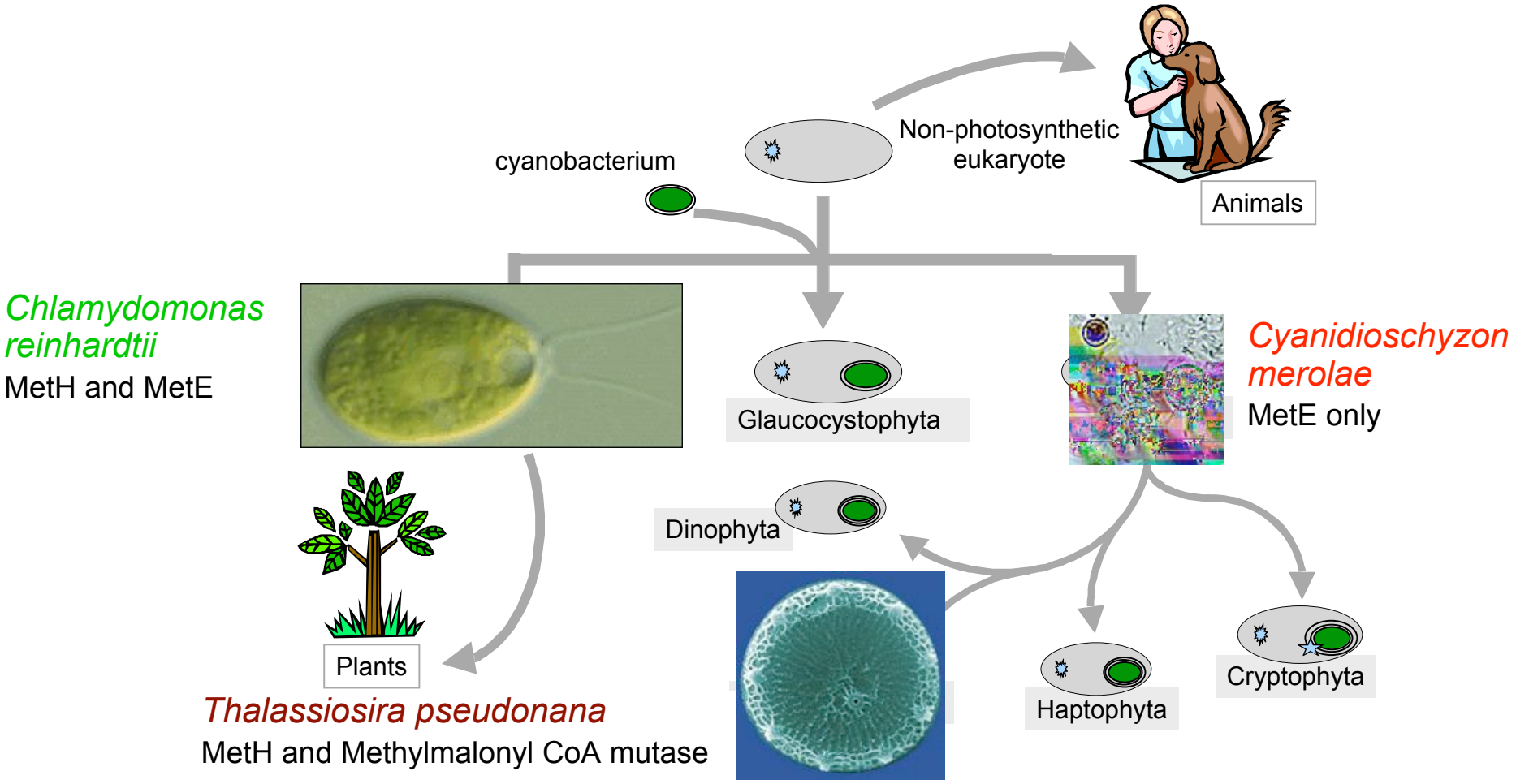
Thiamine

Cobalamin

Croft et al (2006) Eukaryotic Cell 5: 1175-1183

Explanation from genome sequences

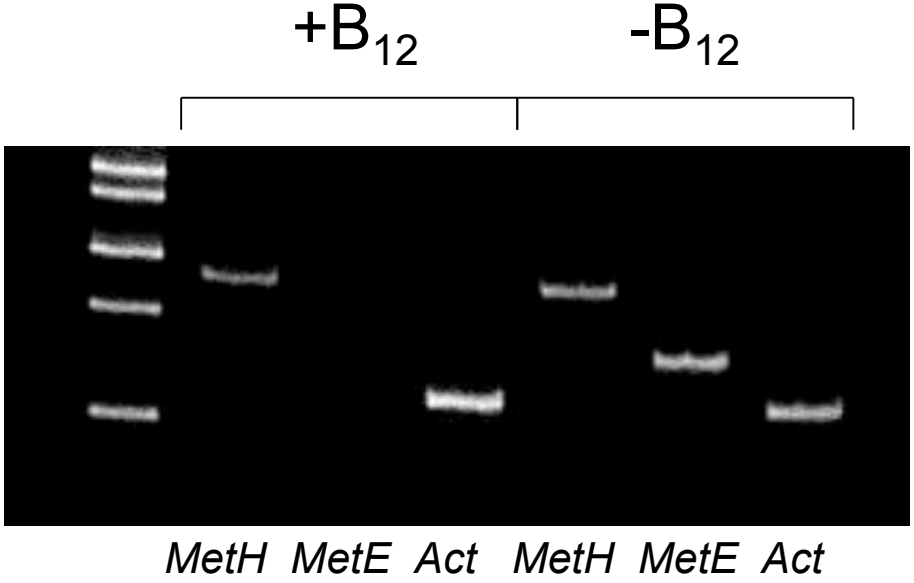
- B_{12} requirement related to type of methionine synthase present



Croft et al (2005) Nature 438: 90-93

B_{12} affects MetE gene expression

- *C. reinhardtii* has both methionine synthase genes

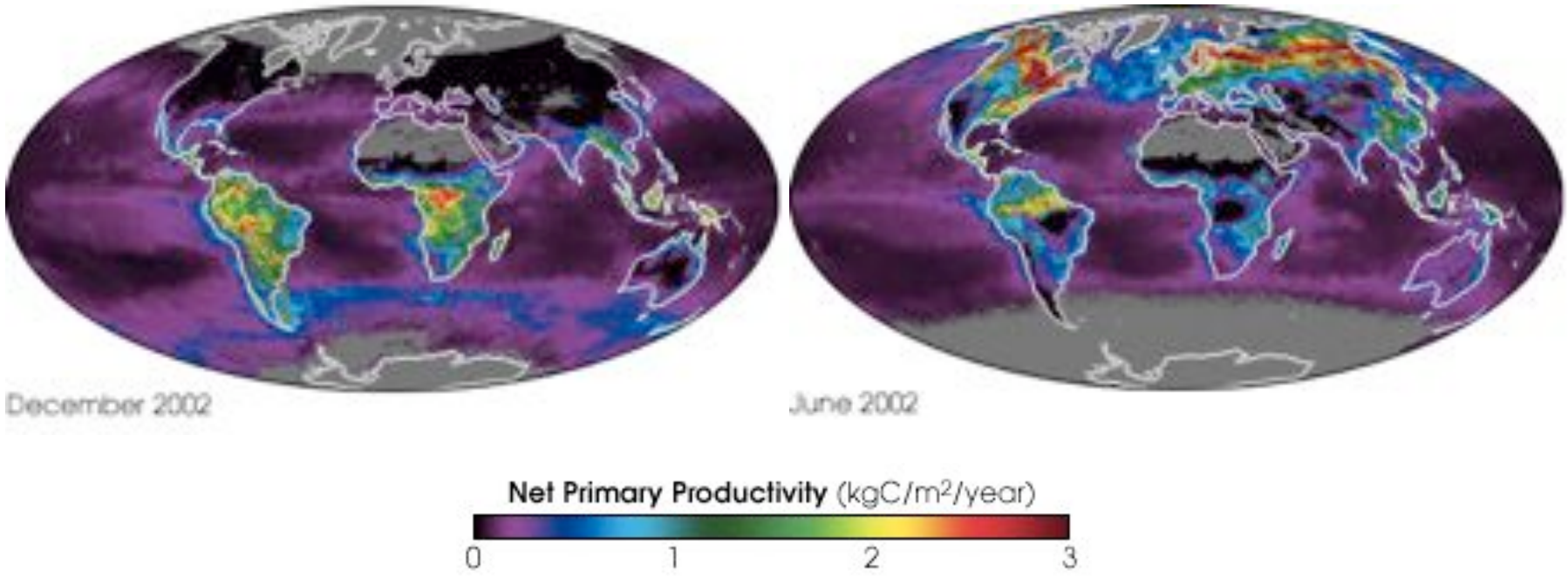


MetH is expressed constitutively
MetE is expressed in absence of vitamin B_{12} only

Croft et al (2005) Nature 438: 90-93

Algae in the marine environment

NASA Earth Observatory

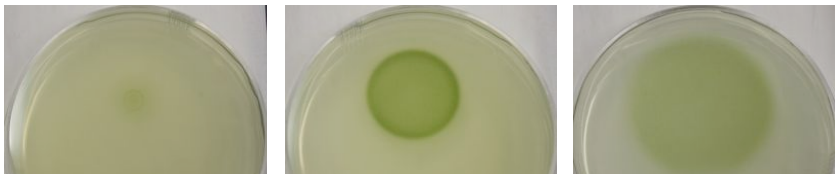


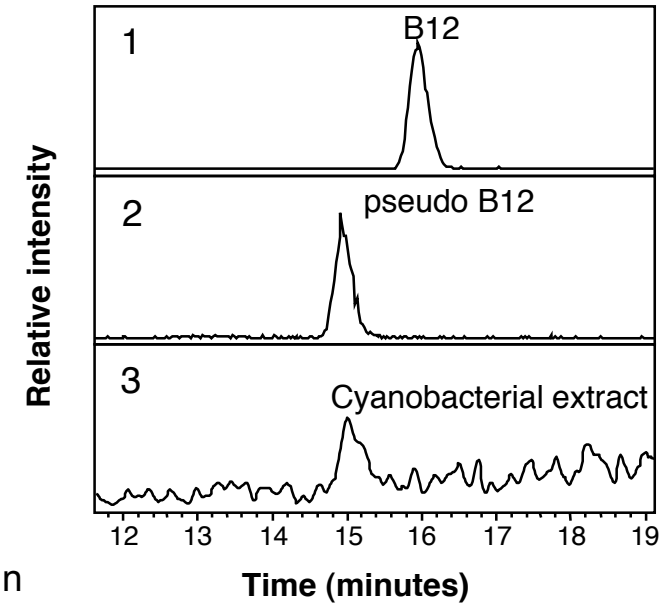
- What is the source of B_{12} for eukaryotic algae?
- Dominant oxygenic phototrophs in tropical & subtropical oceans are cyanobacteria, eg *Prochlorococcus, Synechococcus* sp.

Corrinoids in cyanobacteria

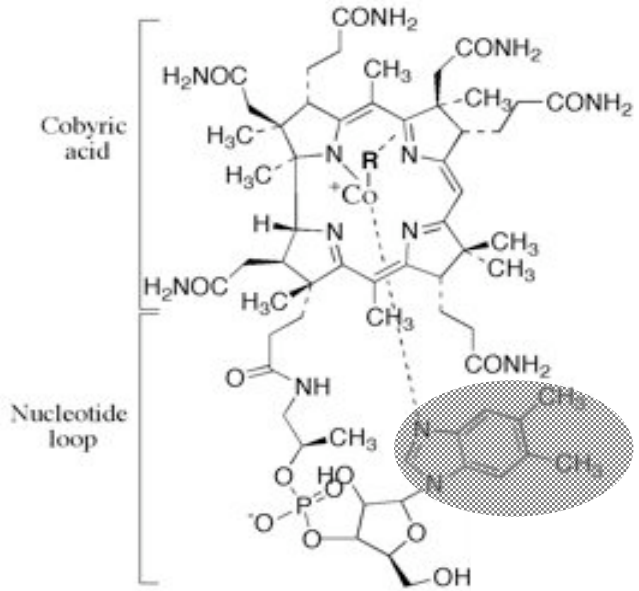
- Bacterial extracts spotted onto lawn of *Lobomonas rostrata* (B_{12}-dependent)

Synechococcus *S. meliloti* *M. loti*

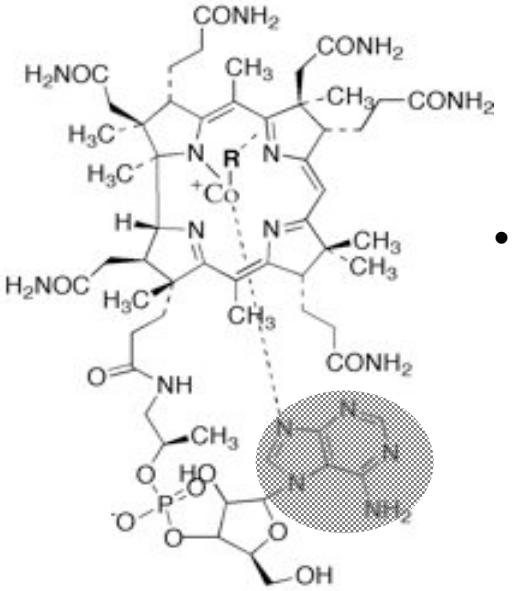




Cobalamin



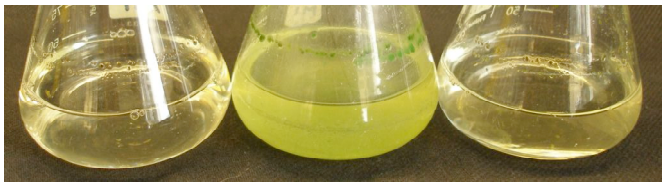
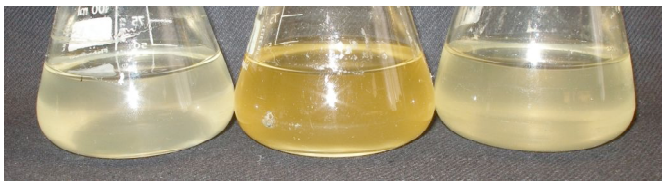
Pseudocobalamin



- Pseudocobalamin is not bioavailable for humans

Croft et al, in revision

PseudoB$_{12}$ does not support growth of algae

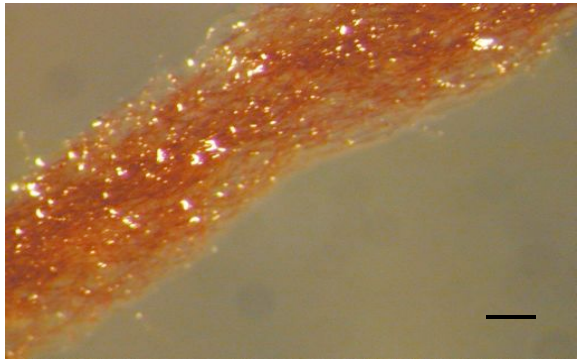
	no B_{12}	vitamin B_{12}	pseudoB_{12}
Lobomonas rostrata Chlorophyta			
Ankyra judayi Chlorophyta			
Porphyridium sp. Rhodophyta			
Thalassiosira pseudonana Heterokontophyta			
Amphidinium carterae Dinophyta			
Euglena gracilis Euglenophyta			

Croft et al, in revision

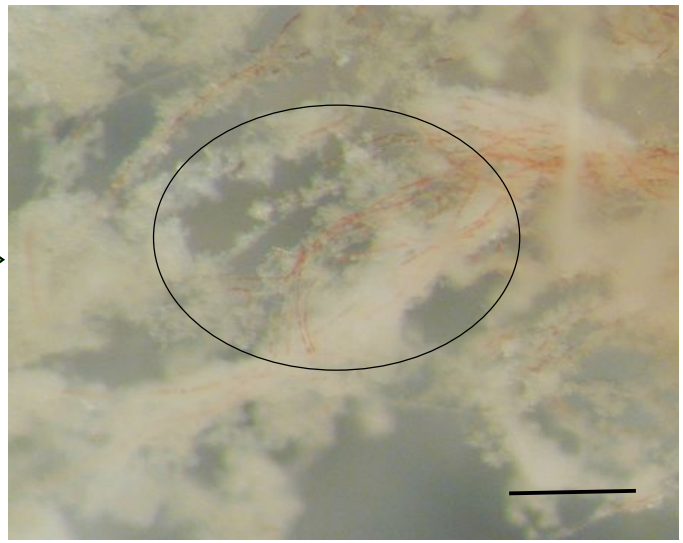
What is the source of exogenous vitamin B_{12}?

- Concentration of free vitamin B_{12} in environment is extremely low
  - Seawater contains < 2 pM (~ 3 ng/l)
  - minimum of 10 ng/l required

- Bacteria frequently found associated with algae
  - *Halomonas* sp.isolated from *Porphyra* blades, *Amphidinium carterae* (dinoflagellate)

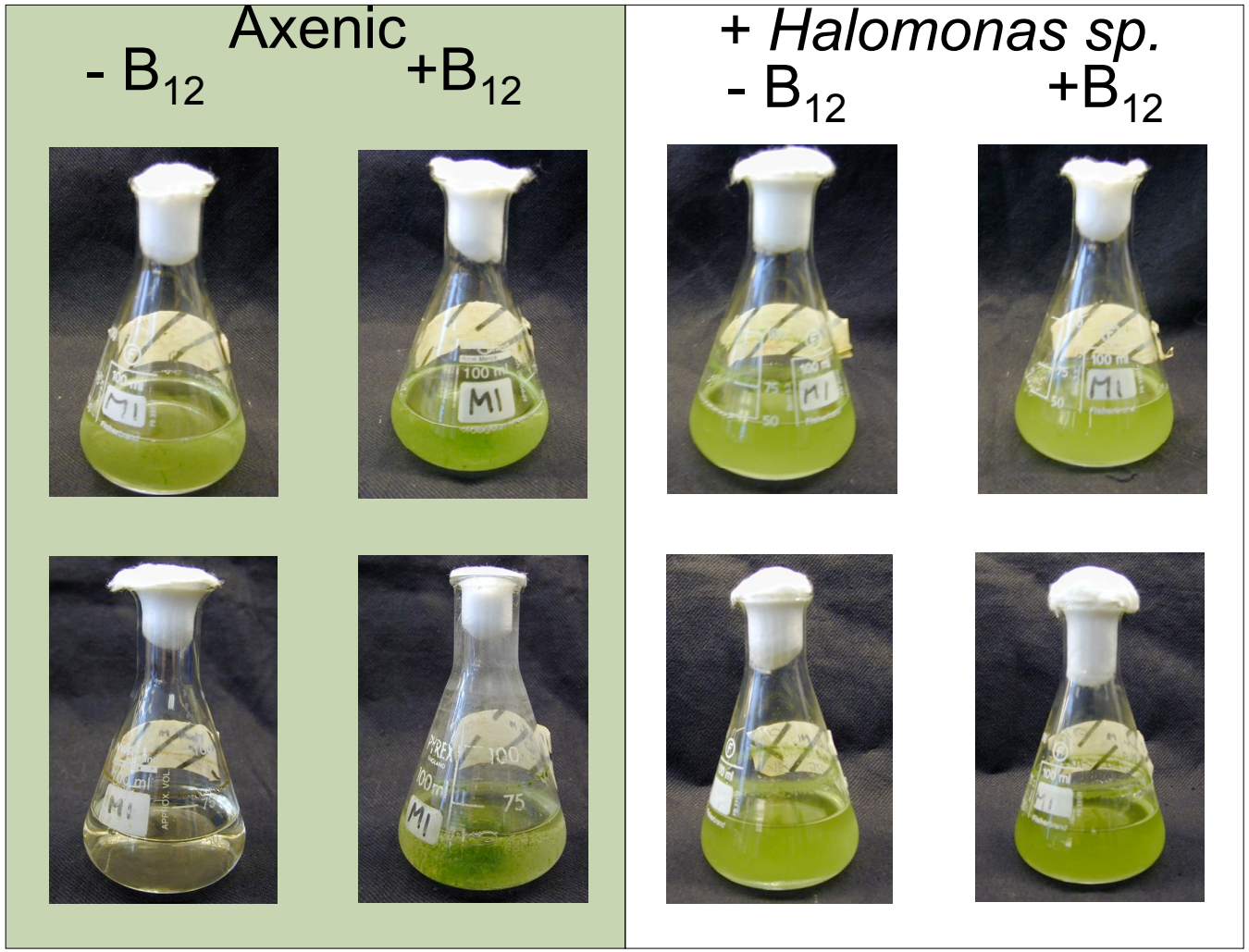


Porphyria miniata



Halomonas sp. can support algal growth

Porphyridium spp. in filter-sterilised sea water



Croft et al (2005) Nature 438: 90-93

Is the interaction specific?

Successful interactions

Alga	Phylum	Bacterium
Porphyridium sp.	Rhodophyta	*Halomonas sp.*
Amphidinium carterae	Dinophyta	*Halomonas sp.*
Amphidinium operculatum	Dinophyta	*Halomonas sp.*
Pavlova gyrans	Haptophyta	*Halomonas sp*
Euglena gracilis	Euglenophyta	*Bacillus megaterium*
Lobomonas rostrata	Chlorophyta	*Mesorhizobium loti*
Lobomonas rostrata	Chlorophyta	*Rhizobium leguminosarum*

Unsuccessful interactions

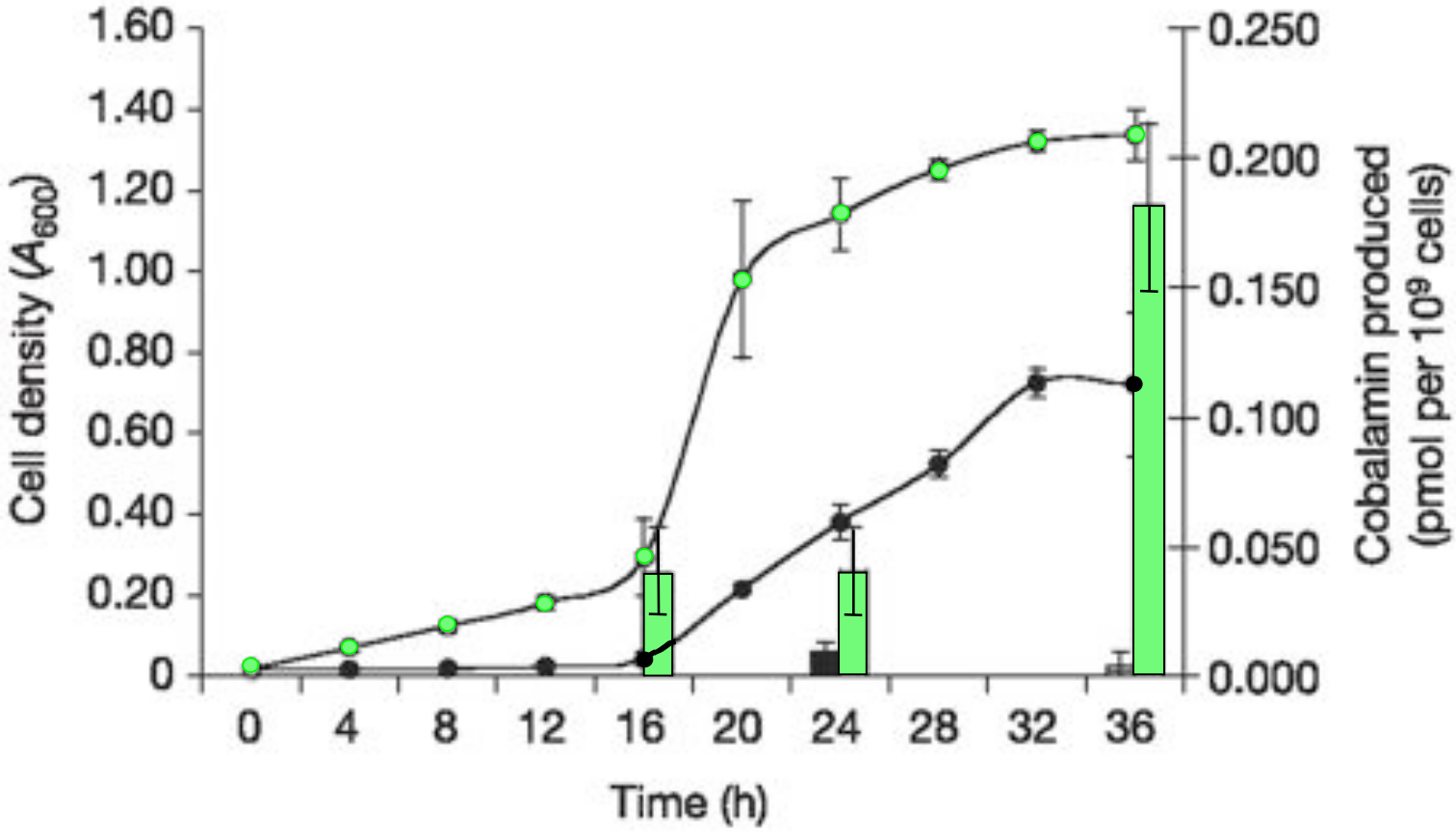
Alga	Phylum	Bacterium
Thalassiosira pseudonana	Heterokontophyta	*Halomonas sp.*
Lobomonas rostrata	Chlorophyta	*Sinorhizobium meliloti*
Lobomonas rostrata	Chlorophyta	*Synechocystis sp.* PCC 6803

- So not just release of B_{12} into medium

Croft et al, in revision

Bacteria stimulated by algal extract

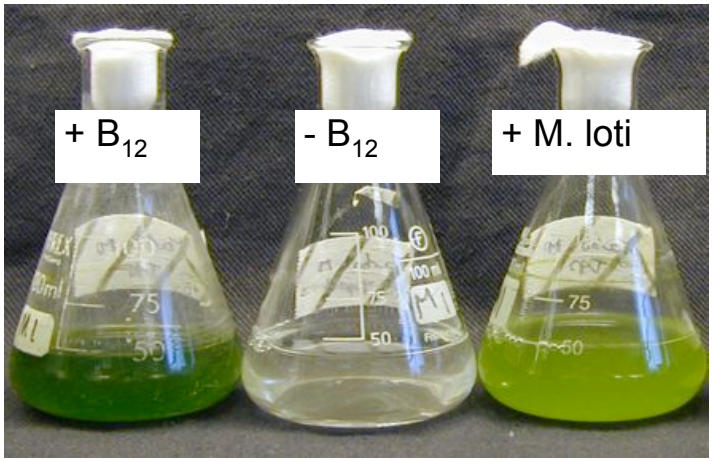
- Fucoidin added to *Halomonas* cultures

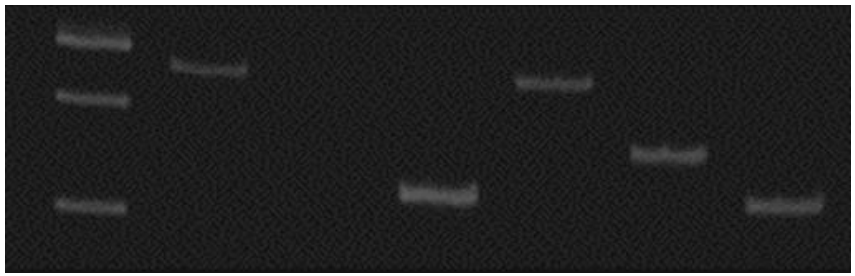


Croft et al (2005) Nature 438: 90-93

Probing the interactions

- *Mesorhizobium loti* MAFF303099 with *L. rostrata* & *C. reinhardtii*





MetH MetE Act MetH MetE Act

+ M. loti

- Rhizobial species form root nodules with legumes

Martin Croft, Severin Sasso

Algal projects ongoing

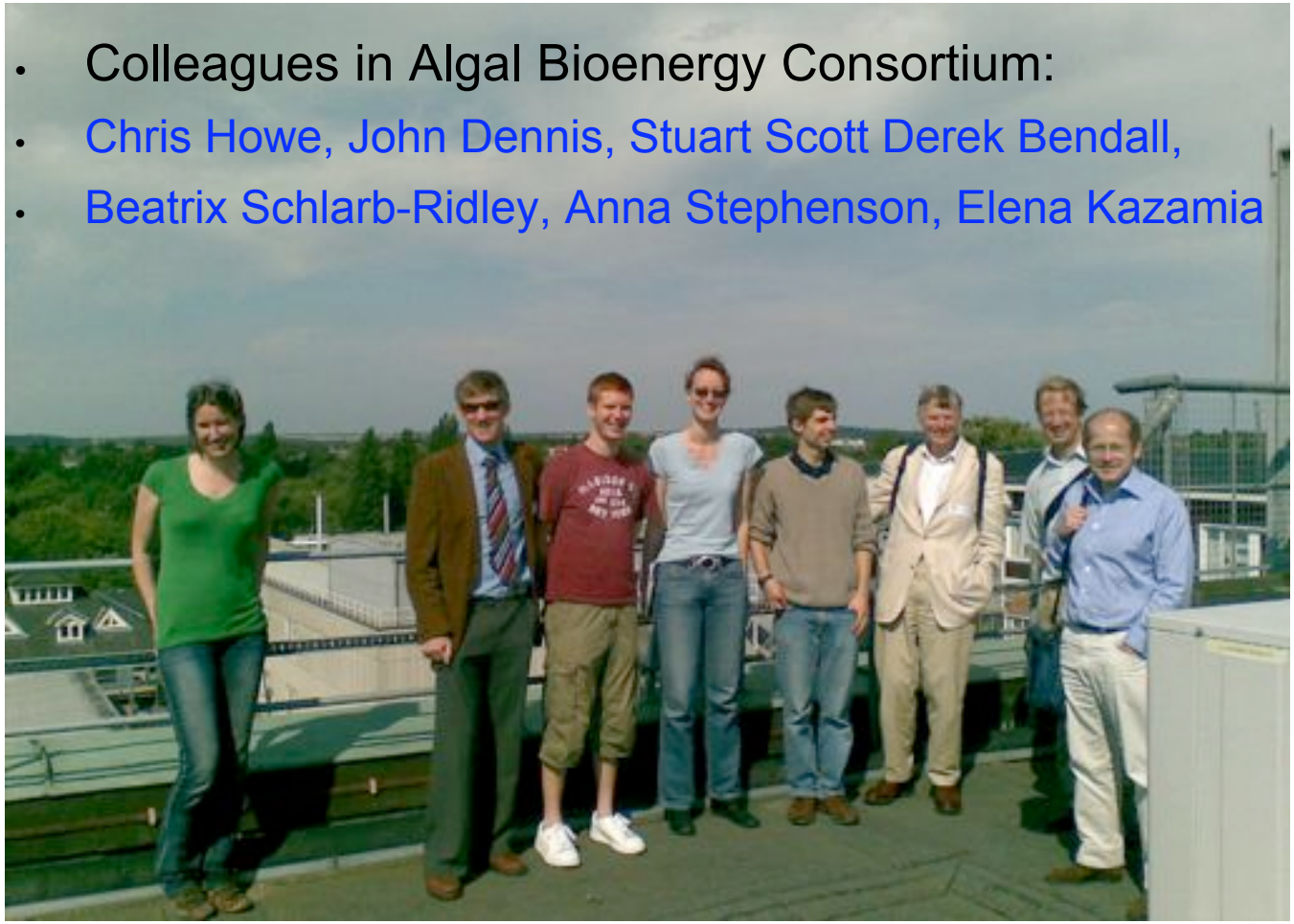
- Cocultures
  - avoid need for vitamin supplementation
  - consequences for contamination
- Algal-bacterial symbiosis
  - Molecular basis of interactions
  - Role of METE in determining B_{12} independence
- Regulation of metabolism
  - Engineering vitamin B_{12} genes into *Chlamydomonas*
  - Regulation of thiamine metabolism in *Chlamydomonas*, role of riboswitches
  - Lipid metabolism - genome analysis, metabolite profiling

Summary and prospects

- Algal biomass production offers enormous untapped potential
  - Current technology is inadequate
- Studies of algal biology will provide both underpinning know-how and unexpected insights
  - In particular of natural aquatic communities
- Genome studies
  - ~ 20 genomes completed to date
  - Need to combine this with development of molecular tools and study of physiological processes

Acknowledgements

- Colleagues in Algal Bioenergy Consortium:
- Chris Howe, John Dennis, Stuart Scott Derek Bendall,
- Beatrix Schlarb-Ridley, Anna Stephenson, Elena Kazamia



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