The Microalgae biorefinery

P.J. Harvey

University of Greenwich

p.j.harvey@gre.ac.uk

Talk outline

- How did we get into this area?
- The global shift to algae biorefineries
- Our shift to algae biorefineries
  - The D-Factory
  - AB-SIG

EU ACP S&T

2009-2013

http://www.acp-nonfood.com/

Capacity-building in South Africa, Namibia and Ghana to Create Sustainable, Non-food Bio-oil Supply Chains

Dunaliella salina

1st Energy Crisis 1975, Glycerol Algal Farm,
500 hectares in Sinai

Halophyte

~50-85% dry wt glycerol

t_d = ~15 h


NBT Eilat, courtesy A Ben-Amotz

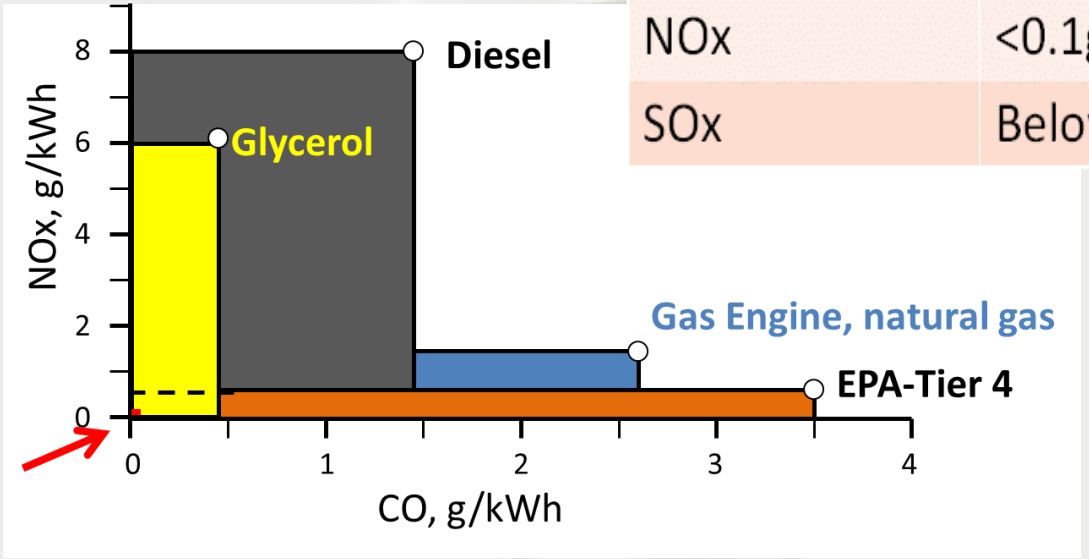
Glycerol: Very low emissions on combustion

Aquafuel™

renewable power specialists

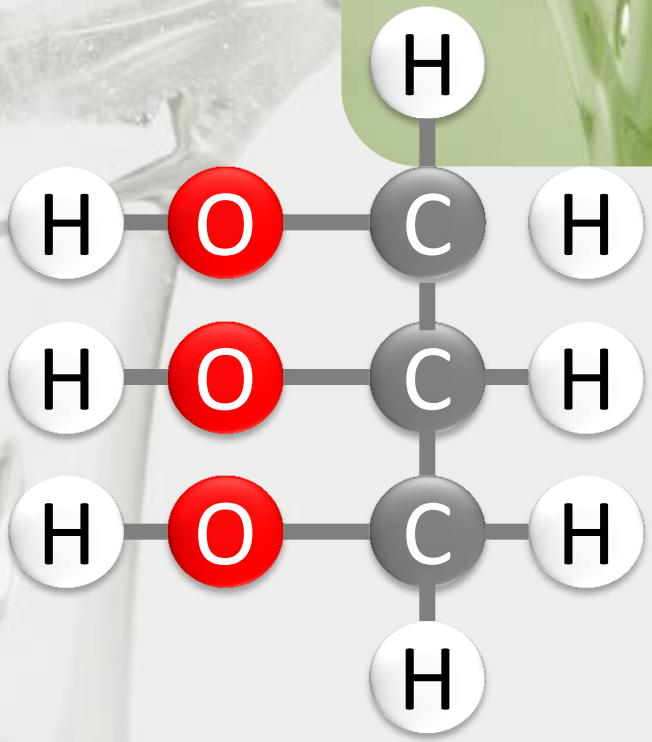
Patent no GB2460996B *Int. Application No.: PCT/EP2009/053274*

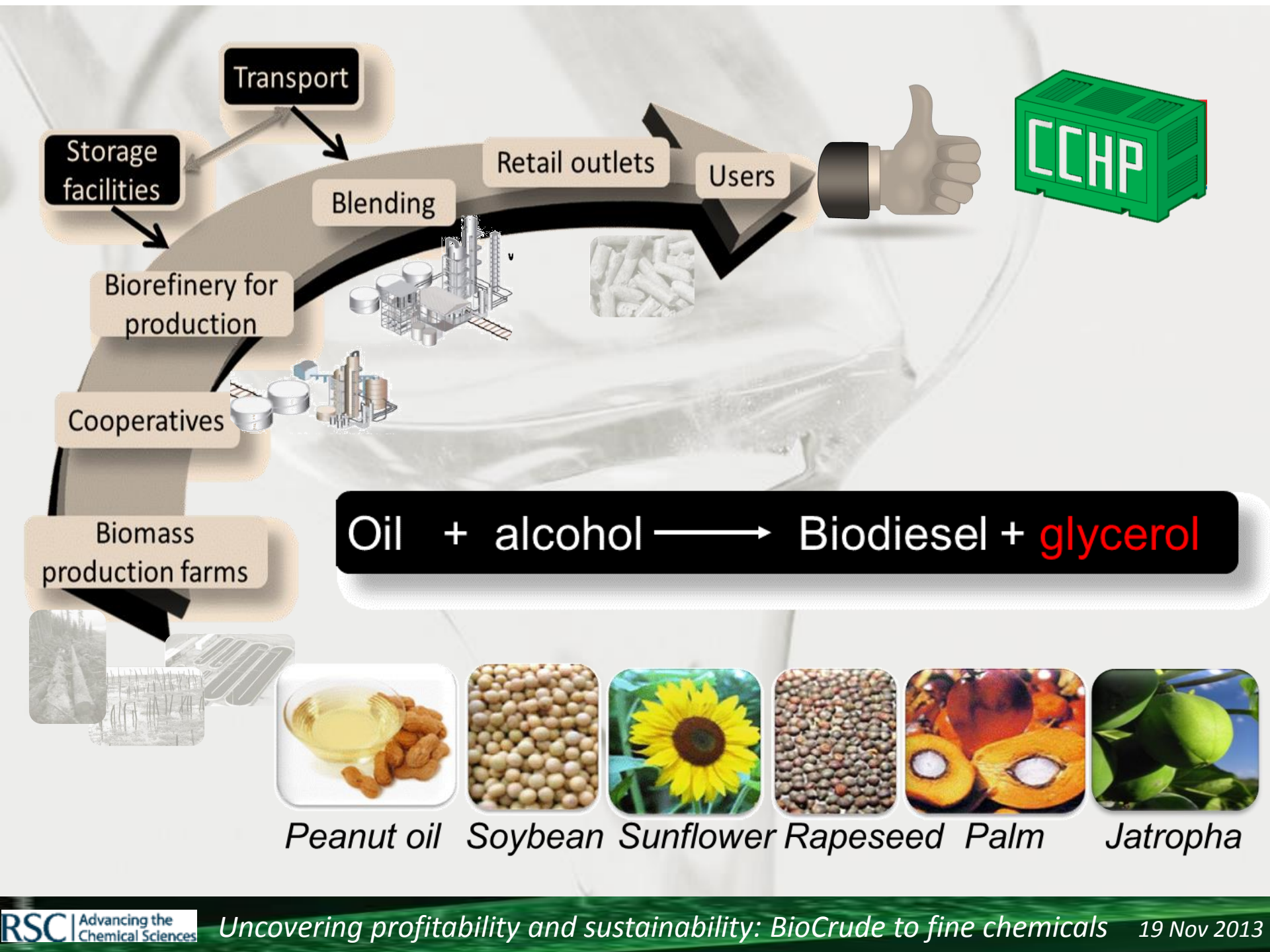
Emissions	Amount
Particulate	Below detection limits
NOx	<0.1g/kWh possible
SOx	Below detection limits



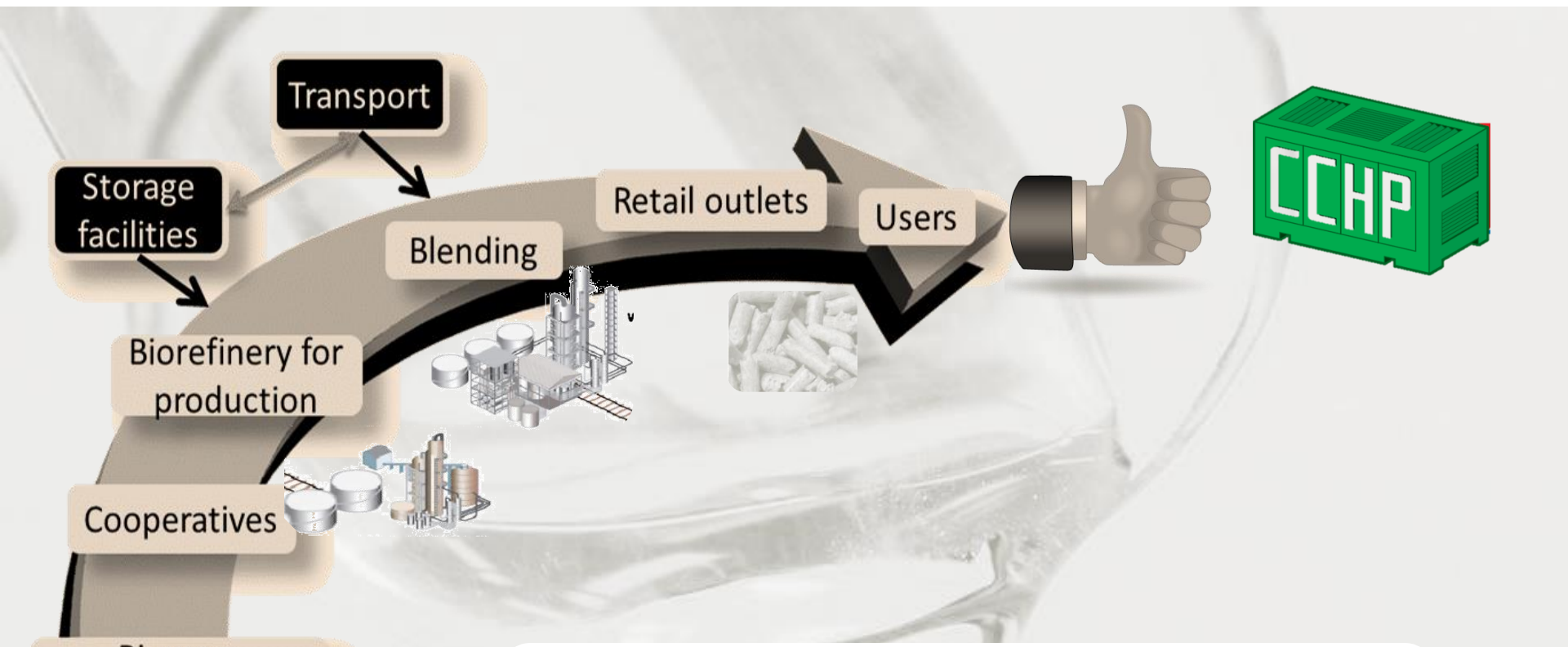
Glycerol

- Water-soluble
- Non-flammable
- Non-volatile
- High boiling point
- Bio-production
- Bio-degradable
- No environmental pollution



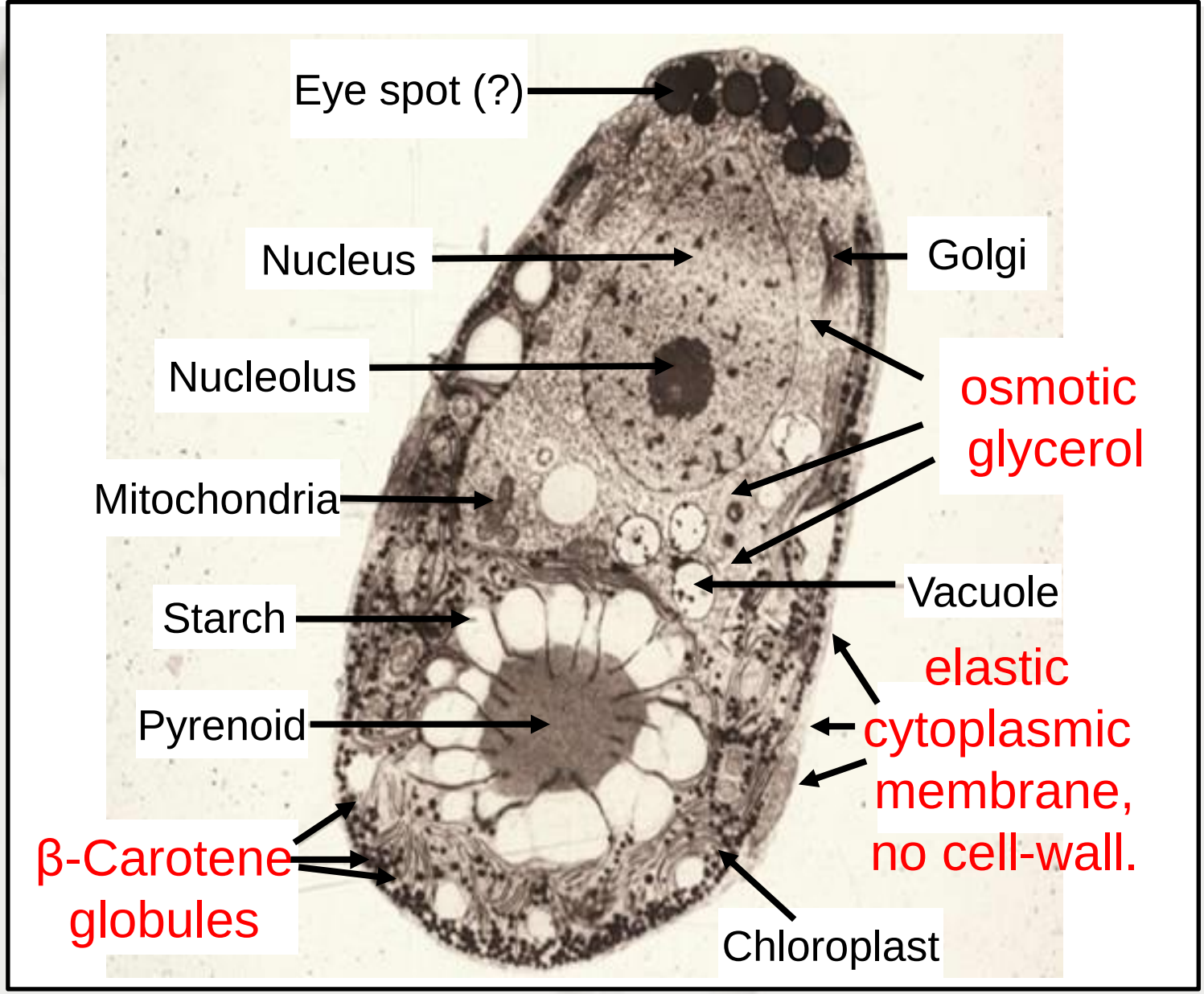

Transport
Storage facilities
Blending
Retail outlets
Users
CCHP
Biorefinery for production
Cooperatives
Biomass production farms
Oil + alcohol ⟶ Biodiesel + glycerol
Peanut oil
Soybean
Sunflower
Rapeseed
Palm
Jatropha

Medway Campus: Engineering Science Faculty running on glycerol-CHP



2020: Biofuels limited (5.5%) from food / energy crops

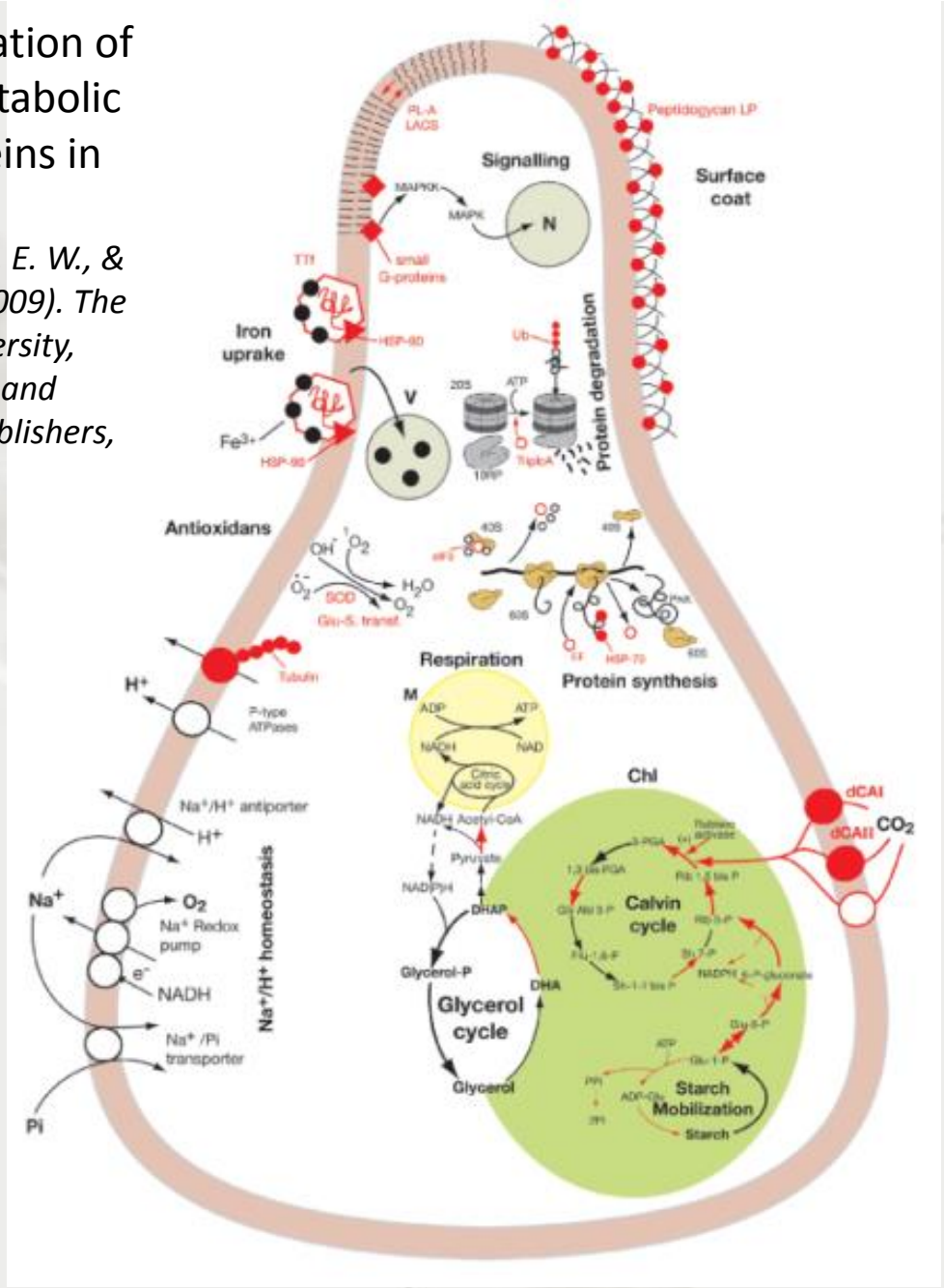
Glycerol from microalgae



TEM of Dunaliella to show cellular structures and distribution of β carotene and glycerol

Schematic representation of salt-upregulated metabolic networks and proteins in Dunaliella

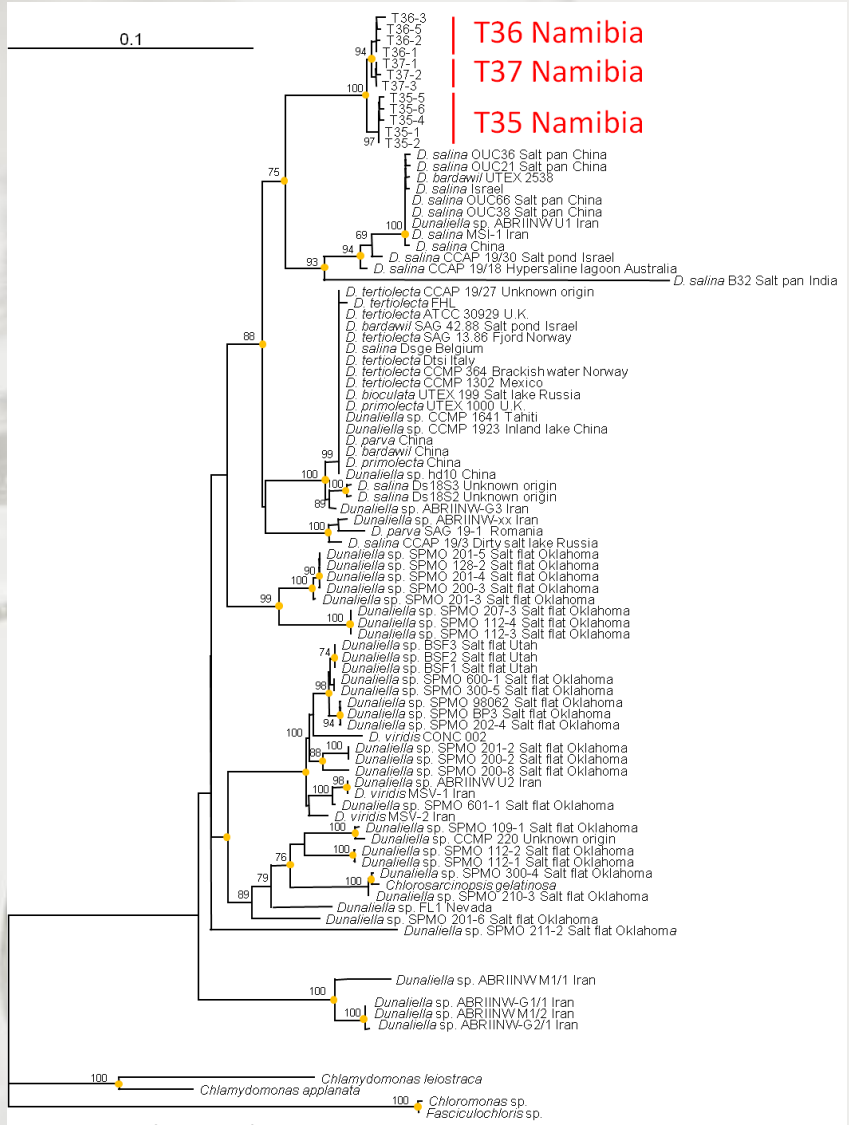
(from Ben-Amotz, A., Polle, E. W., & Subba Rao, D.V., Editors (2009). The Alga Dunaliella: Biodiversity, Physiology, Genomics and Biotechnology. Science Publishers, Jersey, Plymouth)




glycal
ACP S&T
• Productivity
• CO_2 source, nutrients
• Lake / raceway
• Seasonality/cropping
• Energy inputs
• Ecosystem

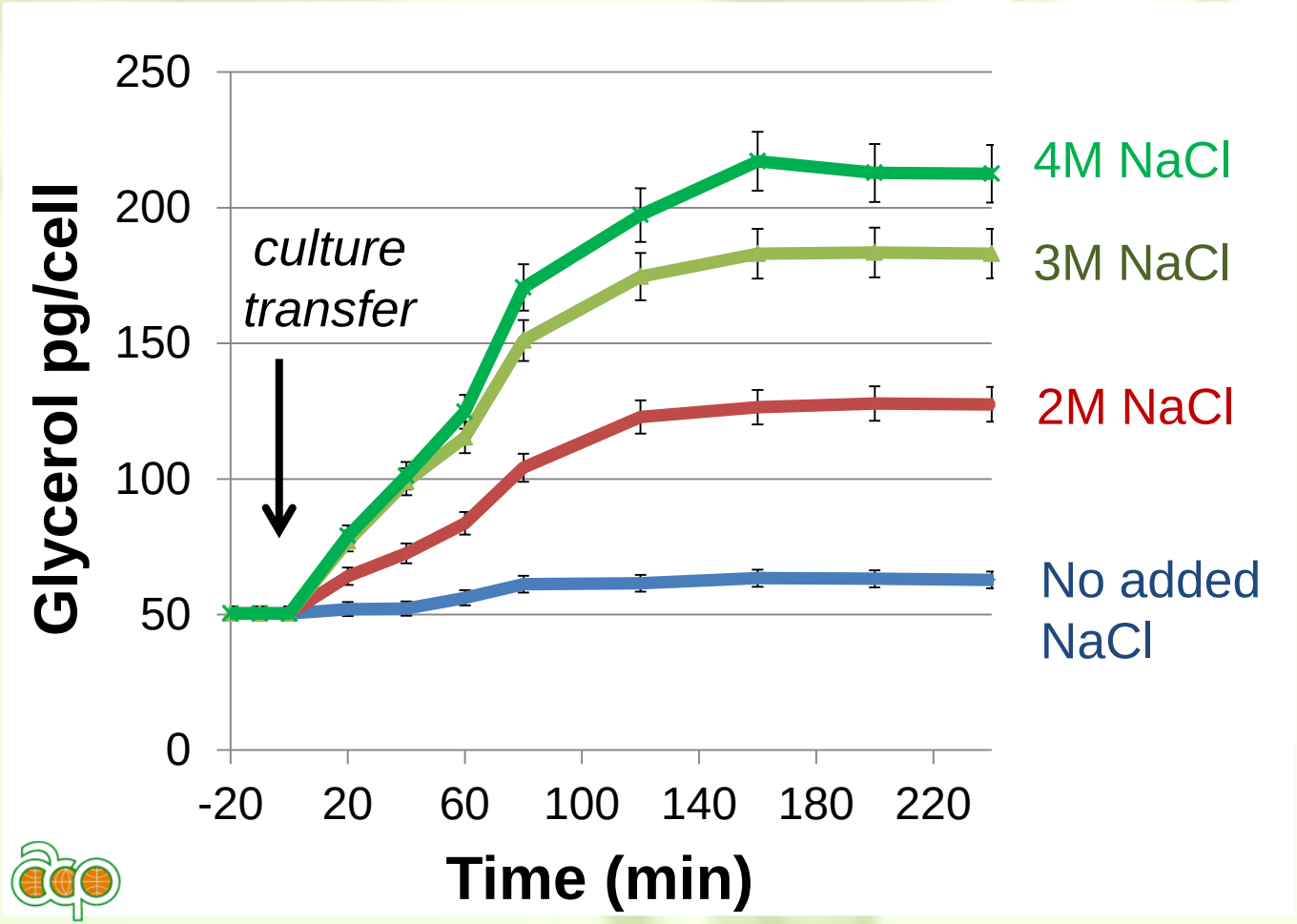
Bioprospecting for algae

- Sequencing and phylogenetic analyses of the 28S rRNA gene
- Namibian strains genetically distinct from other Dunaliella species

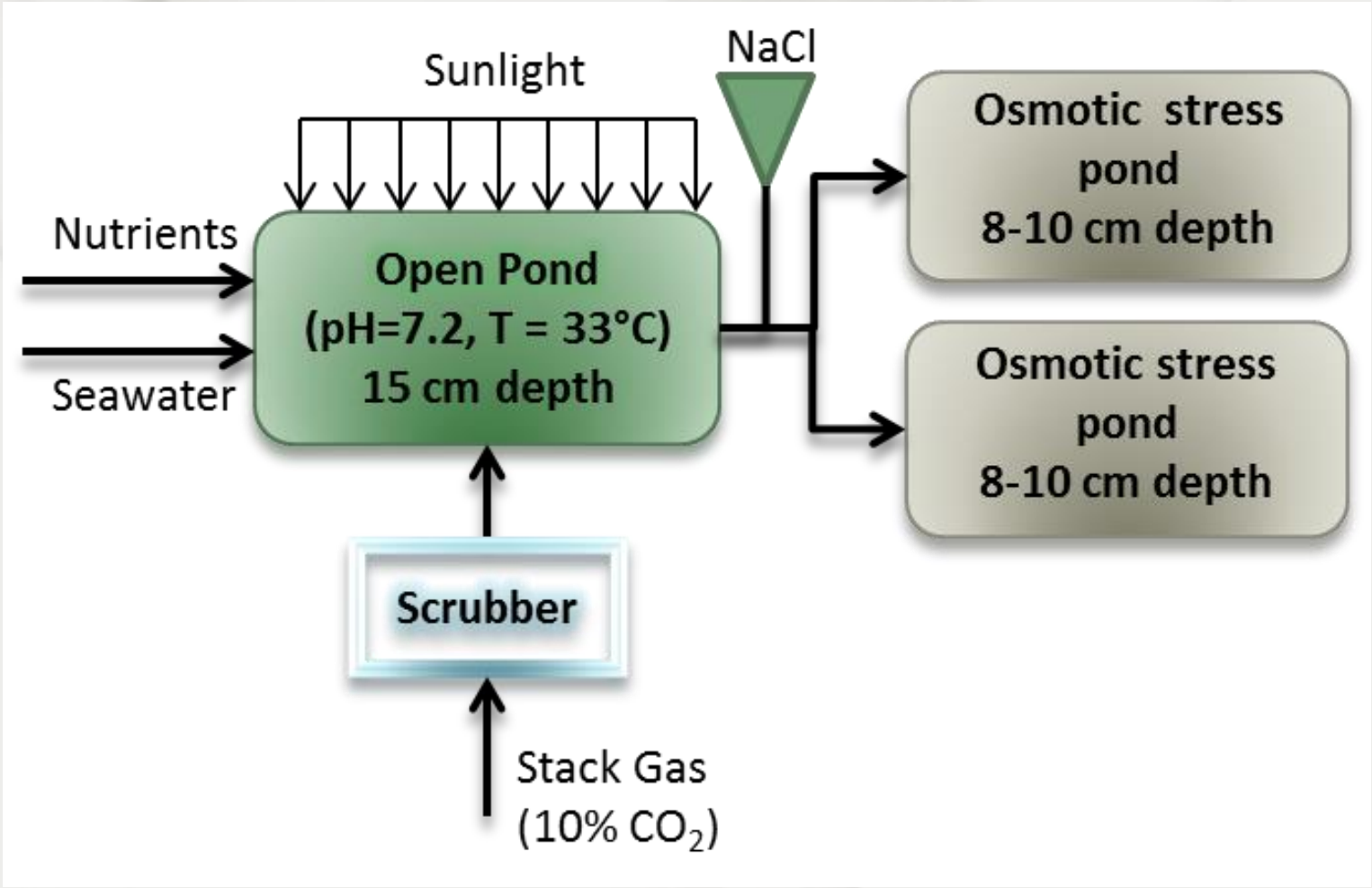


Harvey, P.J., et al 2012 20th EU Biomass Conf.&Exhib., 18-22 June 2012, Milan Italy pp 85-90.

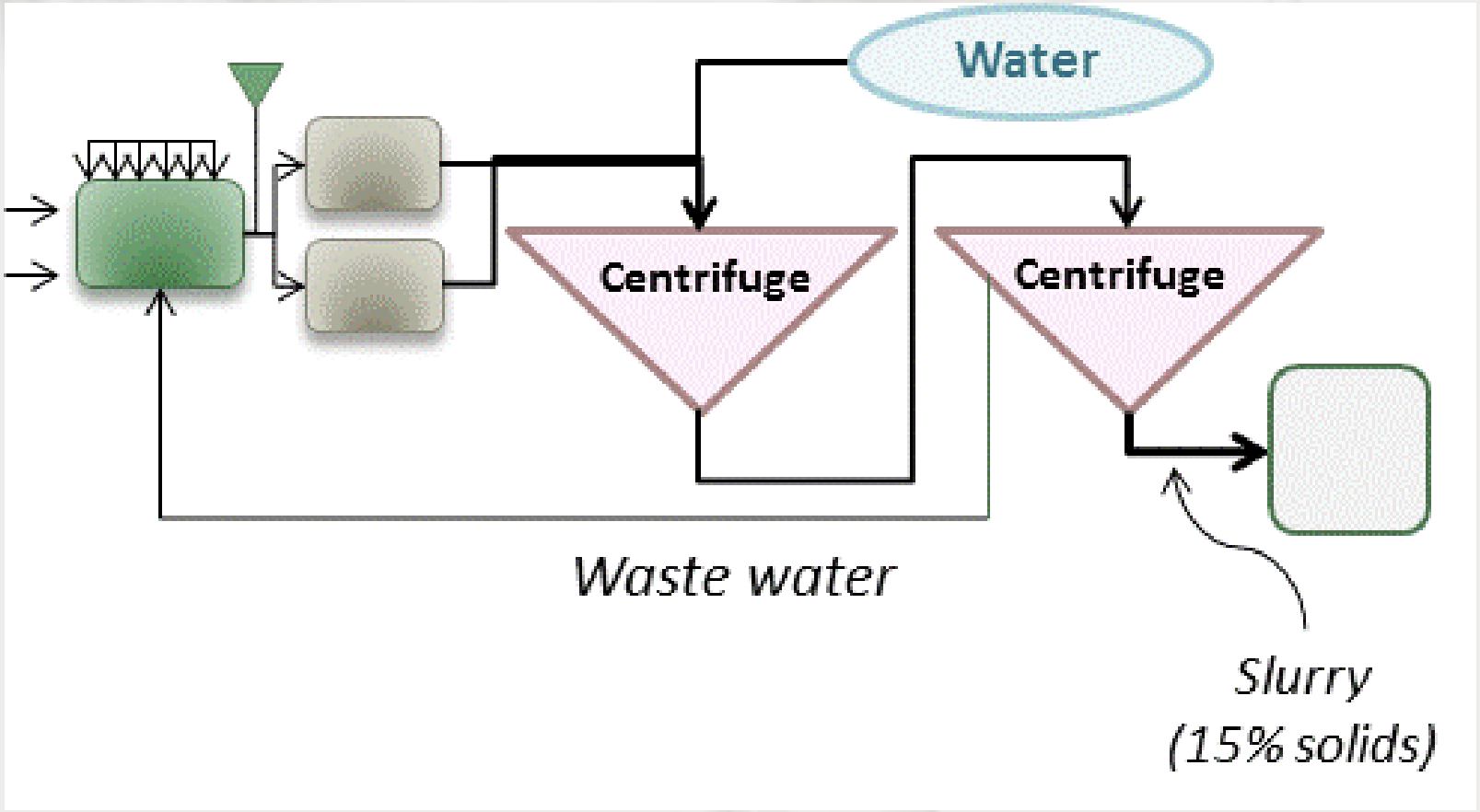
Glycerol synthesis in response to osmotic shock



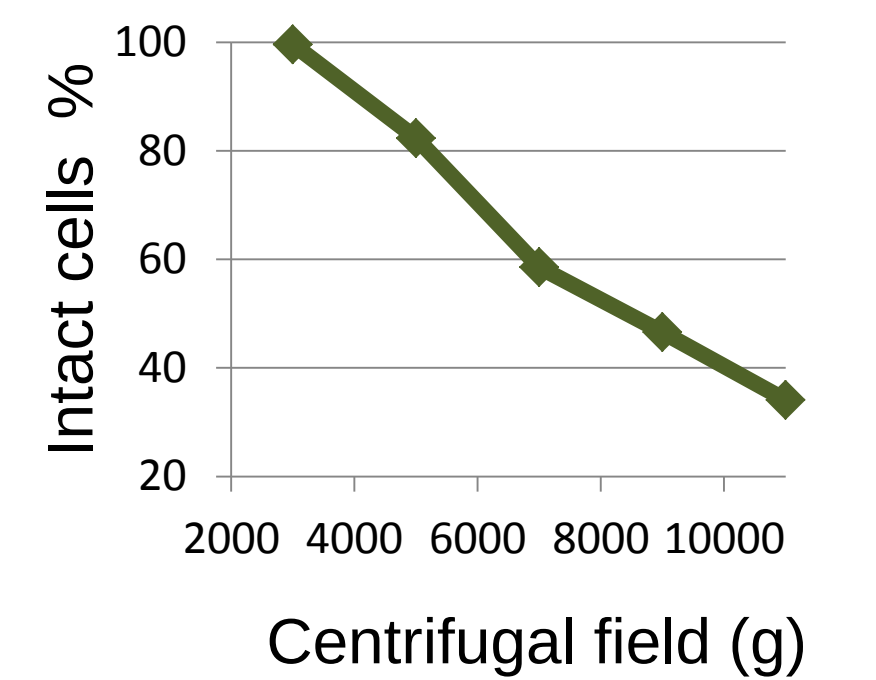
Modelling: Cultivation



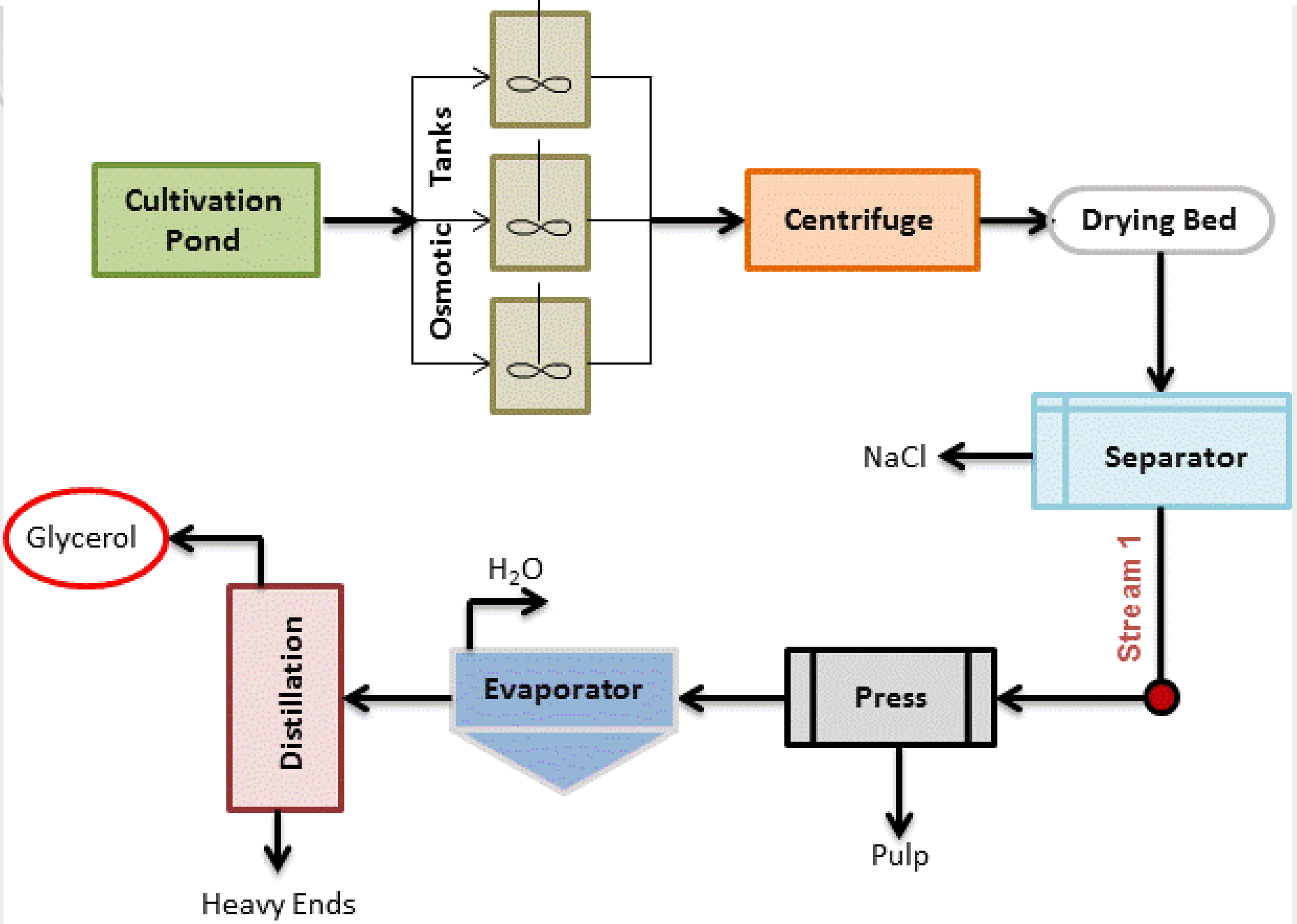
Harvesting



Harvesting



Algae paste in Evodos SPT package:
>90% viable cells


Cultivation Pond
Osmotic Tanks
Centrifuge
Drying Bed
Separator
NaCl
Stream 1
Press
Pulp
Evaporator
H_2O
Distillation
Glycerol
Heavy Ends

Economics

0.5 a raceway
nes biomass

Cost (€/yr)	Glycerol o
Energy for process	
Algae cultivation	-26
Glycerol (€250/	+8,305

A financial nonsense

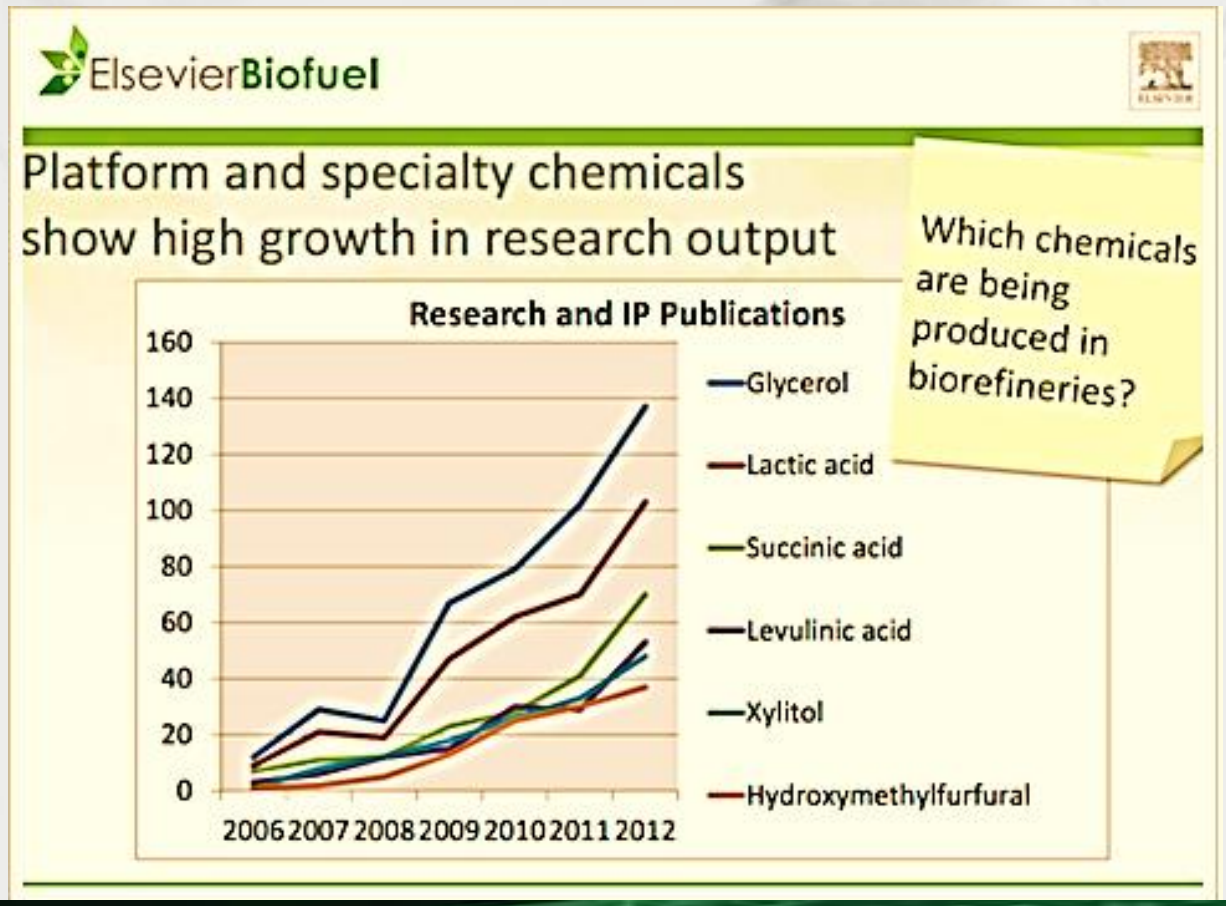
tricity (€0.100/KW)	7 200
Fertilizers (N,P,K, Fe) and other chemicals	523 593
Domestic Land City Taxes , Manpower, fresh water	6 775
CO_2 €400/tonne (cost not included)	87 460
Sea Water (€0.25/m3)	9 560

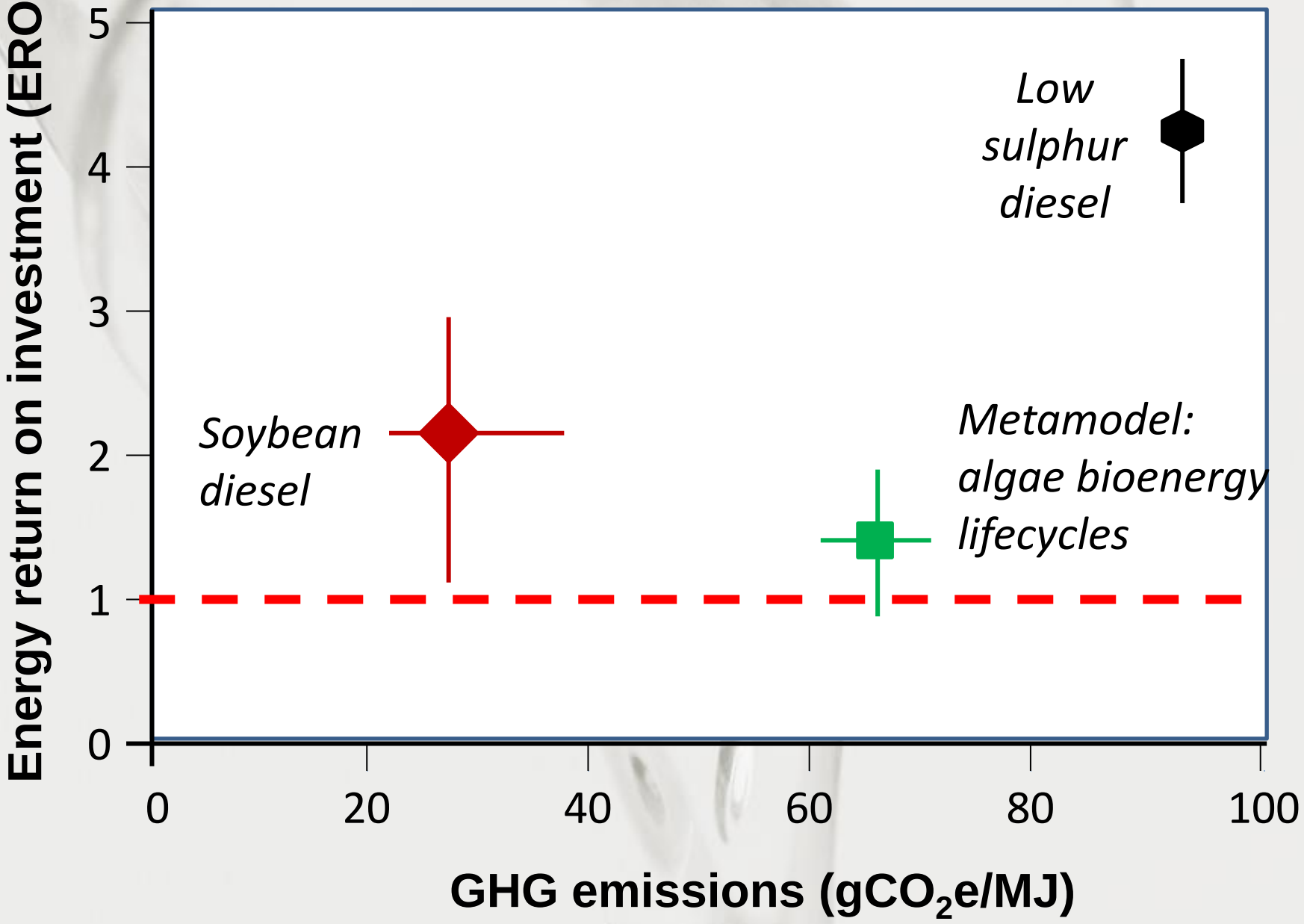
Cost (€/yr)	Glycerol only	Glycerol & β-carotene	Optimize 2	Optimize 3
Solvents	—	1 865 720	3 437 333	2 067 206
Ethanol	—	739 544	739 544	739 544
Cyclohexane	—	741 217	741 217	—
n-hexane	—	—	—	1 327 663
Alum/Ferric Chloride	—	384 959	384 959	—
Trichloroethane	—	—	1.571.613	—
Energy	880 147	2 639 711	2 639 711	1 305 193
Cultivation	539 928	539 928	539 928	539 928
Products	48 305	14 329 313	14 329 313	14 329 313
Glycerol	48 305	48 305	48 305	48 305
β-carotene	—	14 281 008	14 281 008	14 281 008
Profit/loss	**-1.4m**	**9.3m**	**7.7m**	**10.4m**

Process integration still to be undertaken

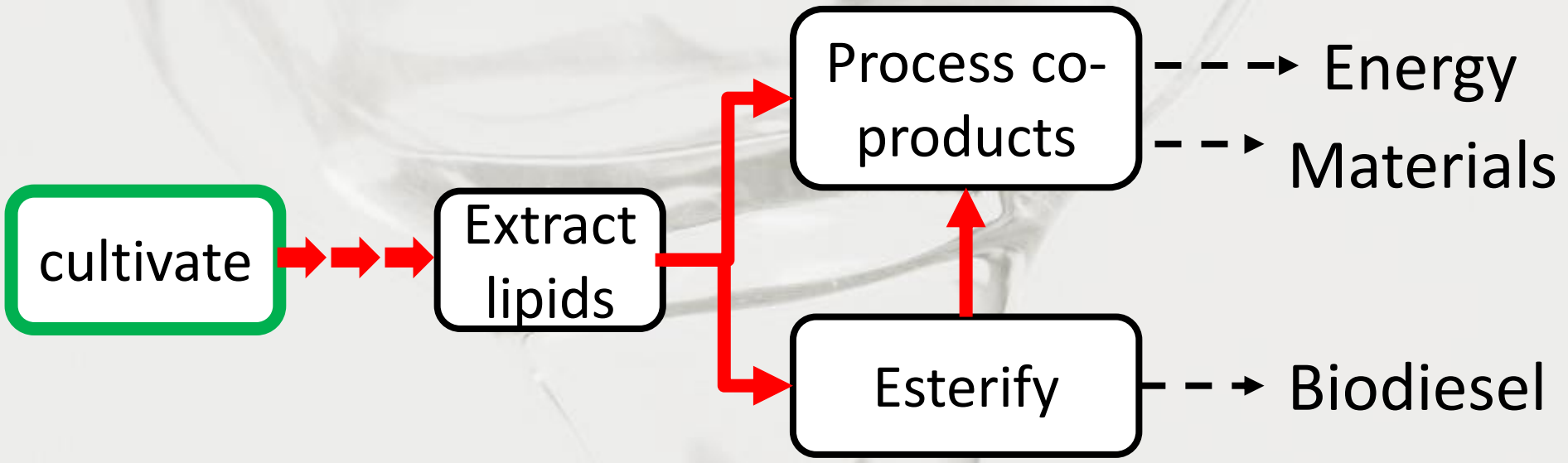
Market trends, anyone? How about the shift from fuels to chemicals?

Biofuels Digest 30 Oct 2013




Energy return on investment (EROI)
5
4
3
2
1
0
0
20
40
60
80
100
GHG emissions (gCO2e/MJ)
Low sulphur diesel
Soybean diesel
Metamodel: algae bioenergy lifecycles

Approach 1:
Lipids extraction and co-products



THE 50 HOTTEST COMPANIES IN BIOENERGY 2013-2013

2008

2008 - Road testing the world's first 100% in-spec algae derived diesel.

solazyme

2010

2010 - Solazyme's algae derived Naval distillate fuel successfully demonstrated in ships

2012

Solazyme's Firming & Lifting skincare line, from renewable oils

admin | January 13, 2012

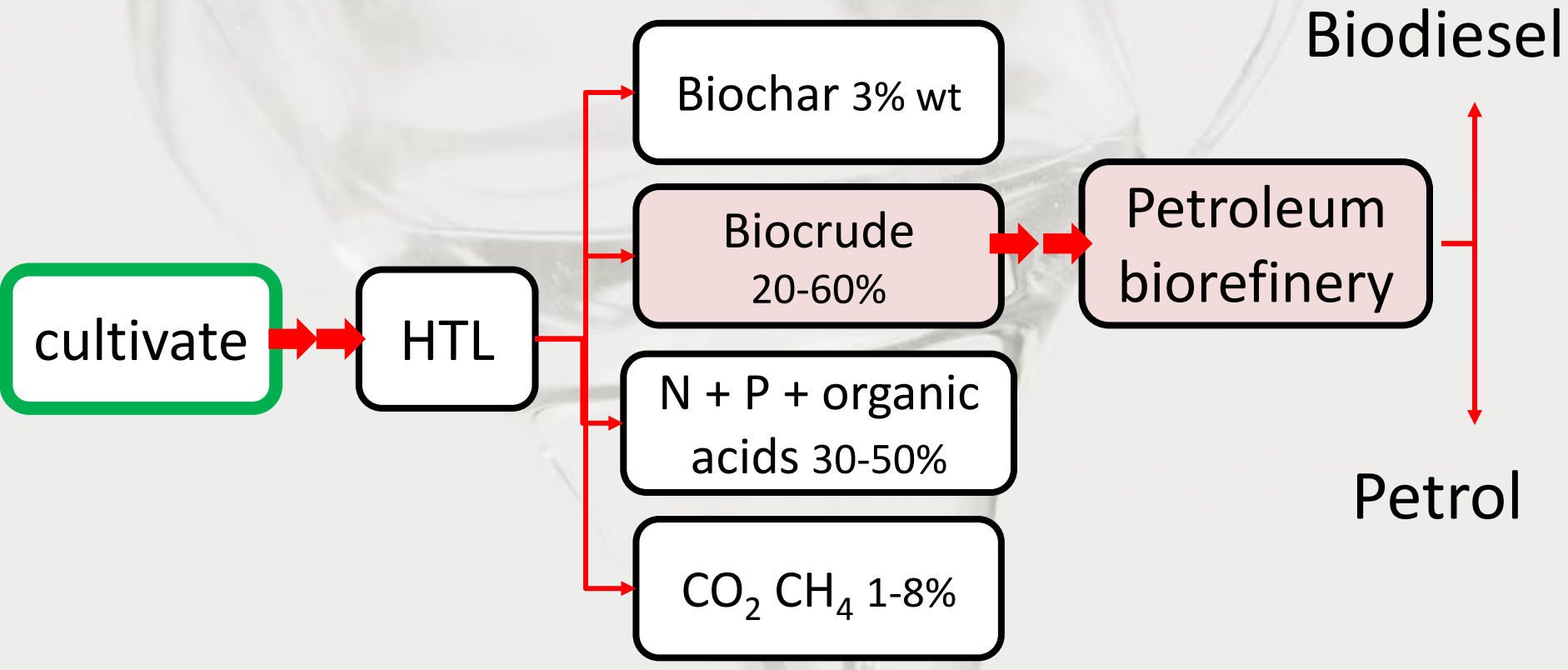
2013

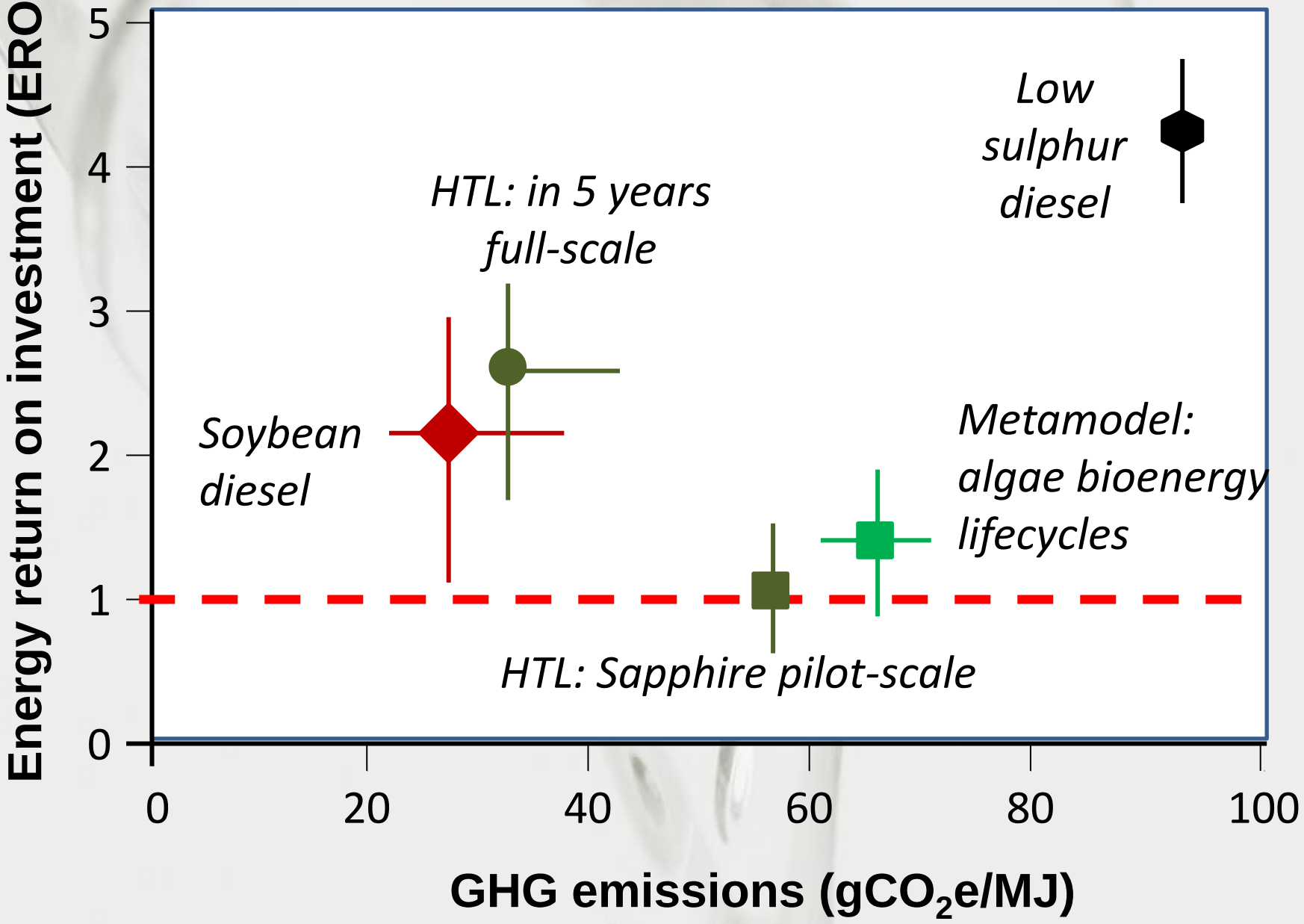
Solazyme to showcase Whole Algal Protein and Whole Algal Flour at SupplySide West

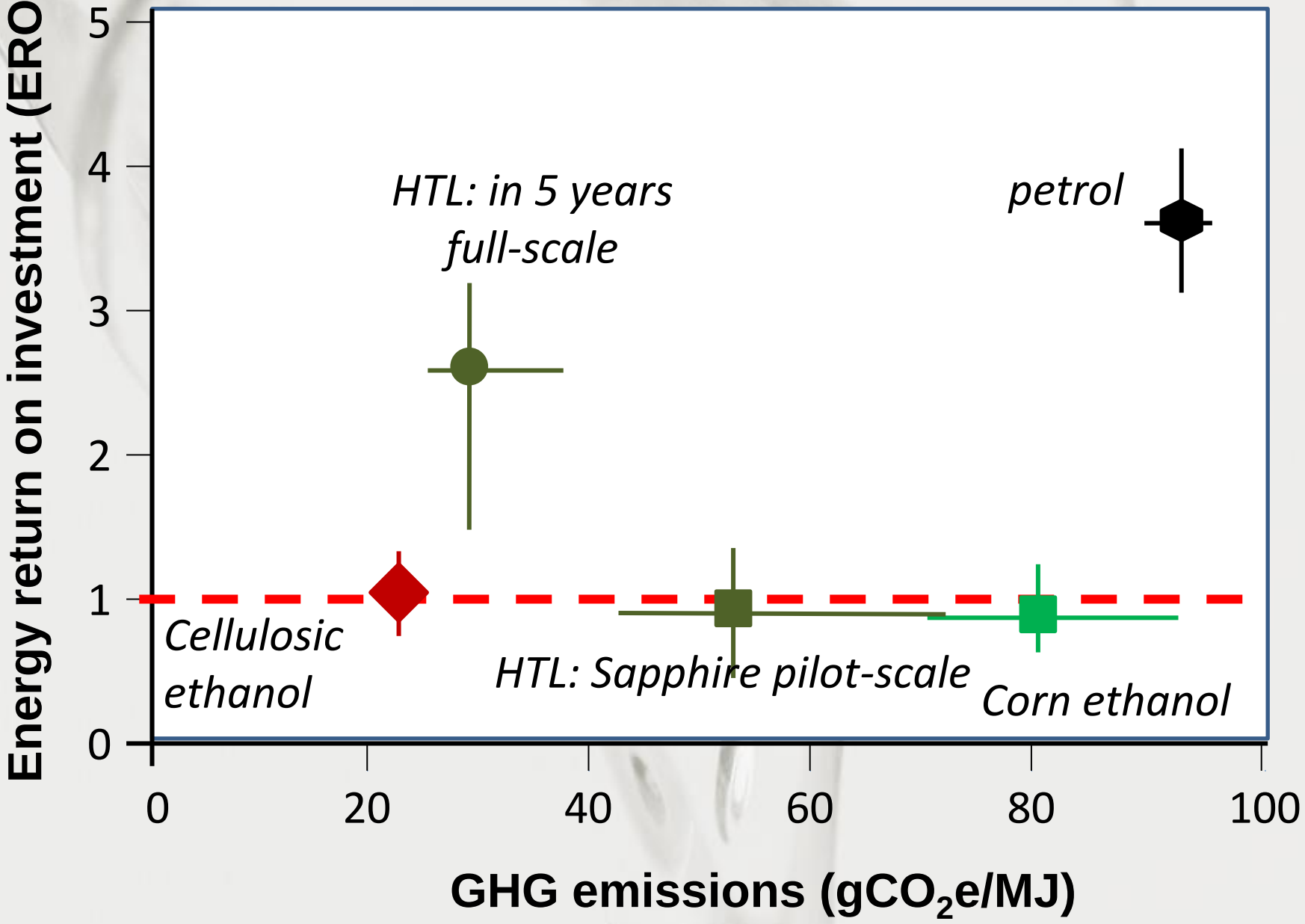
Thomas Saidak | November 6, 2013

PetroAlgae → PARABEL™

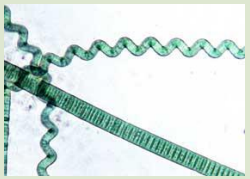
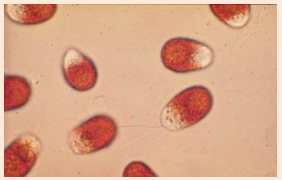
Approach 2: Hydrothermal liquefaction




Energy return on investment (EROI)
5
4
3
2
1
0
0
20
40
60
80
100
GHG emissions (gCO2e/MJ)
Low sulphur diesel
HTL: in 5 years full-scale
Soybean diesel
Metamodel: algae bioenergy lifecycles
HTL: Sapphire pilot-scale


Energy return on investment (EROI)
5
4
3
2
1
0
HTL: in 5 years
full-scale
petrol
Cellulosic
ethanol
HTL: Sapphire pilot-scale
Corn ethanol
0
20
40
60
80
100
GHG emissions (gCO2e/MJ)

Composition of microalgae vs. carrots (per 100g)

	Spirulina [b]	Chlorella [a]	Dunaliella[cde]	Carrots [b]
				
Protein	**57 g**	**67 g**	**35.4 g**	**1 g**
Total fats	**8 g**	**12.9 g**	**7 g**	**0**
Carbohydrates	**24 g**	**1.1 g**	**29.7 g**	**10 g**
Energy	**1214 KJ**	**1600 KJ**	**1893 KJ**	**180 KJ**
Fibre	**4 g**	**8.7 g**	**0.4 g**	**3 g**
Chlorophyll	**1 g**	**3.9 g**	**1.54 g**	**NA**
ß-carotene	**0.34 mg**	**119 mg**	**8800 mg**	**8.3 mg**
Lutein/zeaxanthin	**0.0 mg**	**503 mg**	**97.6 mg**	**0.26 mg**

a. Japan Food Research Labs no. 102042170, 21 May 2002; 103044178002, 20 May, 2003
b. USDA National Nutrient Database for standard references (release 18) 2005
c. National Measurement Institute, Australia, 2005
d. Craft Technologies Inc, USA
e. National Institute of Oceanography Israel 2005

The Microalgae biorefinery:

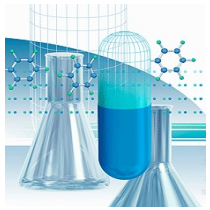
"The D-Factory"

KBBE.2013.3.2-02 (No: 613870)

The D-Factory

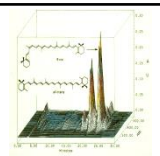
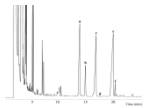
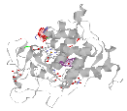
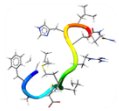
1. 10 million Euro FP7-funded project
2. 13 partners from 8 countries
3. Flexibly and sustainably produce suites of compounds from *Dunaliella* to meet market requirements.
4. Showcase a sustainable biorefinery demonstration






Algae product 'tuning'

- light
- nutrients including CO_2
- salinity
- muta-genesis
- chemicals
- T^o

Current		Dunaliella –spray-dried
The D-factory		carotenoid isomers, oxycarotenoid isomers
		Lipids, phytosterols
		enzymes
		bioactive peptides
		glycerol
		starch
		Recycling of saline process water

Economic Assessments

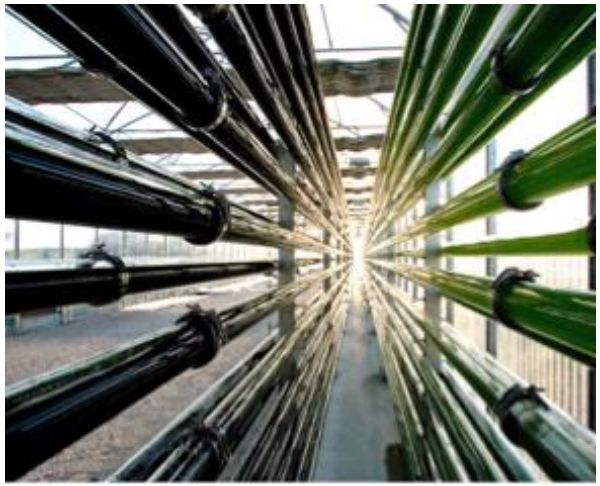
Environmental Assessments

CO_2 Algal Biorefinery Demo

Cultivation, harvesting of strains

Open Raceways

Nature Beta Technologies - N.B.T Ltd



Photobioreactors

a4f algae for future

evodos Separation Excellence. Today

Extraction technologies

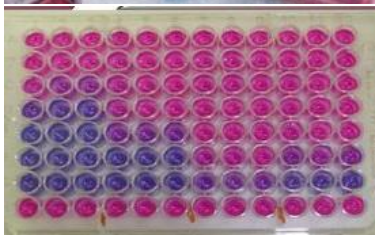
Dynamic extractions

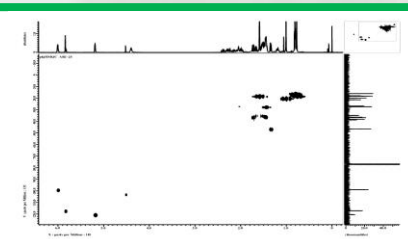
NATECO$_2$

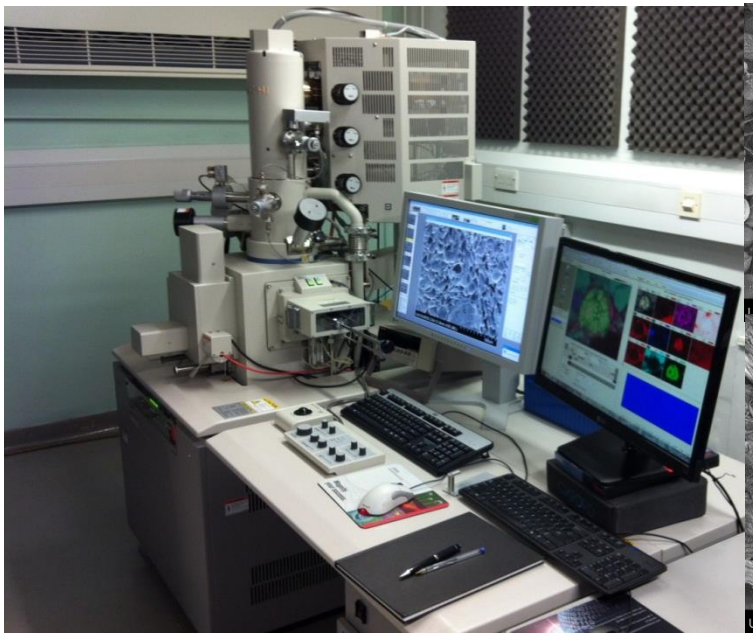
UNIVERSITY of GREENWICH

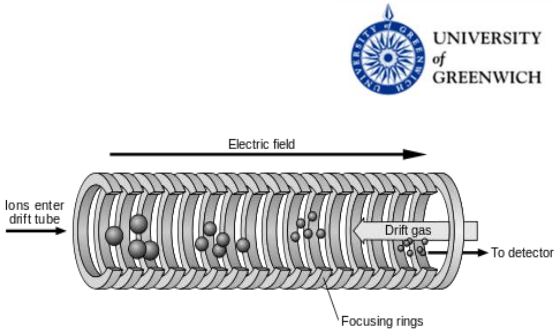
iBET

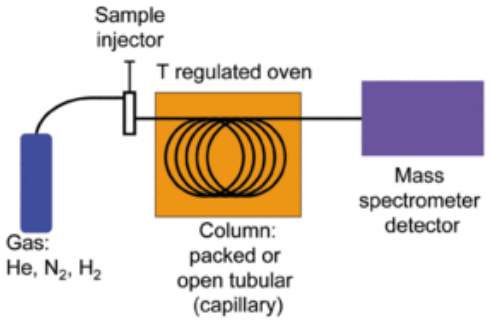
Analytical and formulation technologies

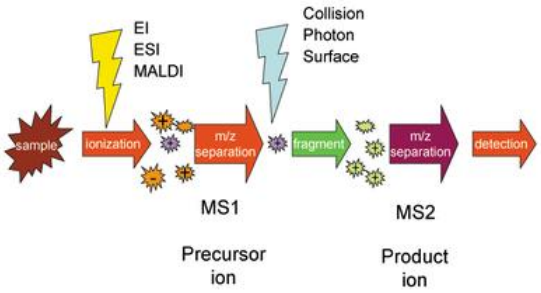








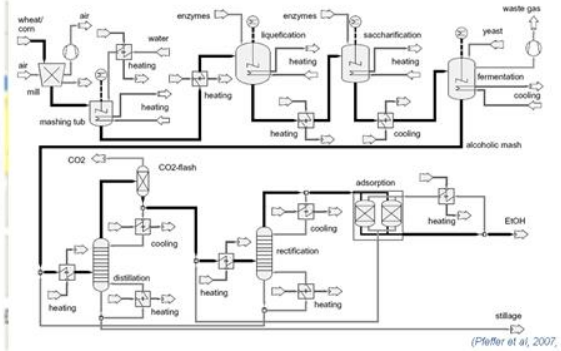




Modelling – Assessments
Dunaliella Innovation Platform

ifeu –
Institut für Energie- und Umweltforschur Heidelberg GmbH

HAFREN INVESTMENTS LTD



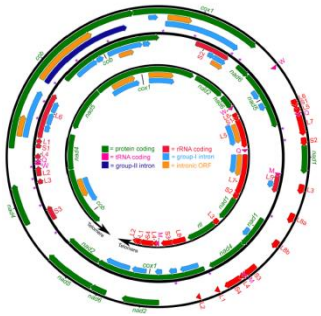
IN SRL

Part. no.	Participant organisation name	Participant short name	Country	Organ. type
1 Coord.	University of Greenwich	UG	UK	UNI
2	A4F AlgaFuel S.A.	A4F	P	SME
3	Dynamic Extractions	DE	UK	SME
4	Evodos	EVODOS	NL	SME
5	Hafren Investments	HI	UK	SME
6	Instituto de Biologia Experimental e Tecnológica	IBET	P	SME
7	Institute for Energy and Environmental Research Heidelberg	IFEU	DE	RES
8	In	IN	I	SME
9	Marine Biological Association	MBA	UK	SME
10	NateCO2	NATECO	DE	LE
11	National Technical University of Athens	NTUA	GR	UNI
12	Nature Beta Technologies	NBT	IL	LE
13	Technical Research Institute of Sweden	SP	SE	RES

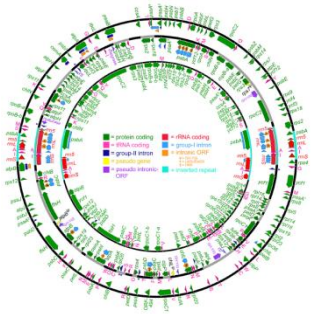
The D-Factory project is likely to start ***1st Jan 2014***

AB-SIG Dunaliella

Genomic approaches



Mitochondrion



Chloroplast

SPARK AWARDS

IOTA Pharmaceuticals

UNIVERSITY of GREENWICH

Summary

- Advanced biofuels - lipid based or glycerol - not currently commercially available in large quantities
- Global shift to algae biorefineries
- Dunaliella - shift to algae biorefineries
  - The D-Factory
  - AB-SIG

Acknowledgements

- EU ACP S&T project: Financial assistance from the European Union: http://www.acp-st.eu/about : Turner & Townsend SA; Corissia, Italy; University of Ghana; The MBA, UK; SANUMARC University of Namibia; Jatropha Africa,; Goldex; P. Hooks, G. Murta (Glycal Namibia), Keith Cowan (Rhodes University).
- Ecotec 21 project: Aquafuel Research and others ,with financial assistance from the European Union and University of Greenwich funded under the Interreg Channel Programme.
- D-Factory collaborators: V Verdelho Vieira, D Rooke, G. Harris, H. Hoekstra, M Brocken, P. Goacher, J. Crespo, C Brazinha, G Reinhardt, L Martinelli, R Pipe, D Schroder, N. Igl-Schmid, A. Kokossis, A Ben-Amotz, K Persson
- University of Greenwich: Financial assistance: A Abubakar; R Swamy; S Habtemariam; V Trivedi; D. Bailey