ROYAL SOCIETY OF CHEMISTRY

Renewable chemicals from waste – securing the molecular value from waste streams

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http://rsc.li/waste-2015

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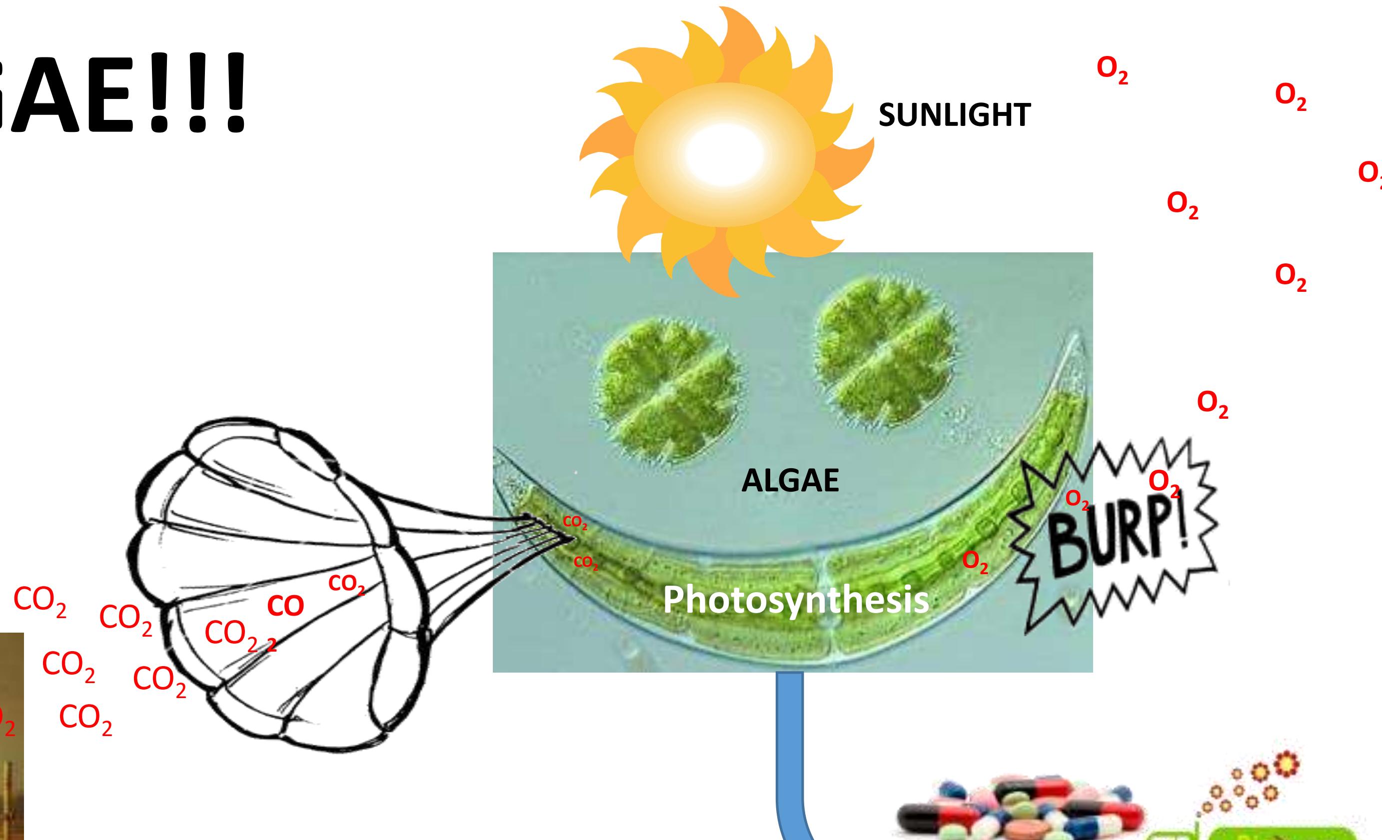
Hey, this stuff could help us save the planet!

How do we evolve from an Industrial World that is causing climate change…

...to a World with sustainable industries that mitigate climate change?

ALGAE!!!



To reverse Global Warming we must rapidly adopt a "Low Carbon Economy" and develop technologies that consume CO_2

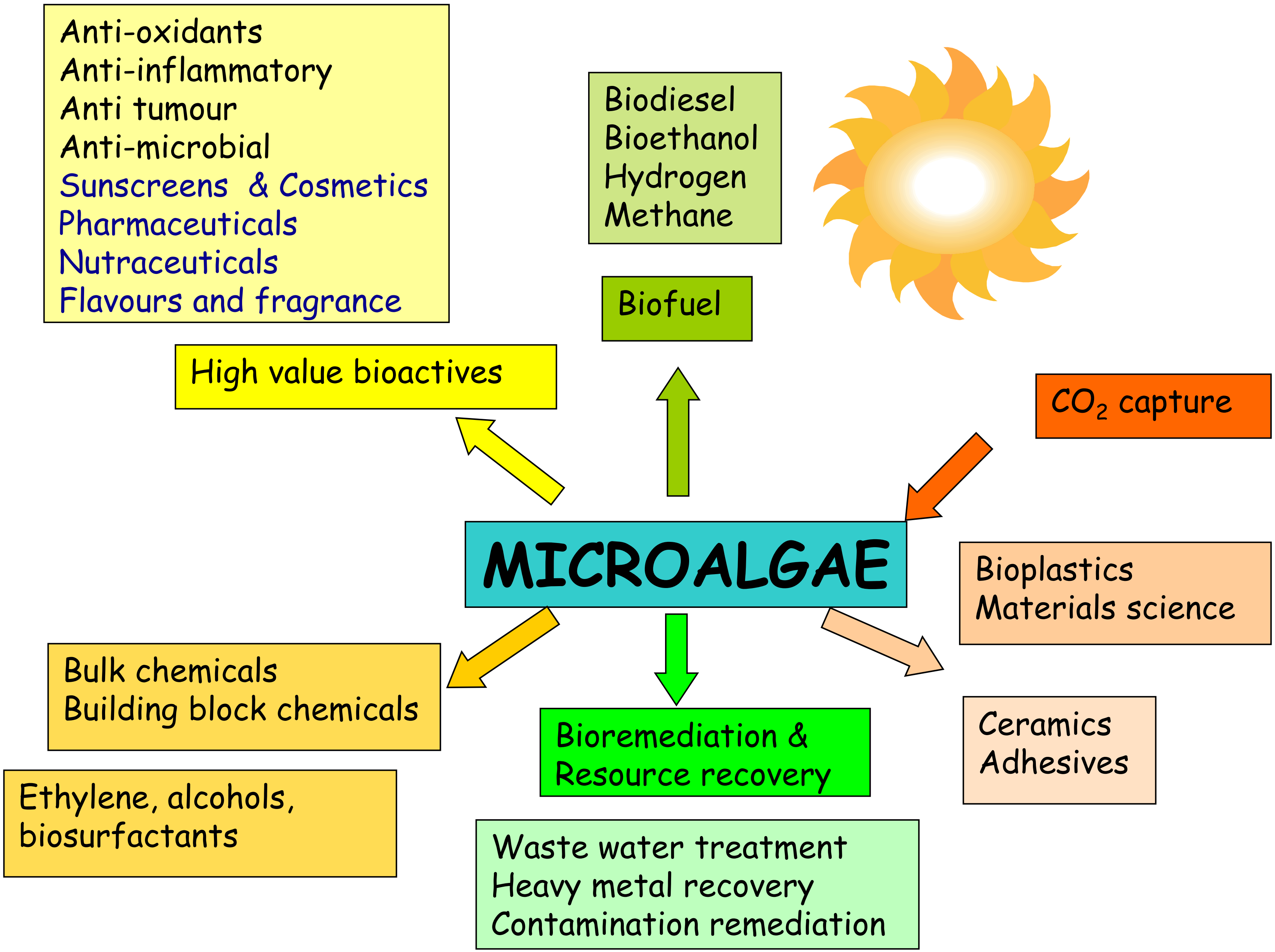
Why Algae?

Algae are the most promising long-term sustainable source of biomass for fuel, food, feed, nutraceuticals, cosmetics, pharmaceuticals, petroleum replacement products.

- Algae consume CO_2
- Algae grow fast and can double their numbers every few hours with productivities many times greater than that of our most productive crops.
- Algae do not compete with agriculture
- **Algae purify wastewaters**
- The Algae Industry is a job creation engine

With Synthetic Biology we can engineer algae to produce commodities to order and also perhaps find new cures for cancer and other debilitating diseases.

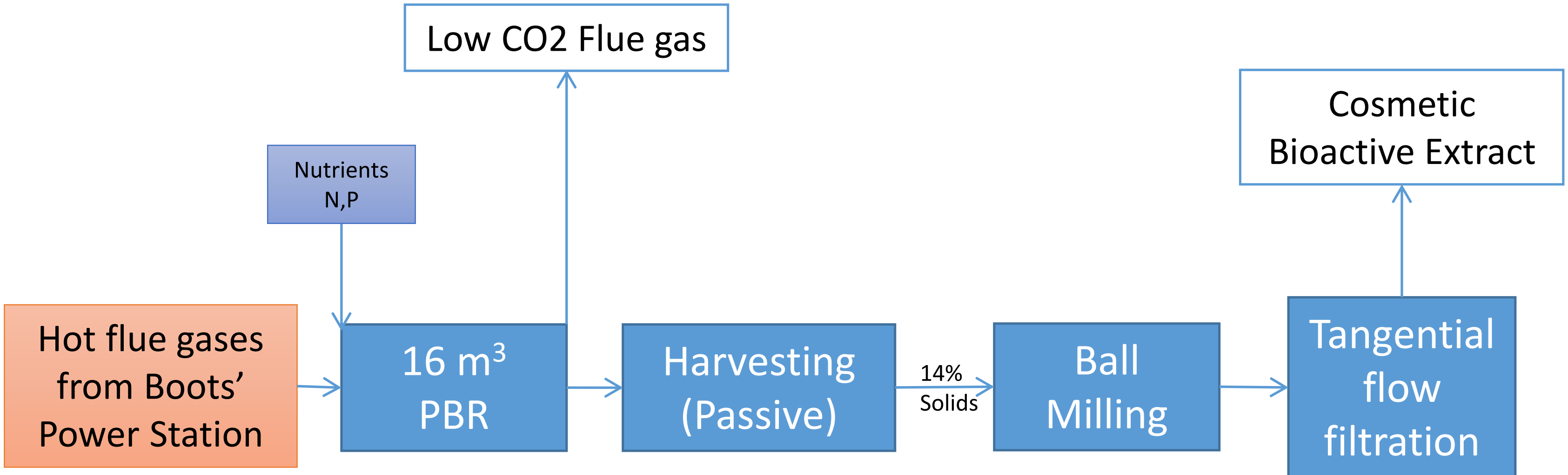
Microalgae Products and Applications



Securing the molecular value from waste streams using **algae**

- Carbon capture
- Acid mine drainage

2008-2014 Microalgal Biorefinery with Carbon Capture

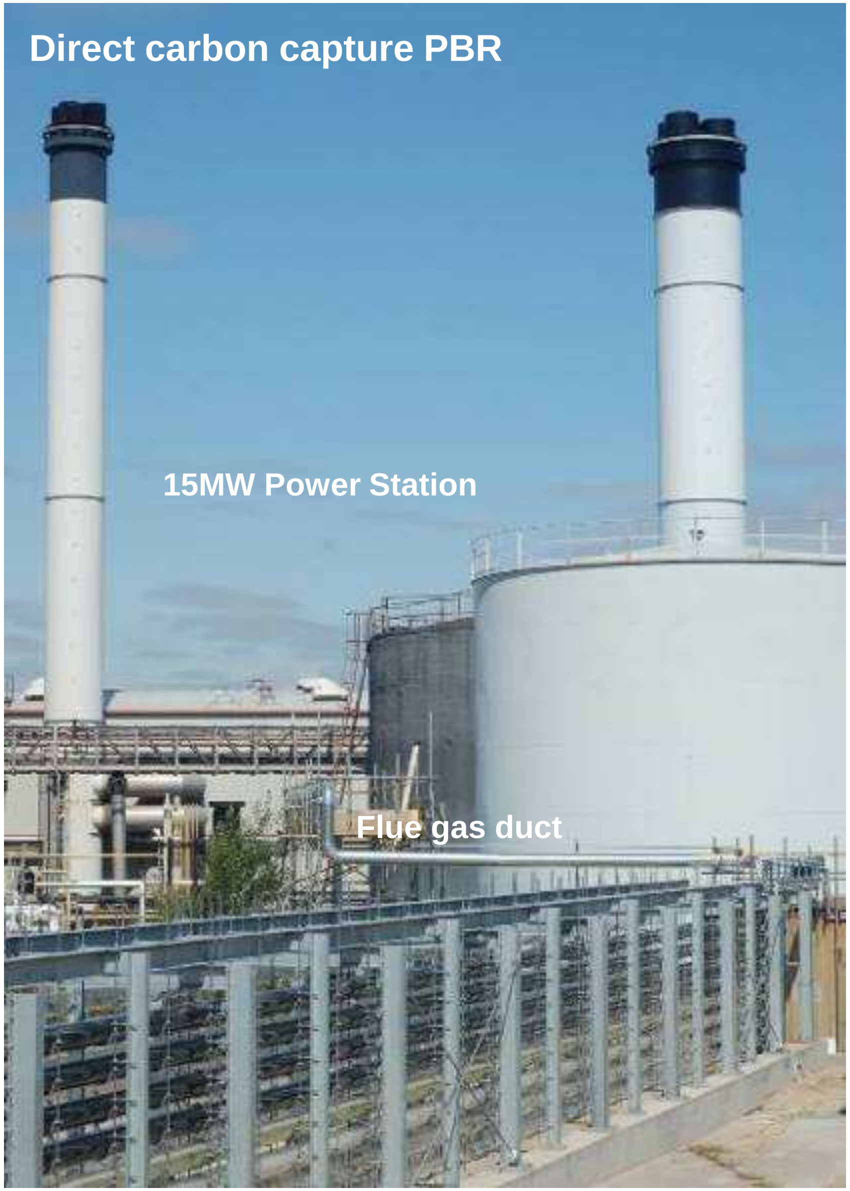


Microbes: Autoflocculating Thermophilic Cyanobacteria
Company: Boots, Cognis (BASF), PML, Carlton Power
Location: Nottingham, UK.
Project Designer & PI: S. Skill
Core funding: Technology Strategy Board £2.1m

PBR- Photobioreactor

Product R&D Focus

- **Antioxidants**
- **UV Protection (Suntan lotions)**
- **Anti inflammatory**
- **Anti ageing**
- **Protein Hydrolysates (hair care)**


Direct carbon capture PBR
15MW Power Station
Flue gas duct


16,000 litre photobioreactor (PBR)
Productivity: 0.3-0.9g/l/day
Energy use: 20-70W/m3

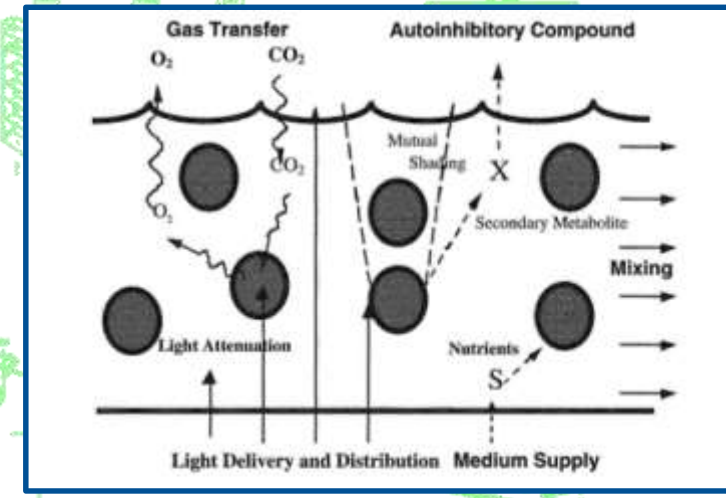




4.7m


Scale-up????

- **Containment** - the most costly component
- **Light**- productivity is proportional to light contacting surface area rather than volume, weather dependent.
- **Mixing** - reducing self shading, increase mass transfer & biofilm prevention. Trade-offs – Energy & hydrodynamic shear
- **Gas exchange** - contact of CO_2 & removal O_2 from broth, hydraulic residence time, energy requirement
- **Temperature** – overheating (cooling?), cold mornings



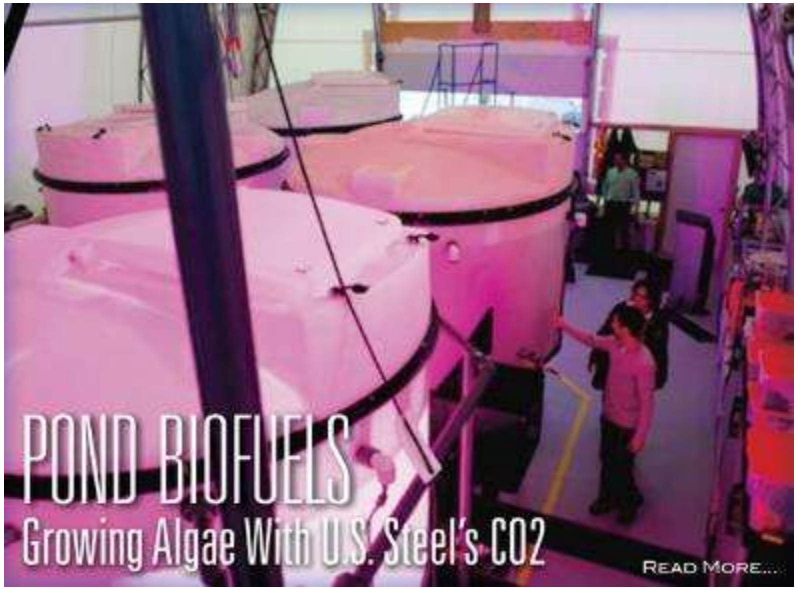
State of the art photobioreactors

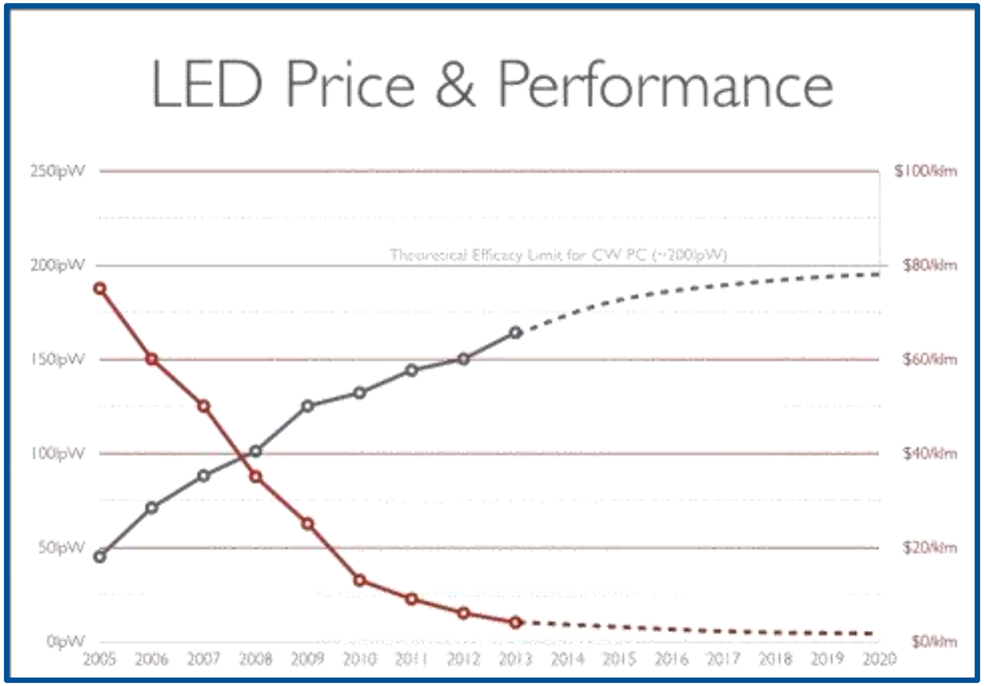
Algenol – Genetically modified cyanobacteria producing ethanol

Direct solar photon capture by algae in photobioreactors unlikely to be economical.

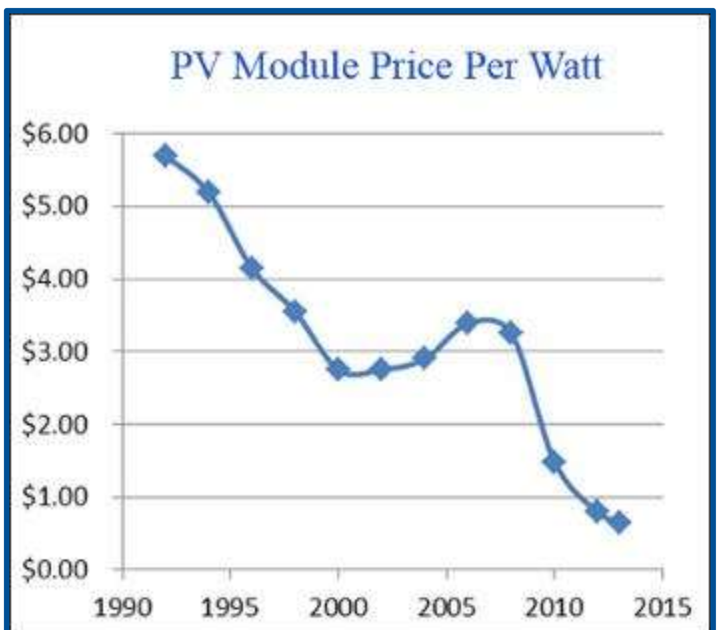
- High capital costs
- High maintenance costs
- Variable productivity (weather)
- Limited control (λ)

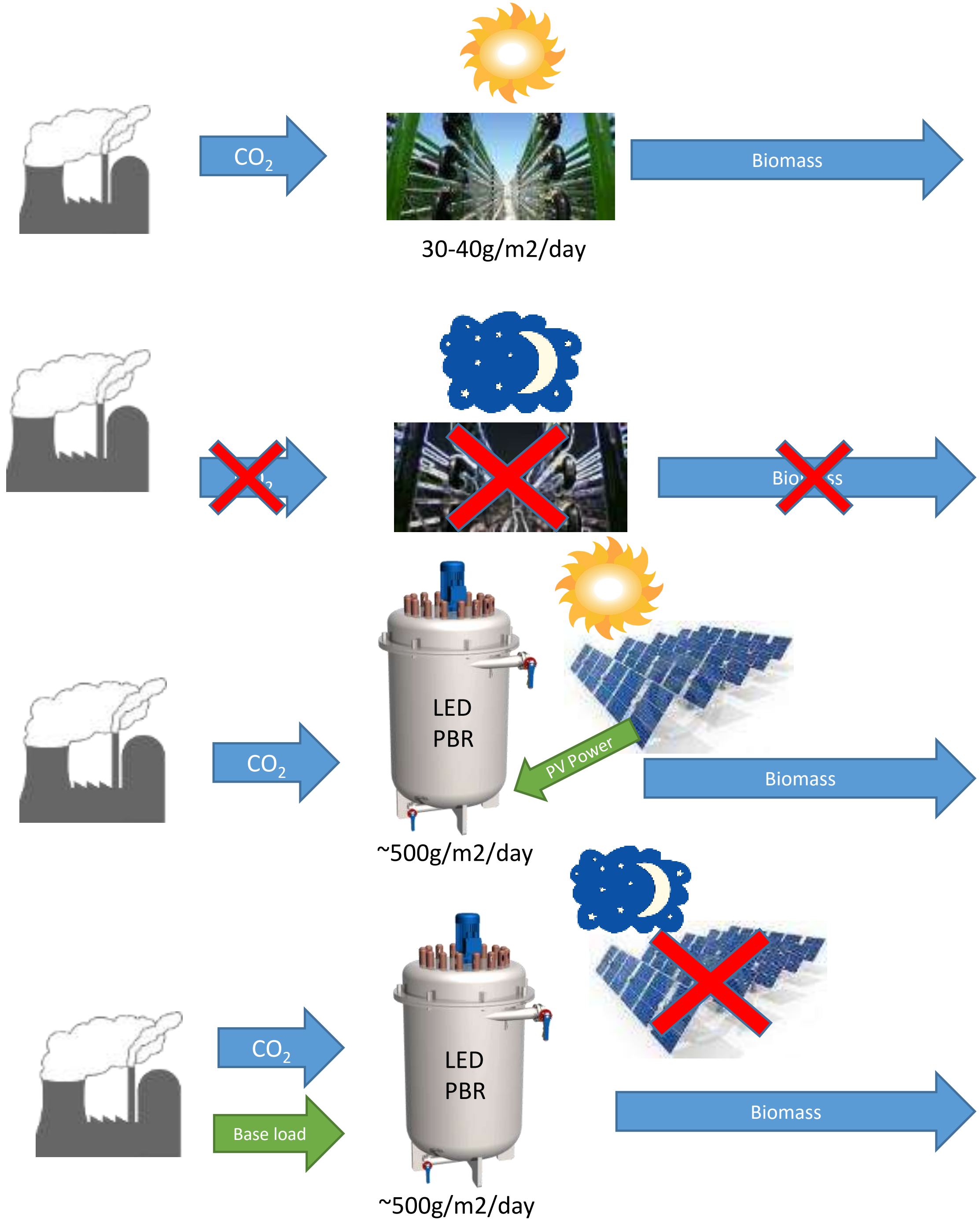
Light emitting diodes ?





Solar Capture
Direct v Indirect?





CO_2
Biomass
30-40g/m2/day
CO_2
LED
PBR
PV Power
Biomass
~500g/m2/day
CO_2
Base load
LED
PBR
Biomass
~500g/m2/day

Benefits of LED illumination

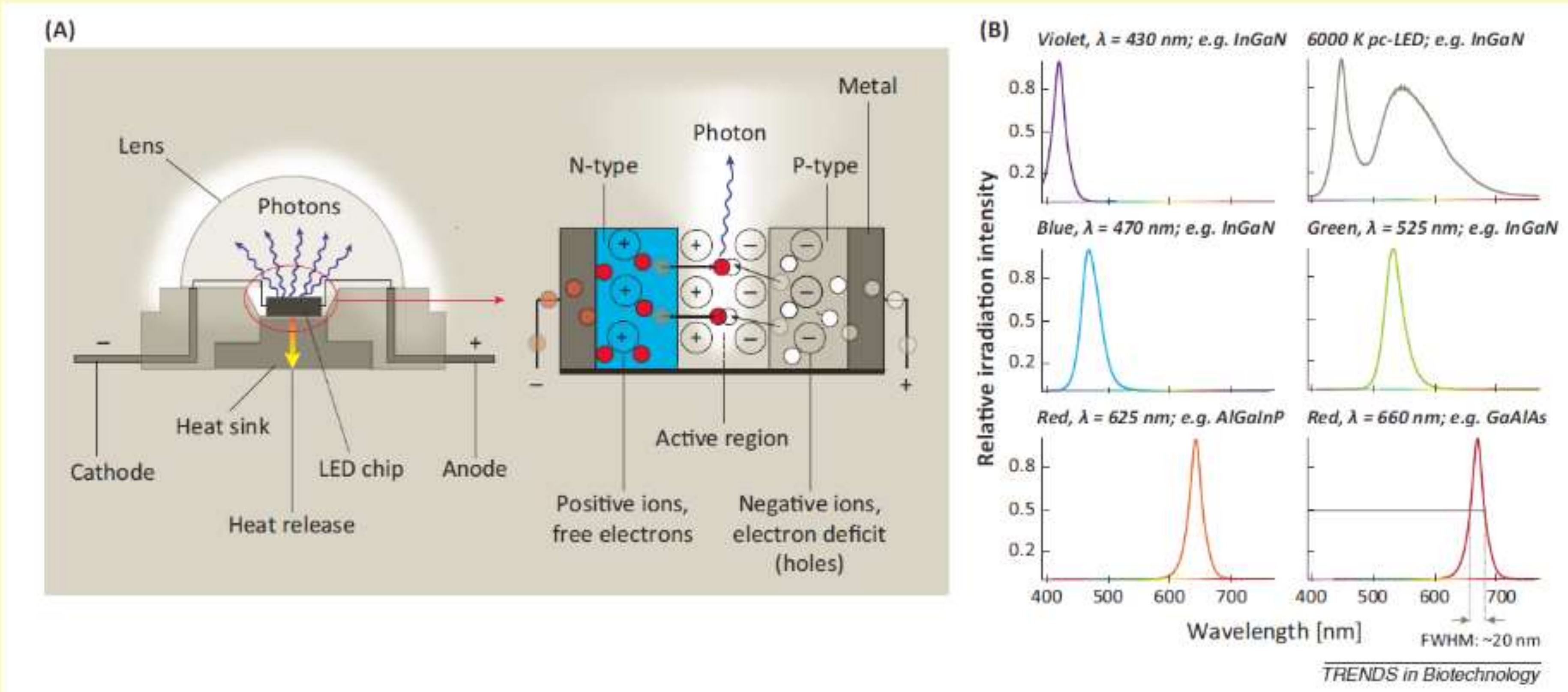
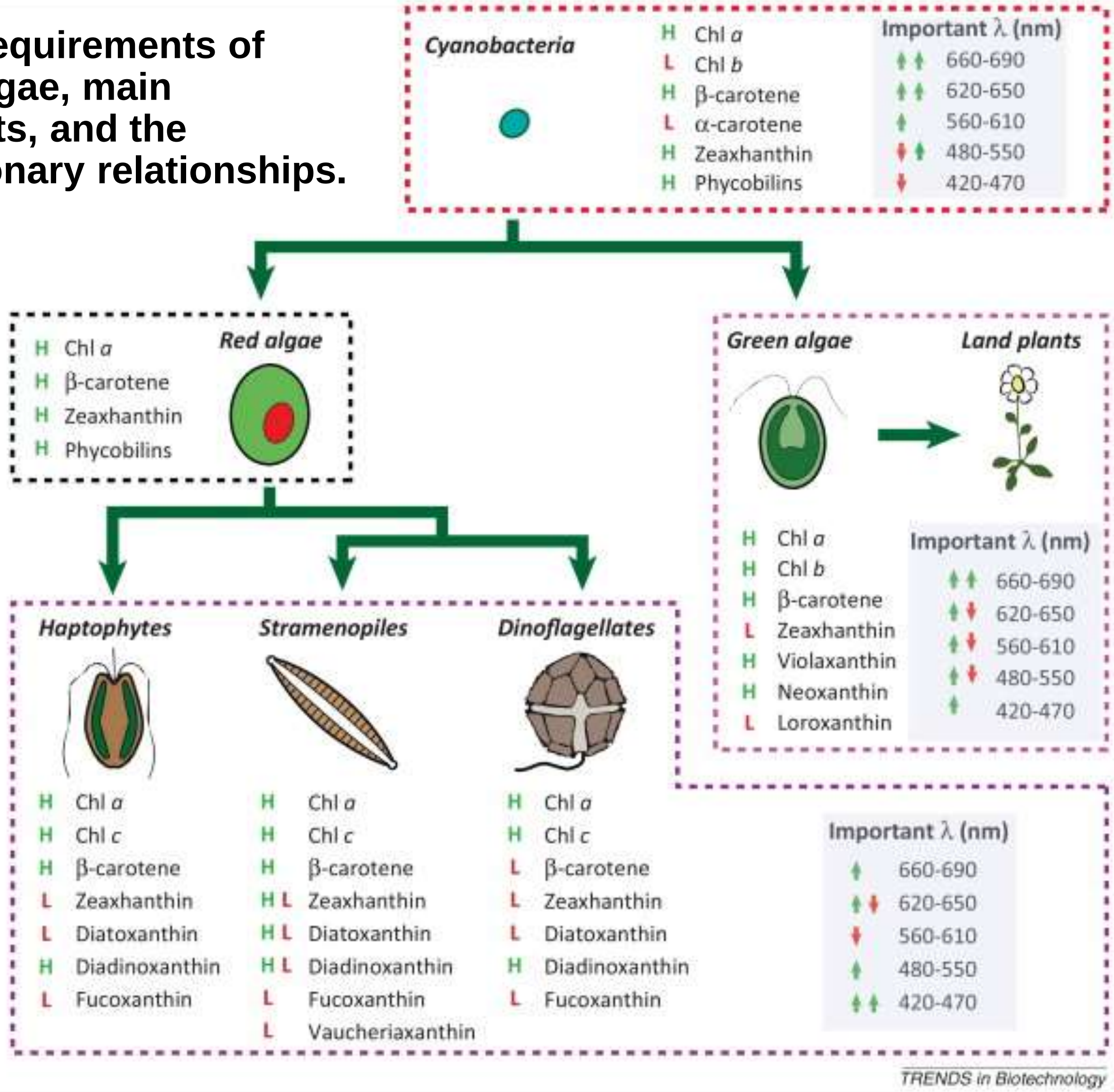


Figure I. **(A)** Simplified diagram showing how low-power (homostructured) LEDs work. **(B)** Emission spectra for different LEDs. The full width at half-maximum (FWHM) corresponds to the wavelength difference (usually 20 nm) for which the LED attains 50% of its maximum intensity.

Schulze.et al., 2014 TIBS, Volume 32, Issue 8, 2014, 422 - 430

Light requirements of microalgae, main pigments, and the evolutionary relationships.



Schulze.et al., 2014 TIBS, Volume 32, Issue 8, 2014, 422 - 430

Table 1. Light quality effects on microalgal biochemical composition at specific wavelengths

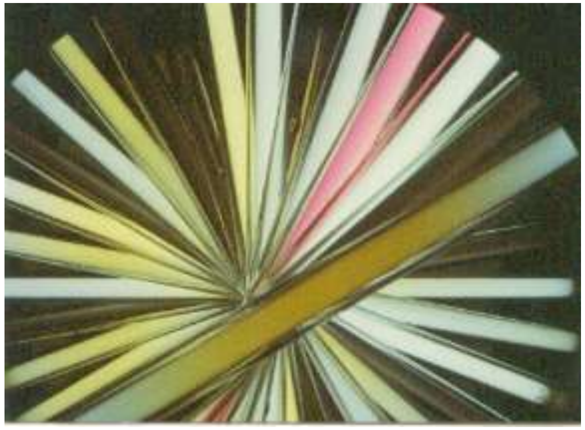
Light	λ_{max} (nm)	Alga	Effects	Refs
Blue	460–475	*Arthrospira platensis* (syn. *Spirulina platensis*)	Lowest chl and phycocyanin content in biomass compared to yellow, green, red, and white LEDs	[16]
	440–470	*Chlorella* sp.	Higher lipid content in biomass compared to red (650–680 nm) LEDs	[19]
	500	*Chlorella sp.*	Blue light induces slightly higher lipid production compared to red light	[46]
	470	*Dunaliella salina*	β-Carotene and lutein accumulation when blue light was supplemented with red (660 nm)	[7]
	470	*Haematococcus pluvialis*	Accumulation of red pigments	[20]
	380–470	*Haematococcus pluvialis*	Astaxanthin accumulation	[26]
	NA	*Isochrysis* T-ISO	Higher protein content and lower carbohydrate and chl content per cell compared to white FLs	[44]
	NA	*Isochrysis galbana*	Higher DHA and phospholipid content compared to red LEDs under intermittent light ($f = 10$ kHz)	[72]
	475	*Nannochloropsis oceanica* CY2f	Blue and red (λ_e ~630 nm) LEDs showed highest EPA content in biomass compared to FLs and white and yellow LEDs	[73]
	470	*Nannochloropsis* sp.	Highest palmitoleic acid and lowest EPA content compared to red, green, and white LEDs under phototrophic conditions; highest total FAMEs per dry weight under blue, green, and white light, lowest under red when grown mixotrophically; similar FAME contents under phototrophic conditions	[6]
	450	*Nitzschia* sp.	Highest chl content compared to red (650 nm) and yellow (590 nm) LEDs	[74]
	NA	*Phaeodactylum tricornutum*	Lager pool of xanthophyll cycle pigments and higher chl *a* content compared to red and white LEDs (low light conditions)	[42]
	470	*Tetraselmis suecica* F&M-M33	Higher chl accumulation compared to cool white FLs and red, green, and blue LEDs; higher carbohydrate content for cells grown under blue compared to red LEDs	[23]
Green	NA	*Chlorella vulgaris*	Higher chl accumulation compared to blue, yellow, orange, and red broadband light spectra	[51]
	550	*Nannochloropsis* sp.	Higher AA content under phototrophic conditions compared to FLs and red and white LEDs	[6]
Red	660	*Botryococcus braunii* Bot-144	Evidence of higher carotenoid/chlorophyll ratio compared to blue and green LEDs	[25]
	660	*Chlorella* sp.	Highest biogas production compared to yellow, blue, and white LEDs	[5]
	660	*Mychonastes homosphaera* (syn. *Chlorella minutissima*)	Increased C18:2 and decreased C18:3 content in FAME; no fatty acid changes between FLs and white LEDs; total FAMEs unaffected among all light sources	[57]
	680	*Nannochloropsis* sp.	Higher oleic acid content compared to blue, green, and white LEDs under phototrophic conditions	[6]
	NA	*Tetraselmis suecica* F&M-M33	EPA content increased under red light compared to blue, green, and white LEDs	[23]
Far-red	NA	*Dunaliella salina* (syn. *D. bardawil*)	Higher carotenoid levels compared to cells grown under FLs	[34]

Abbreviations: AA, arachidonic acid; chl, chlorophyll; EPA, eicosapentaenoic acid; FAME, fatty acid methyl ester; FL, fluorescent lamp; NA, spectrum not available or broadband spectrum.

Schulze.et al., 2014 TIBS, Volume 32, Issue 8, 2014, 422 - 430

The Future?

1984



2014

LED Photobreactors

Fully Addressable LEDs

- UV-PAR-NIR
- Self Cleaning
- Very Low Hydrodynamic Shear
- 0.5 - 25m^3 capacity

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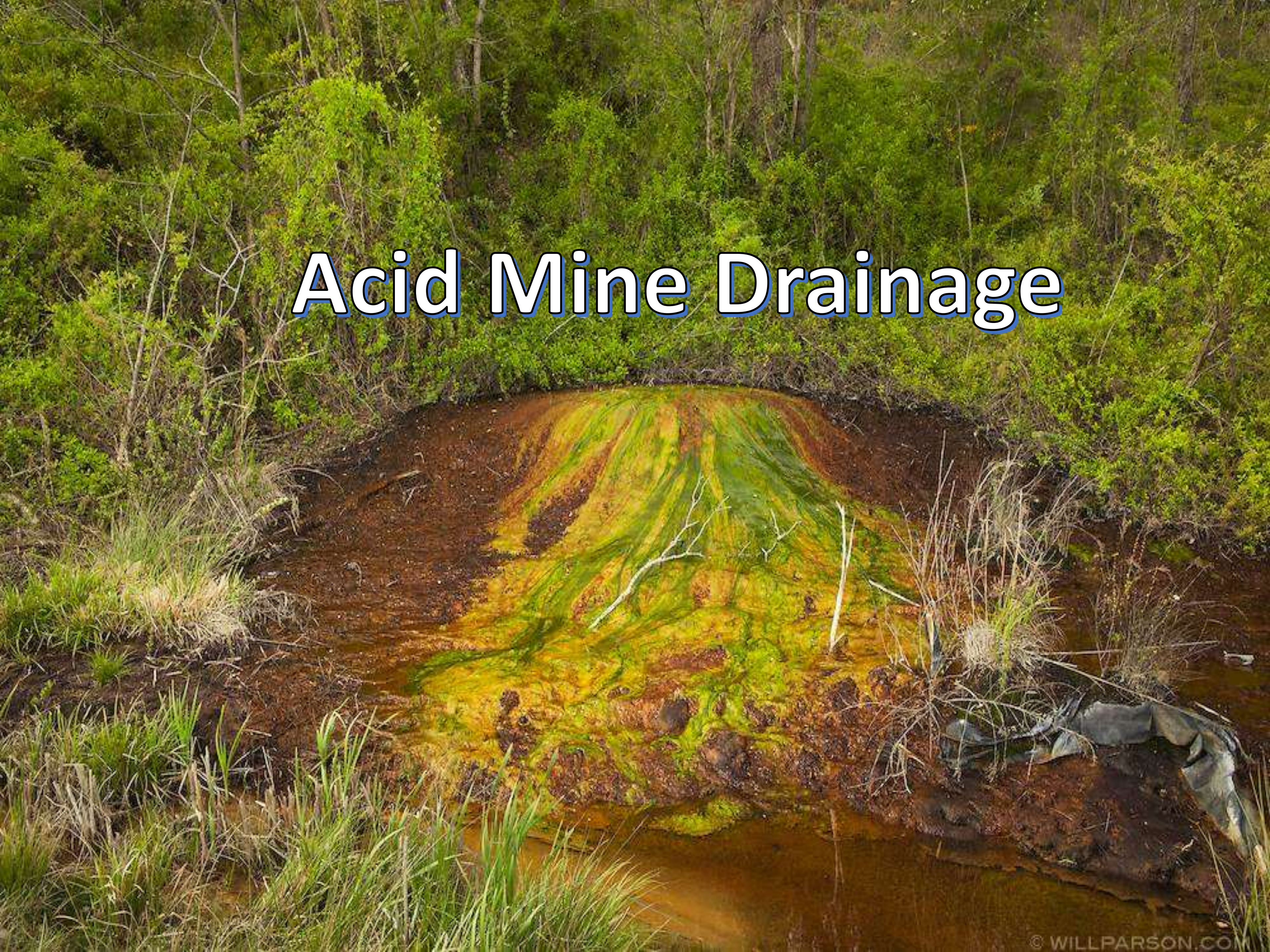
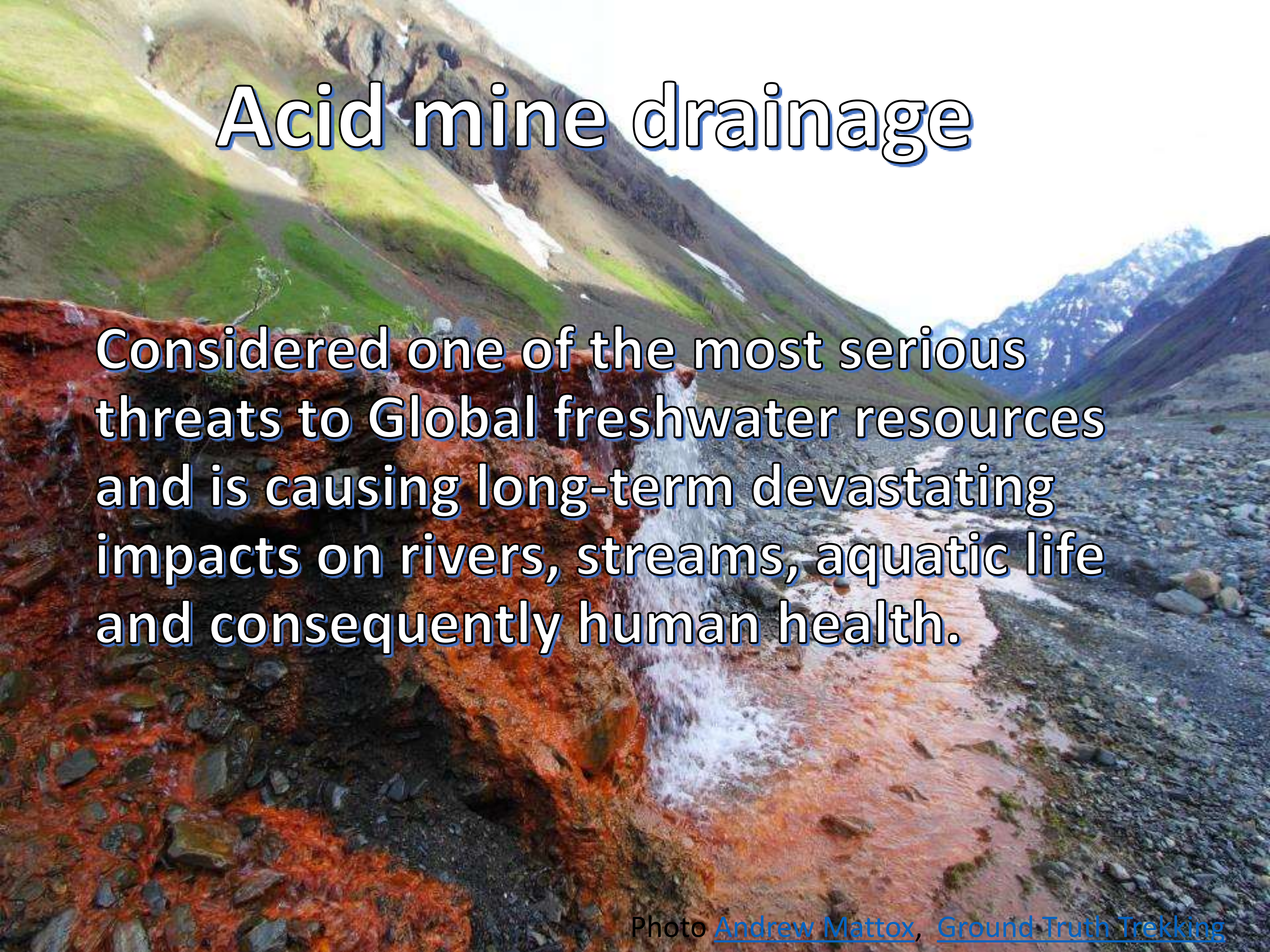
www.greenskill.co.uk

LE(a)D Free Zone?


Acid Mine Drainage
© WILLPARSON.COM

Fri Nov 6, 2015 Samarco mine dam disaster - BHP Billiton
25 minutes to escape: Brazilian village destroyed in dam deluge

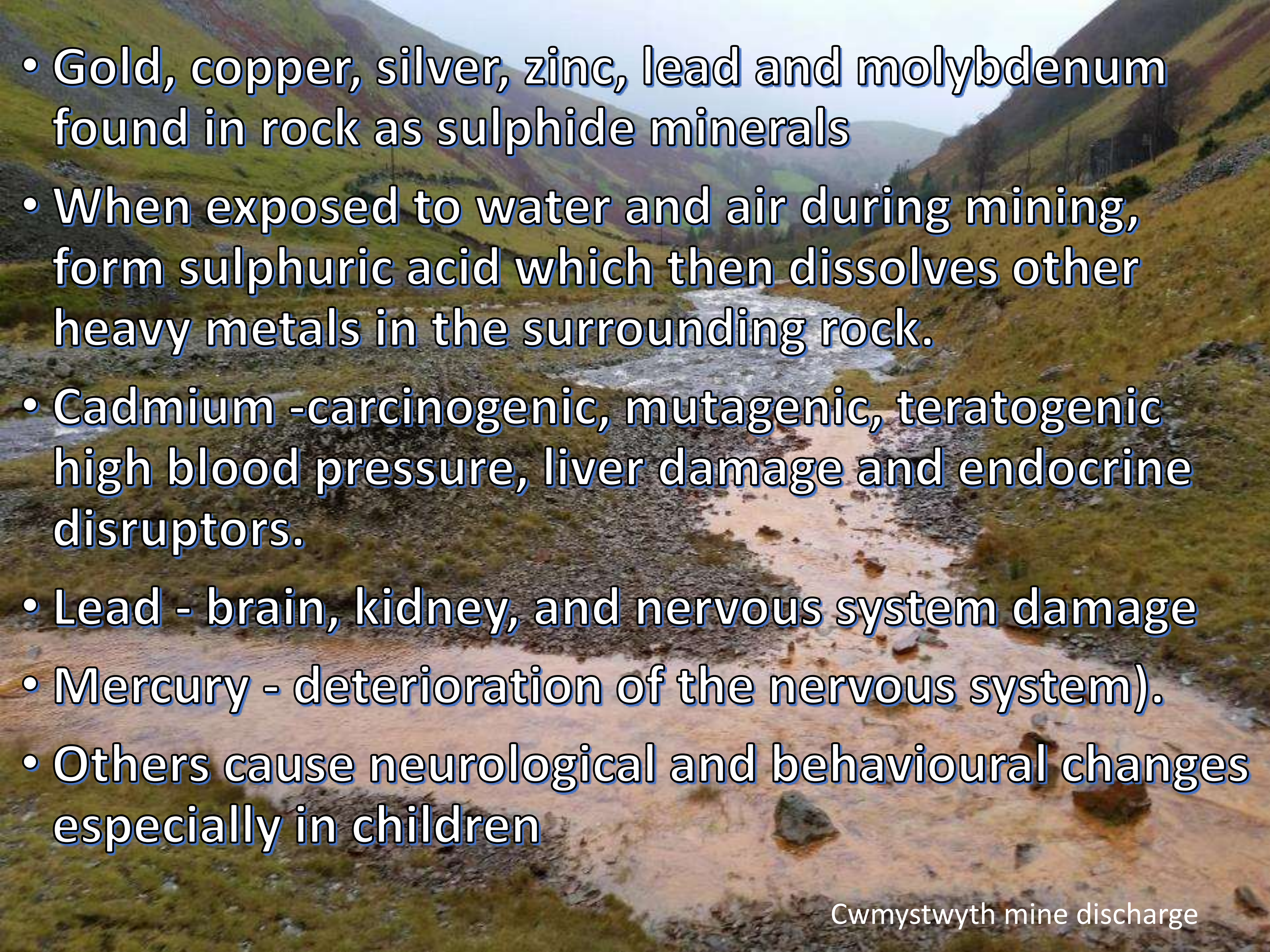


Acid mine drainage

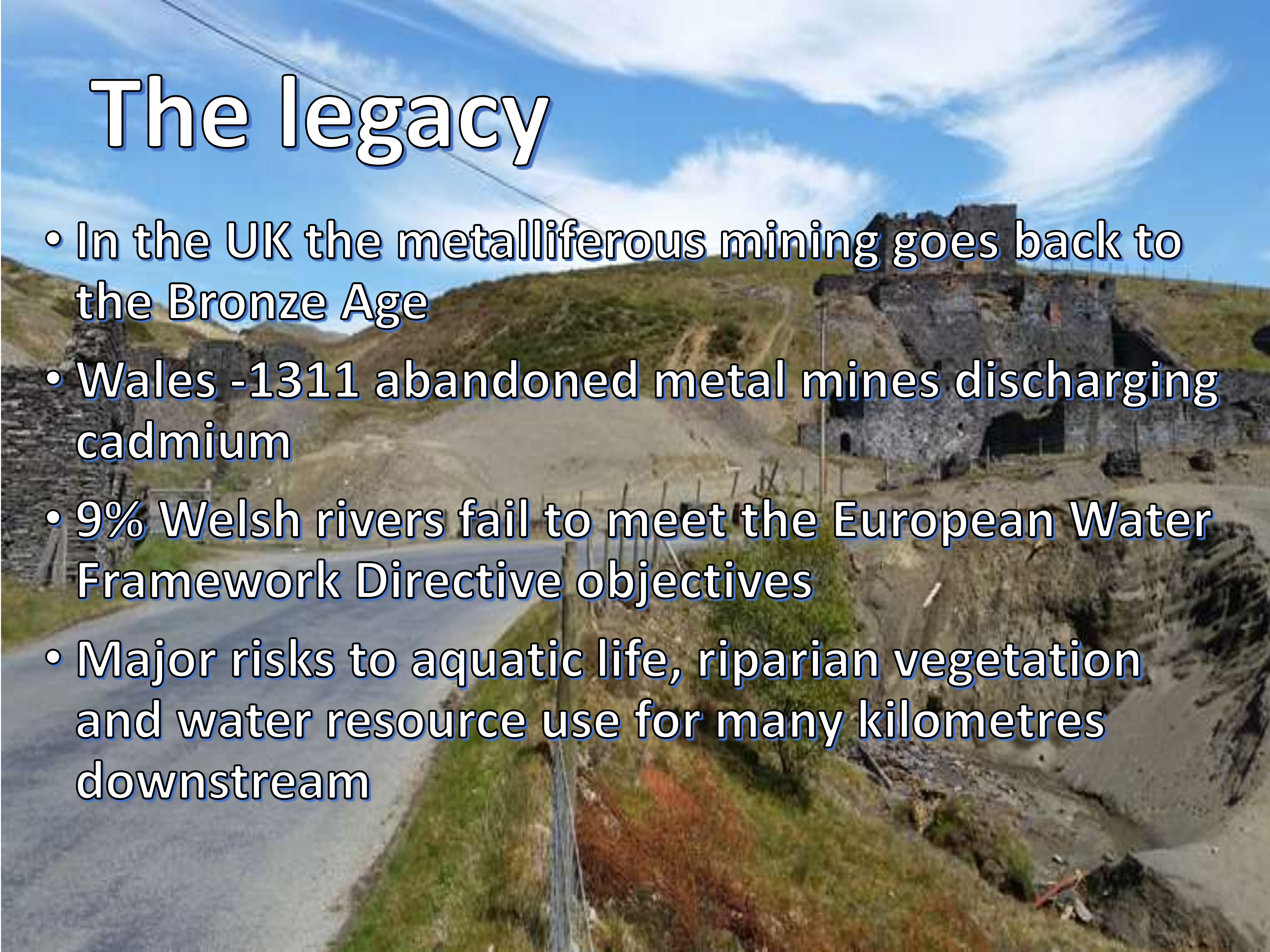
Considered one of the most serious threats to Global freshwater resources and is causing long-term devastating impacts on rivers, streams, aquatic life and consequently human health.

Photo Andrew Mattox, Ground Truth Trekking

- Gold, copper, silver, zinc, lead and molybdenum found in rock as sulphide minerals
- When exposed to water and air during mining, form sulphuric acid which then dissolves other heavy metals in the surrounding rock.
- Cadmium -carcinogenic, mutagenic, teratogenic high blood pressure, liver damage and endocrine disruptors.
- Lead - brain, kidney, and nervous system damage
- Mercury - deterioration of the nervous system).
- Others cause neurological and behavioural changes especially in children



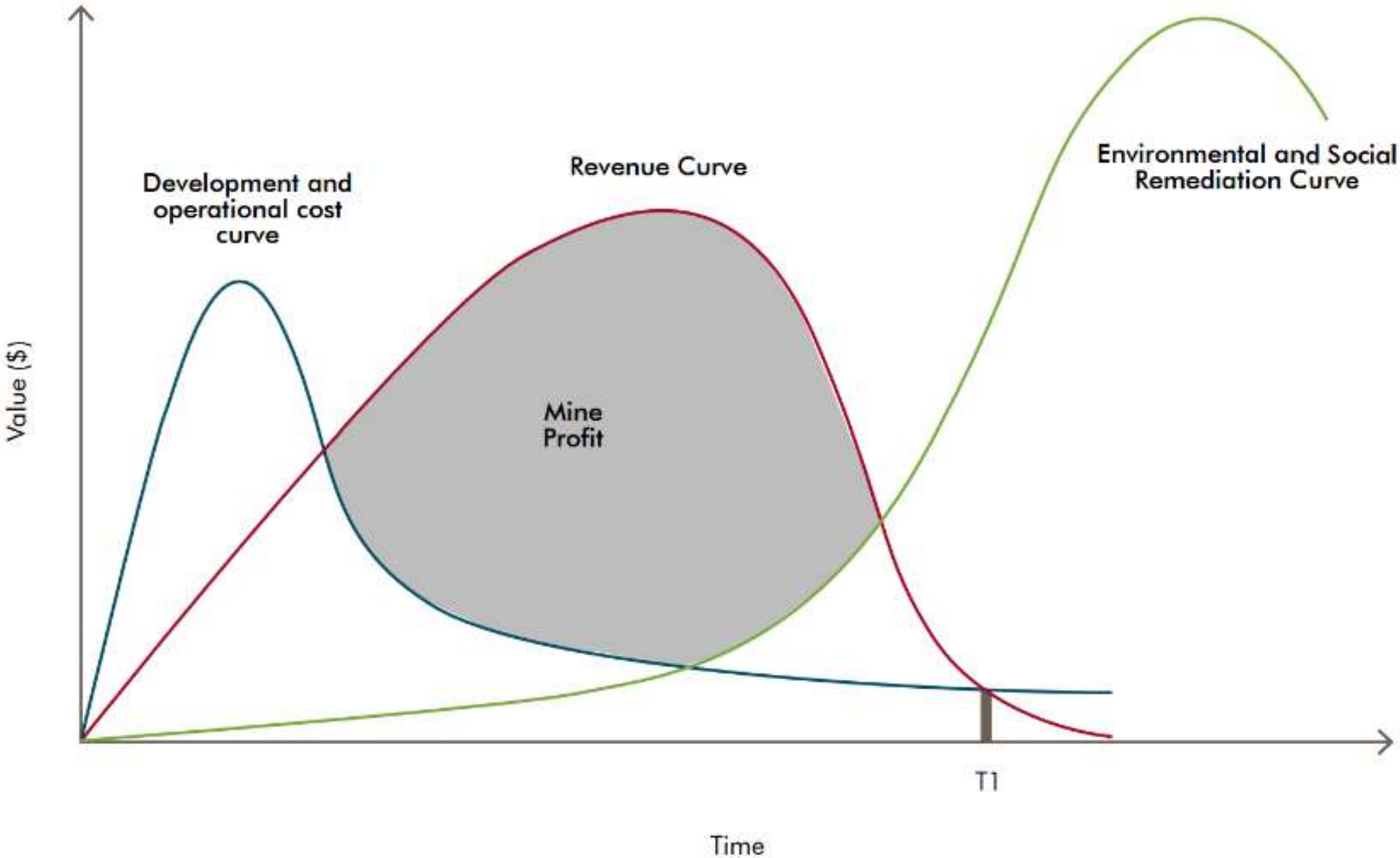
Cwmystwyth mine discharge



The legacy

- In the UK the metalliferous mining goes back to the Bronze Age
- Wales -1311 abandoned metal mines discharging cadmium
- 9% Welsh rivers fail to meet the European Water Framework Directive objectives
- Major risks to aquatic life, riparian vegetation and water resource use for many kilometres downstream

An illustration of the imbalance between money spent on developmental and operational costs, and environmental and social remediation costs (adapted from Adler et al., 2007).



ADLER, R. A., CLAASSEN, M., GODFREY, L., & TURTON, A. R. (2007). Water, mining and waste: an historical economic perspective on conflict management in South Africa. The Economics of peace and Security Journal, 2:2, 32-41.

Current state of the art- Mine water remediation

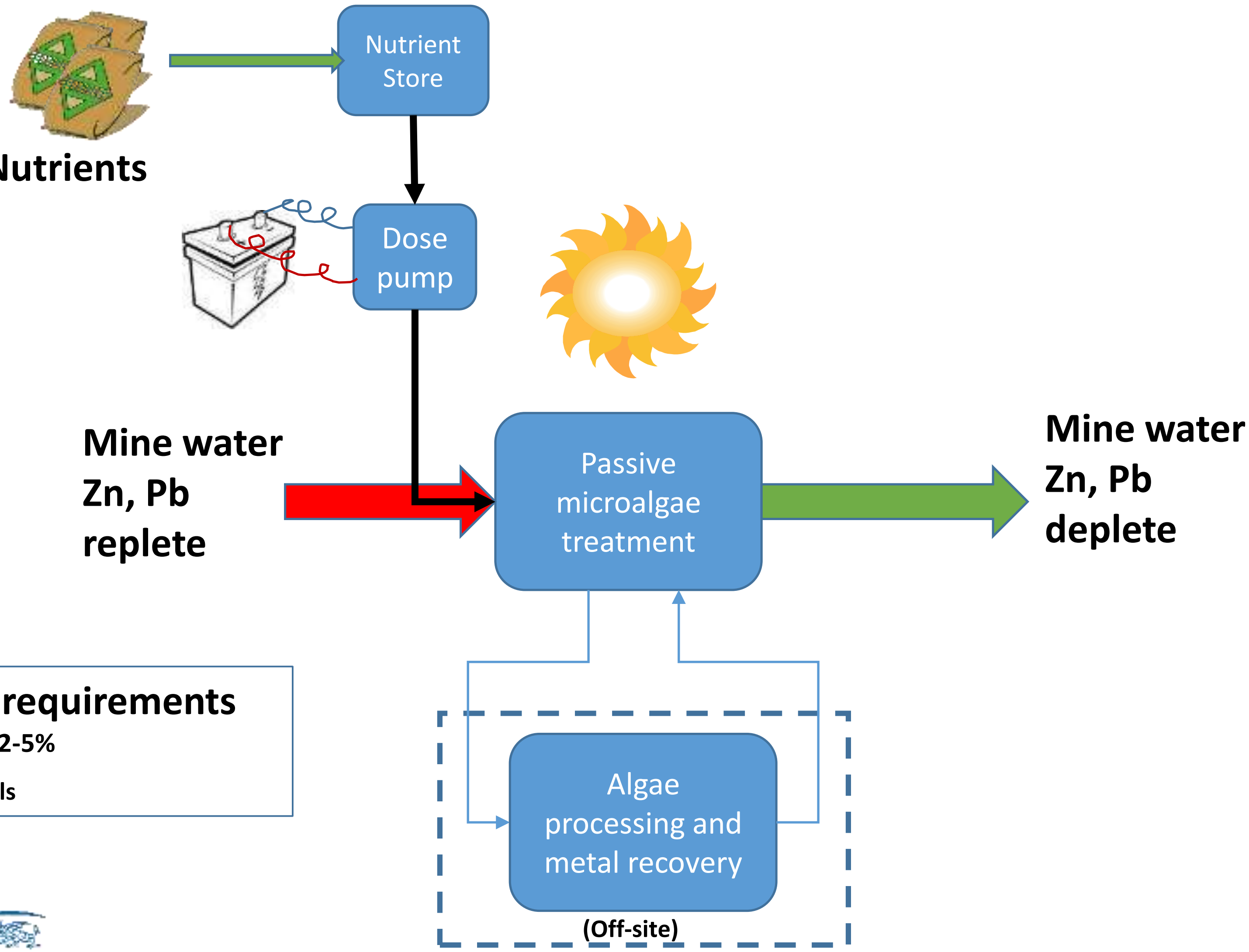
Force Crag Mine - Cumbria

The Coal Authority

Abandoned Lead Mine Ceredigion

Discharge from a single adit
60 litres/sec
1.8 tonnes Lead /year
10.5 tonnes Zinc /year

GREEN MINING – Passive Mine Water Remediation System



Site requirements

Slope 2-5%

No civils

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Metal recovery ?

Typical economic thresholds for recovery

- Copper >4,000 mg kg^{-1}
- Zn and Pb >10,000 mg kg^{-1}.

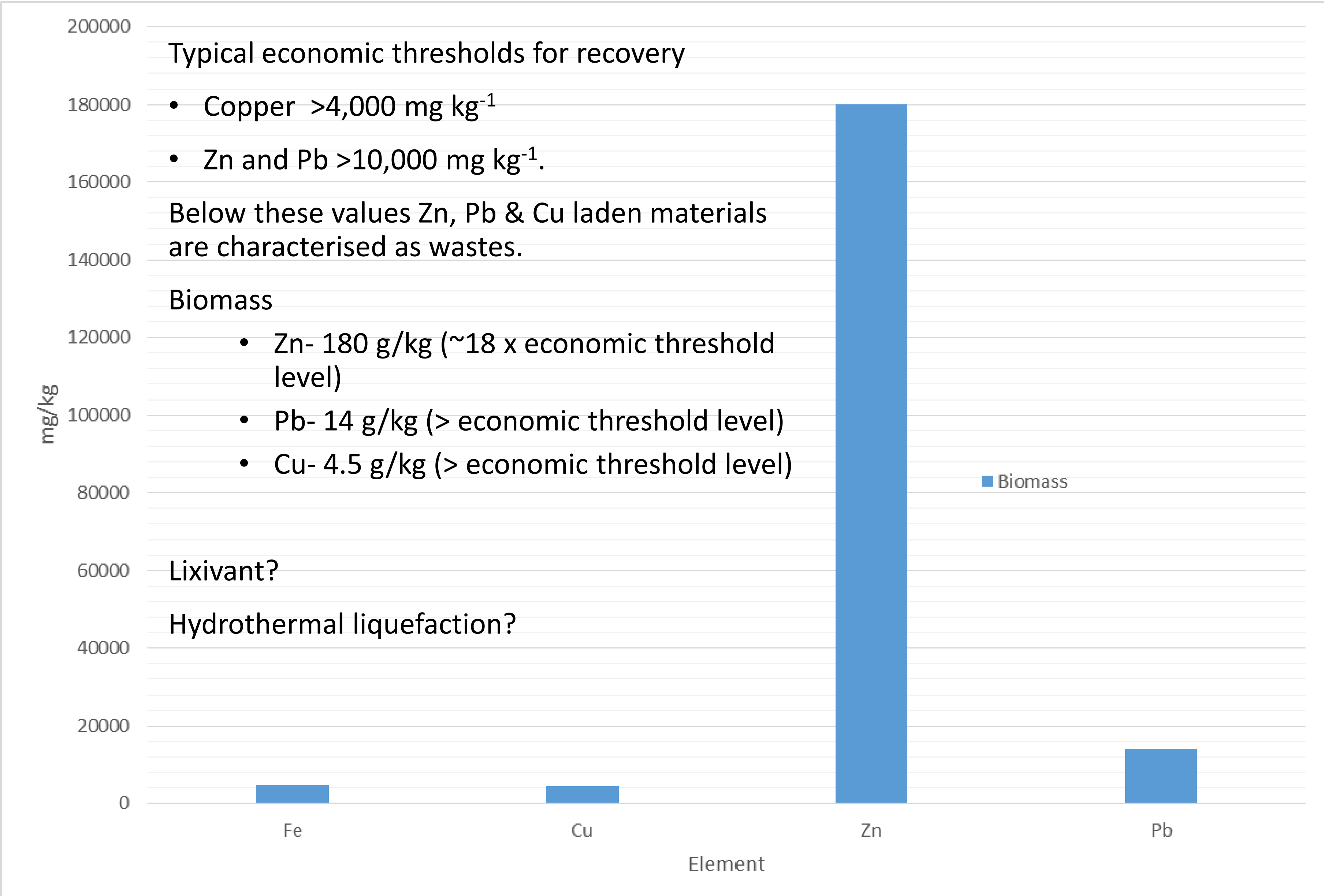
Below these values Zn, Pb & Cu laden materials are characterised as wastes.

Biomass

- Zn- 180 g/kg (~18 x economic threshold level)
- Pb- 14 g/kg (> economic threshold level)
- Cu- 4.5 g/kg (> economic threshold level)

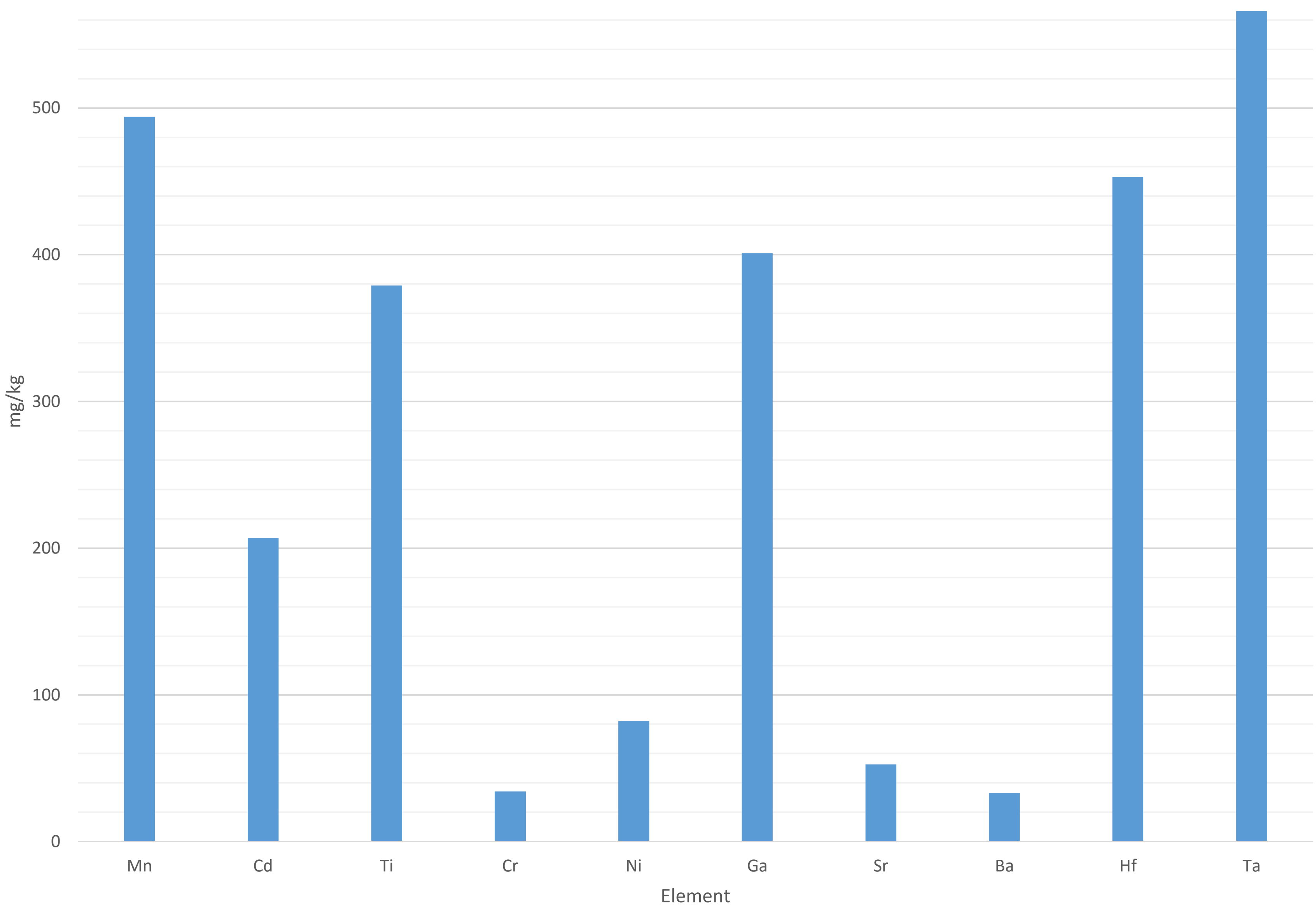
Lixivant?

Hydrothermal liquefaction?



Elemental analysis of algae biomass from AMD treatment

Is it economical to recover rarer metals?



Green Mining - Benefits

- Cost effective to remediate small and large metal mine sites.
- Adaptable for tackling combinations of:
  - point source or diffuse source mine water discharges
  - spoil heap pollution (water)
  - contaminated sediment issues
- Operates with minimal intervention at remote sites without services
- Sustainable and “light touch” in terms of operating costs.
- Applicable for upland areas with steep topography and limited land availability.
- Low risk

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Summary

LED photobioreactors coupled to CO_2 emissions powered by photovoltaics and base load electricity.

- Selected species (incl. GM) for the production of high value metabolites.
- Autoflocculating consortia (incl. GM) for N & P removal from sewage (£0.5/m^3) – Small footprint systems

Passive algae based remediation systems

- Algae for heavy metal recovery – Acid Mine Drainage
- Algae for N & P removal from sewage (medium footprint)

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Knowledge Transfer Centre

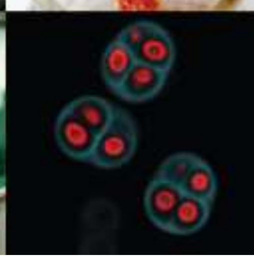
Algal biotechnology for Wales

Research & Development
Information & Advice
Demonstration & Training















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Thank you

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