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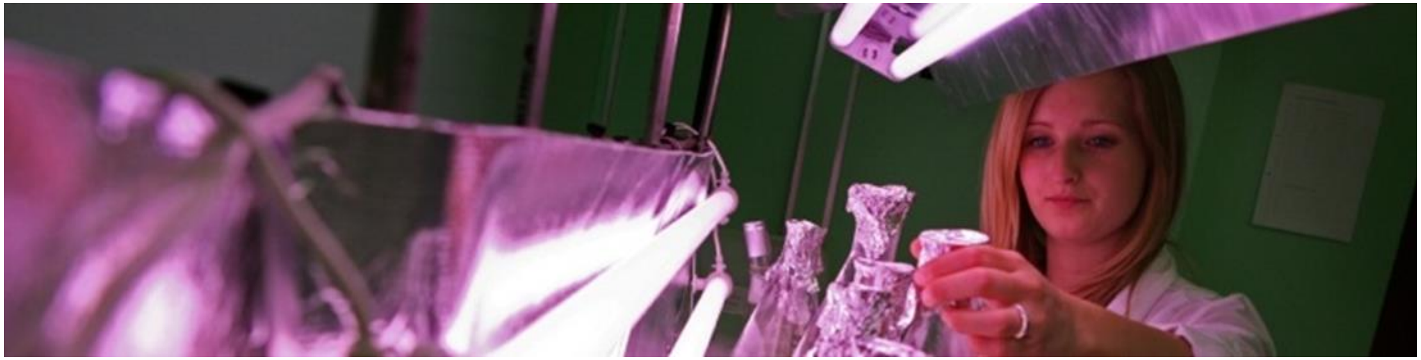

Microalgae and Cyanobacteria towards a Circular Economy

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Plan

- ✓ Introduction
- ✓ History
- ✓ Circular economy definition
- ✓ Effective Industrial symbiosis
- ✓ Microalgae as raw materials for biorefinery and circular economy
- ✓ 3G biorefinery
- ✓ Examples of microalgae integration in 3G bioraffineries and circular economy

Introduction

Linear economy = Conventional industrial process

« take, make, dispose »

« Infinite » non-renewable ressources

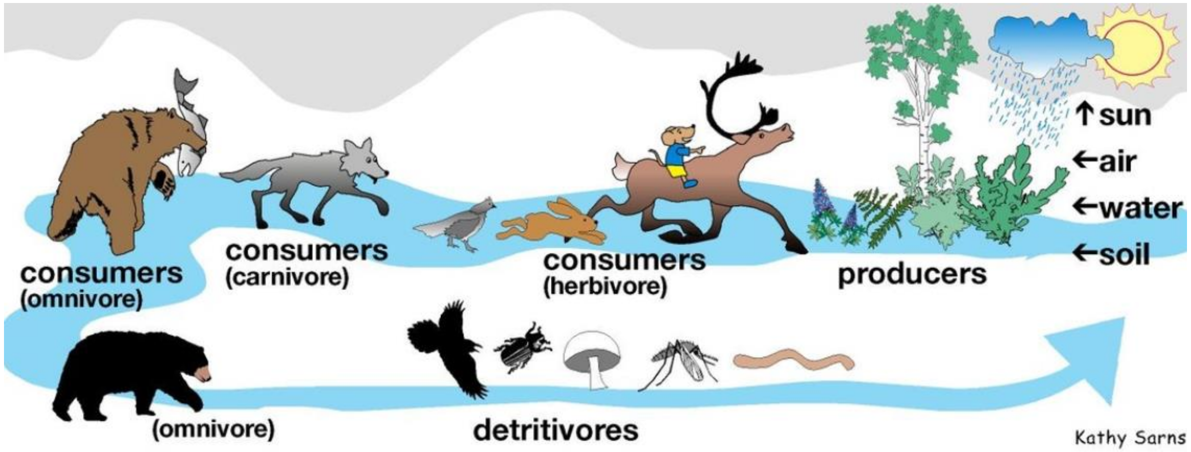
Unlimited waste

Circular economy vs linear economy

Circular economy :

2002 : « Cradle to Cradle » - Michael Braungart and William MacDonough

Sustainable Principle: Production Process including Closed Recycling Loops based on Ecosystem Organisation (biomimetism)

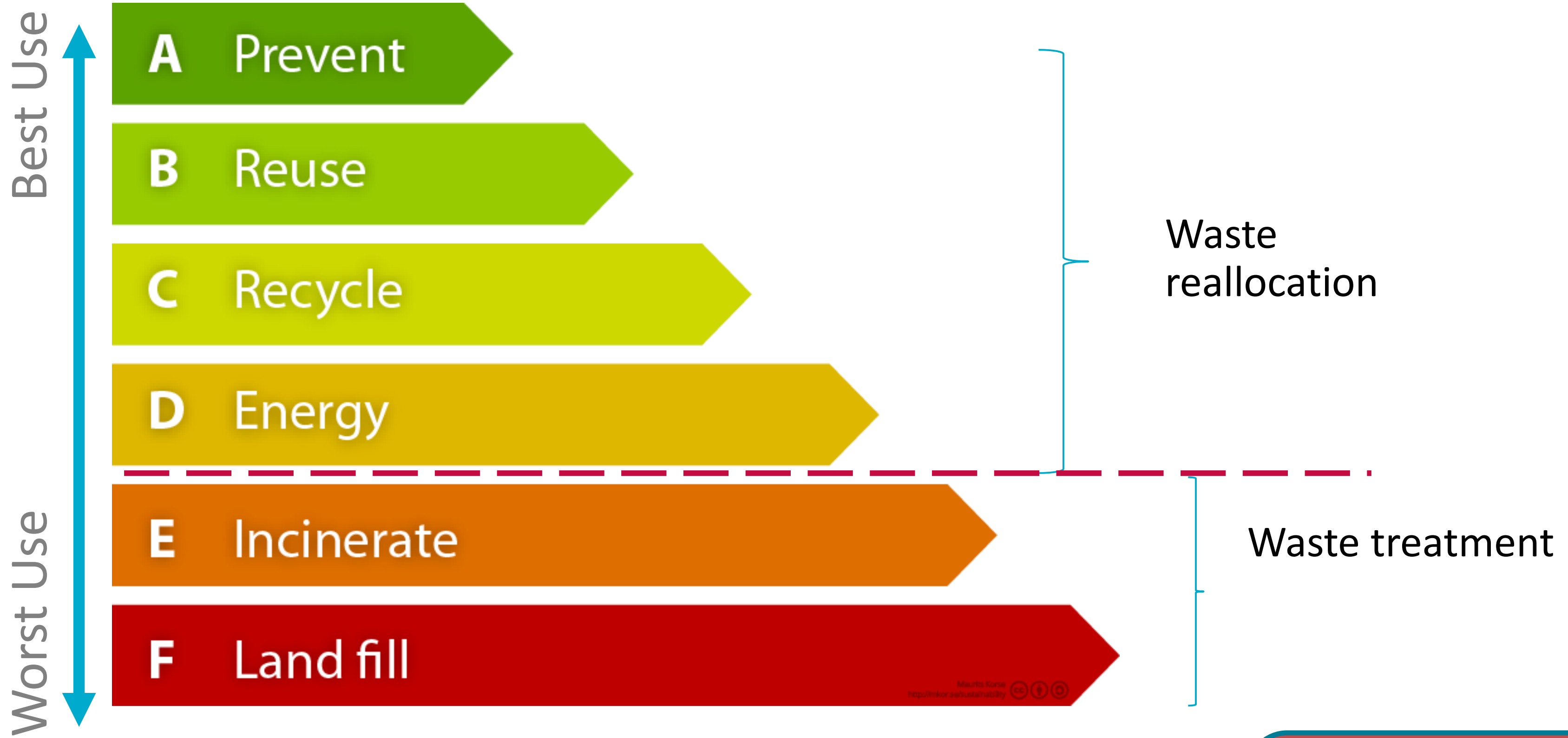


History
Evolution and Elimination of waste concept

- Waste hierarchy
  - Ladder of Lansink (Father of the waste of the hierarchy) - 1979

Waste Hierarchy

Lansink's Ladder



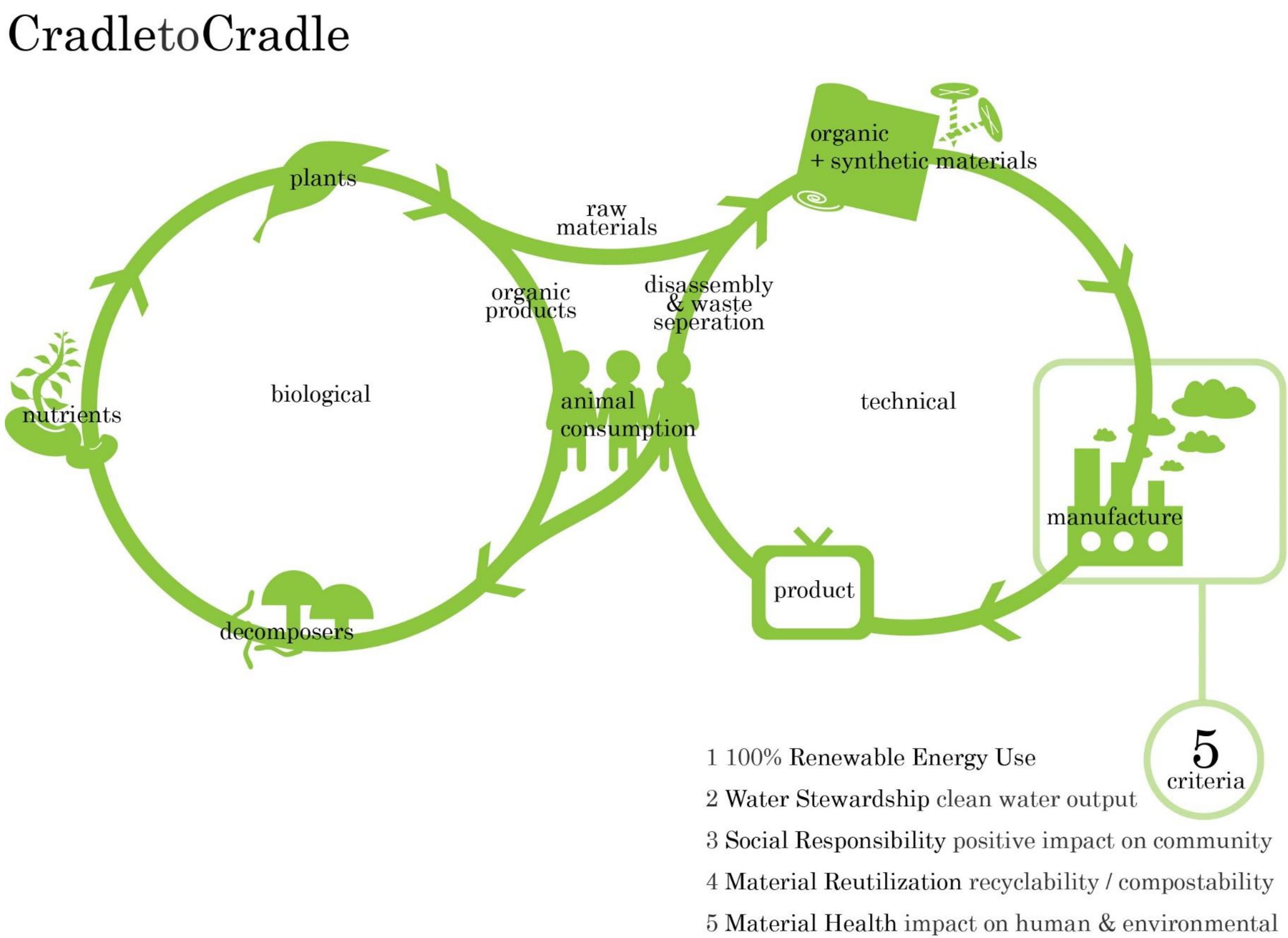
After prevention, source reduction and recycling of manufacturing by-products, waste and effluent treatment can be a new opportunity to create value while reducing polluting flows

Transposable / applicable to microalgal biorefineries

History
Elimination of waste concept

- Waste hierarchy
  - Ladder of Lansink (Father of the waste of the hierarchy) - 1979
- Industrial ecology (Science sustainibility)
  - Material and energy flow through industrial systems – Robert Frosh and Nicolas Gallopoulos – 1989
- Producer responsibility (« Polluter pays »)
  - Extended producer responsibility – Thomas Lindhiqvist - 1990
- Cradle to Cradle (C2C)
  - Michael Braungart and William McDonough (Waste is food) – 2002

Cradle to cradle



History
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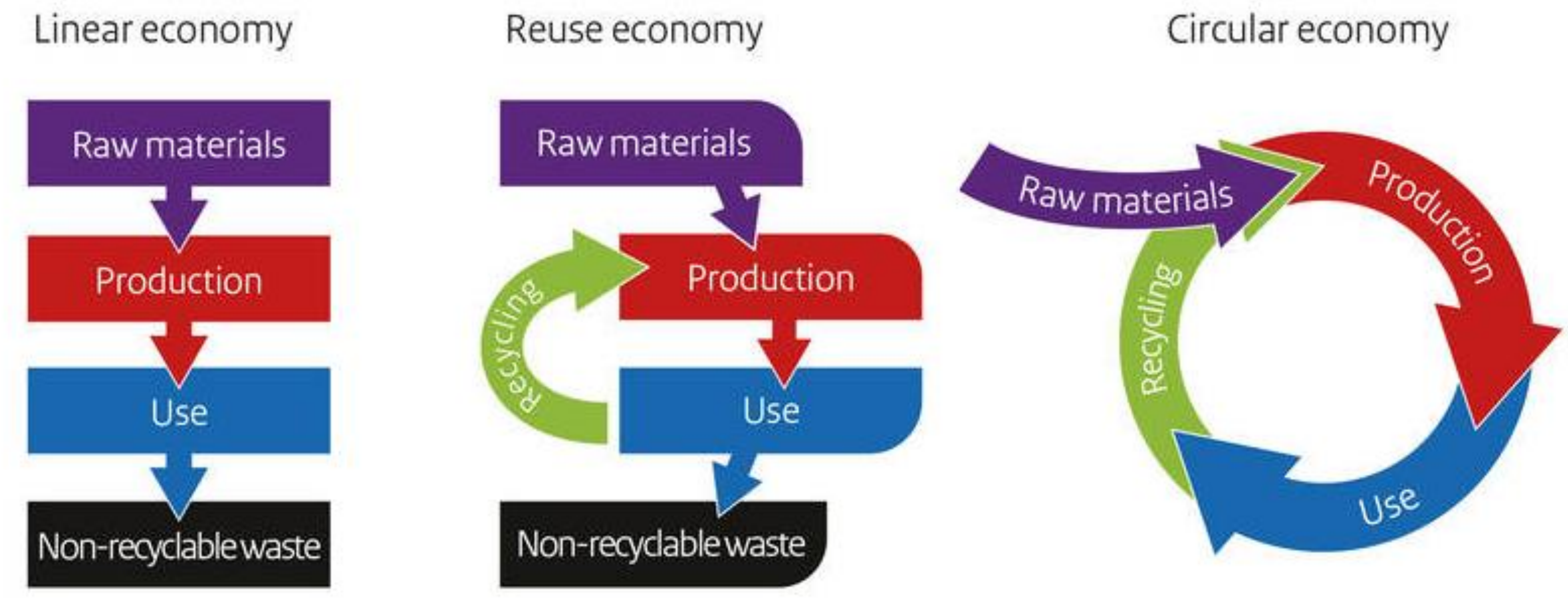
  - Michael Braungart and William McDonough (Waste is food) – 2002
- Circular Economy
  - Mac Arthur Foudation 2010

From linear to circular economy



Past **Present** **Future**

Circular economy

7 Key Principles :

- Ecoconception
- Industrial Ecology
- The functional Economy
- Re-employment
- Repairs
- Ruse
- Recycling

Attempt to reconcile:
growth (economic, demographic),
resources
and environment

PRINCIPLE 1

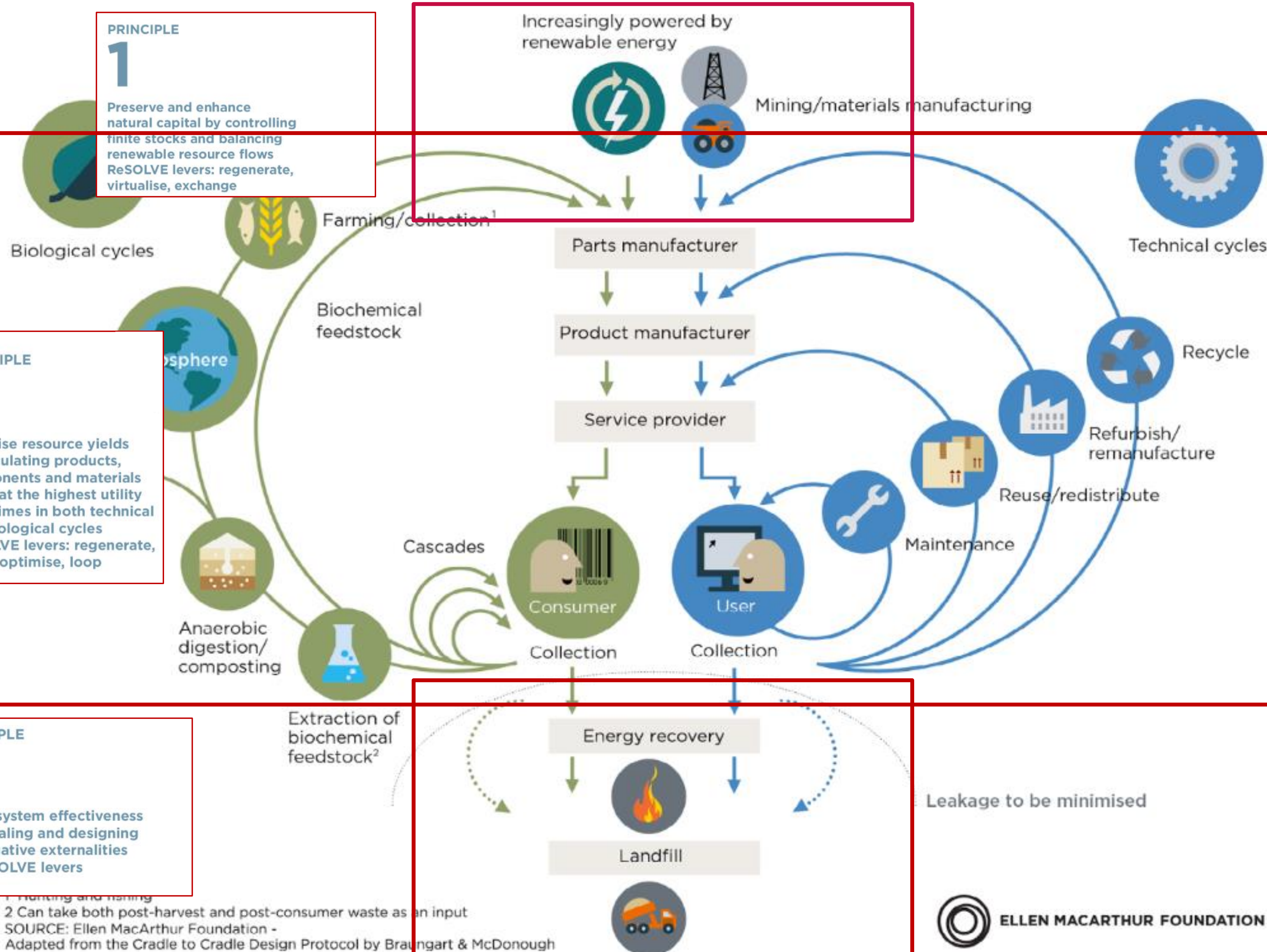
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows
ReSOLVE levers: regenerate, virtualise, exchange

PRINCIPLE 2

Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles
ReSOLVE levers: regenerate, share, optimise, loop

PRINCIPLE 3

Foster system effectiveness by revealing and designing out negative externalities
All ReSOLVE levers



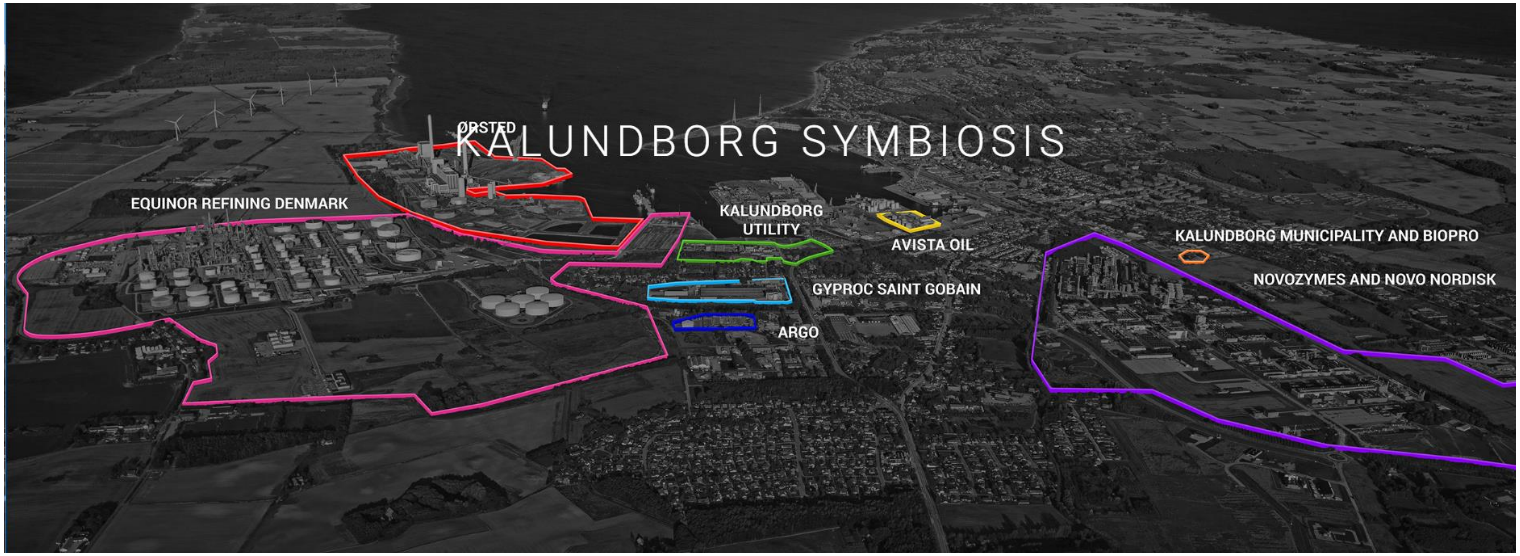
1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
SOURCE: Ellen MacArthur Foundation - Adapted from the Cradle to Cradle Design Protocol by Braungart & McDonough

Effective industrial symbiosis

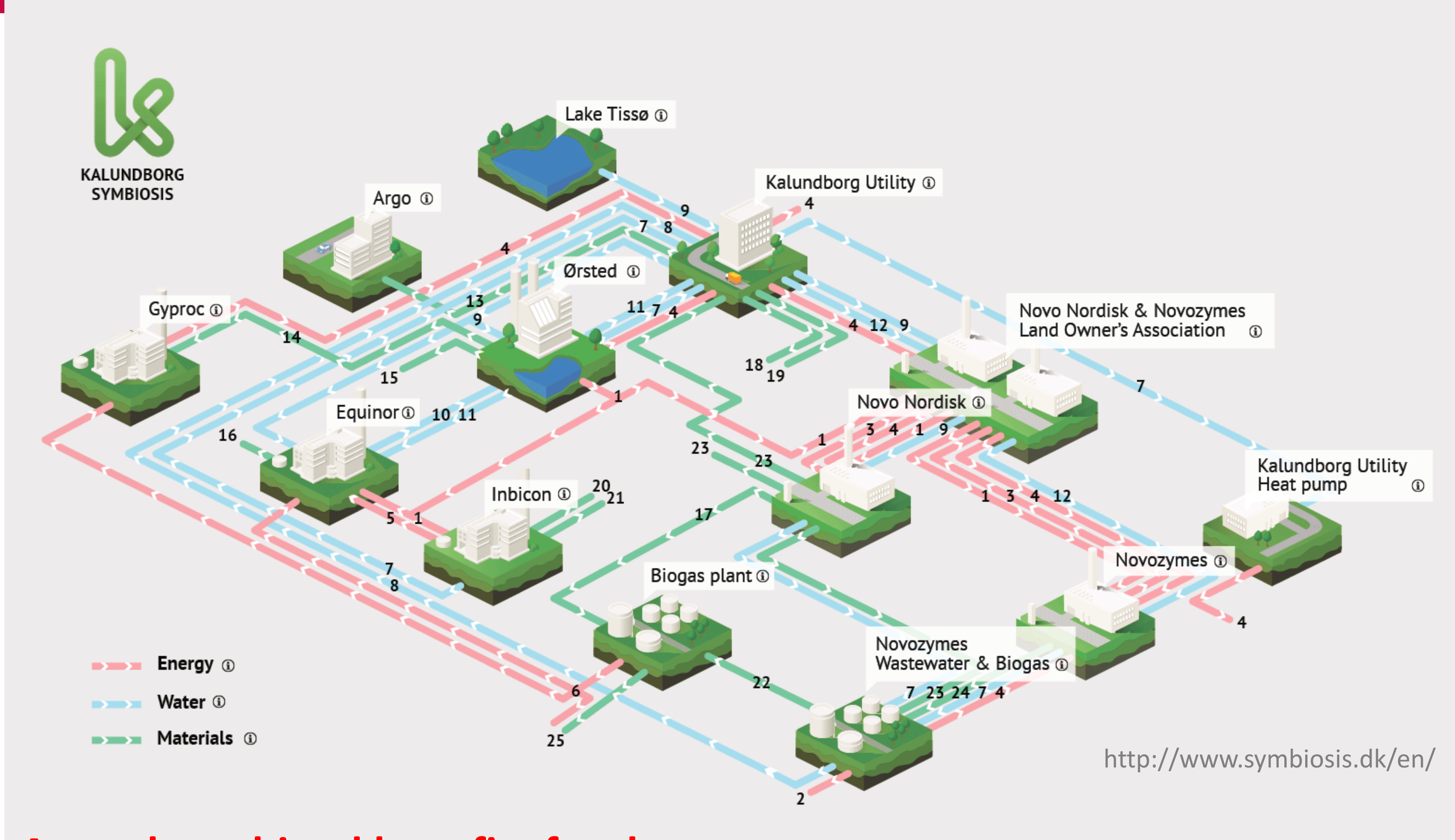
Kalundborg Symbiosis : 1er functioning example

Based on exchanges of energy, water and materials in closed loops

- Located in Kalundborg, Denmark
- 6 private partners
- 3 public partners
- Over 5000 employees combined
- 25 different resource streams exchanged
- Collaboration dating back to 1961
- Winner of Gothenburg Sustainability Award 2018



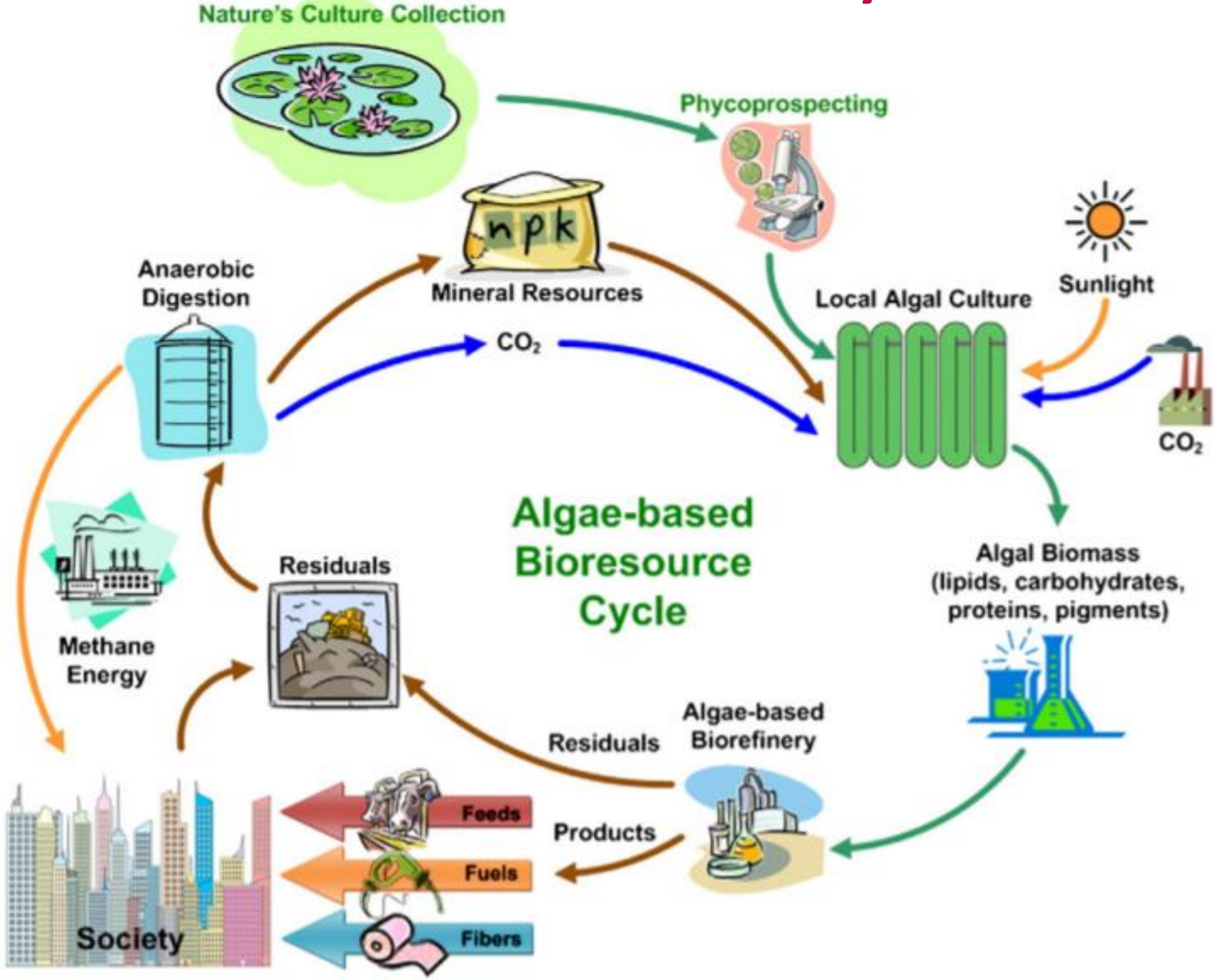
http://www.symbiosis.dk/en/



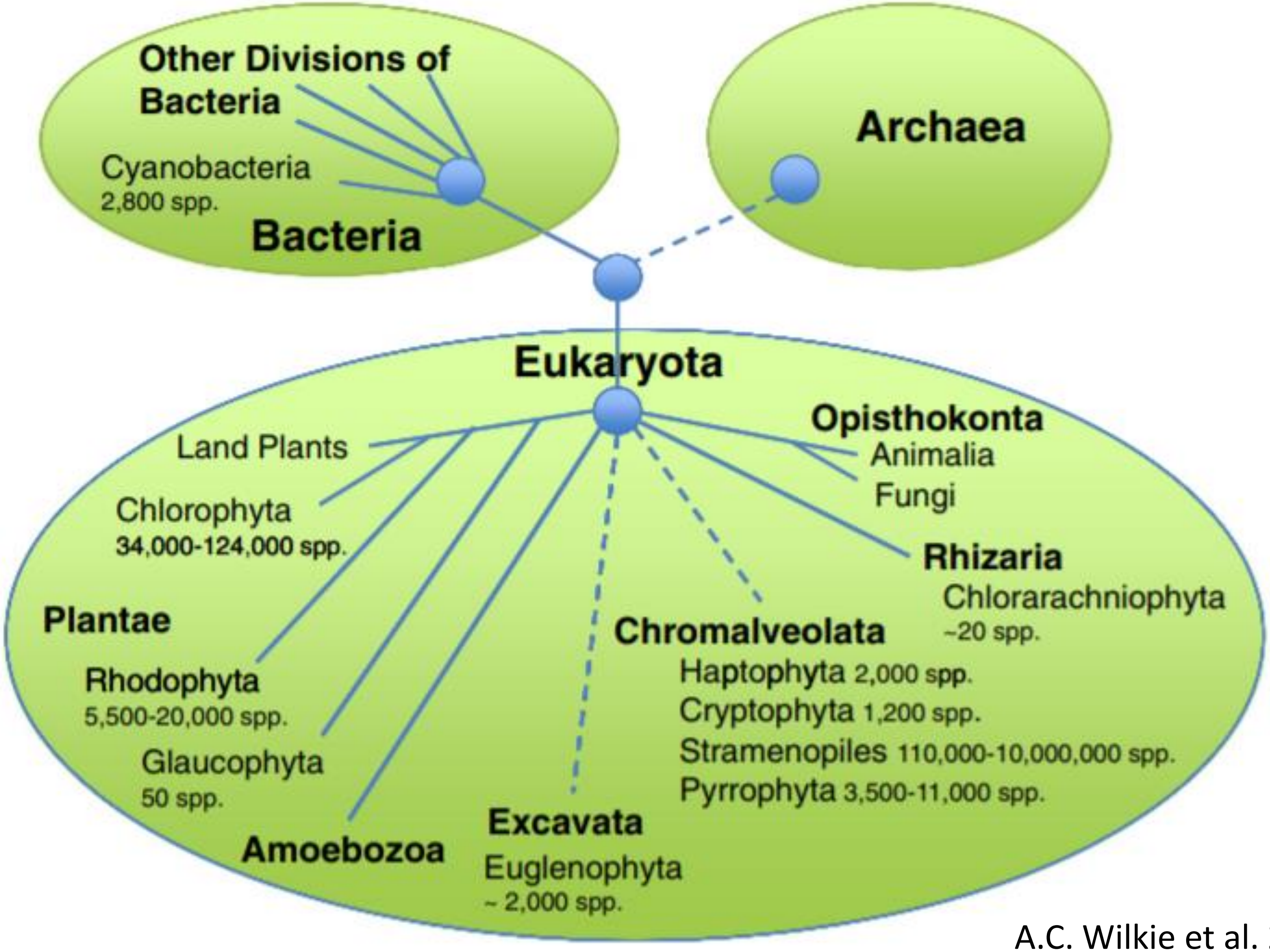
Annual combined benefits for the partners :

- Bottom-line savings of 24 million €
- 14 million € in socio-economic savings
- 635,000 tons of CO_2
- 3,6 million m³ water
- 100 GWh of energy
- 87,000 tons of materials

Microalgae as raw materials in biorefinery concept and circular economy



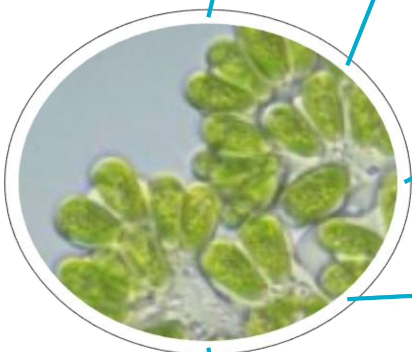
Migroalgae : a versatile raw materials for biorefinery and circular economy



A.C. Wilkie et al. 2011

Biochemical composition

High plasticity to direct bioproduction to specific fatty acids or other metabolites of interest



Triacylgy-cerides

Storage lipids
(triacylgycerides with mainly C_{16} to C_{18} fatty acids, unsaturated)
Up to 70% of dry weight

Membrane lipids

Glyco- et phospholipids
(up to 40 % of fatty acids are polyunsaturated, i.e. eicosapentaenoic acid (EPA))
Up to 7% EPA of dry weight

Carbo-hydrates

Storage products
α-(1-4)-glucane, β-(1-3)-glucane, fructane, glycerol
Up to 50% of dry weight

Proteins

Proteins with all amino acids
Partly soluble and partly bounded as particulate
Up to 50% of dry weight

Valuable compounds

Carotenoids (astaxanthin, fucoxanthin, lutein)
Phytosteroles, all vitamins et antioxidants
Antifungal, -viral ou –microbial
From 1 – 5% each of dry weight

Factors Affecting Biochemical Profiles

Factors

- Light (photo-period and intensity)
- Temperature
- Nutrient-status (nitrogen availability)
- Nutrition (media)
- Salinity
- Carbon availability (CO_2 or organic carbon)
- Growth phase

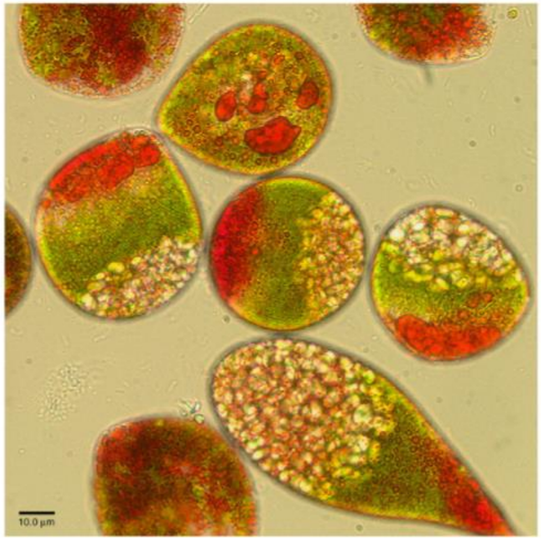


Fig. 3. Indigenous alga with high-value compounds. *Euglena cf. sanguinea* collected from a pond enriched by agricultural run-off. The photo, taken under brightfield transmission illumination, shows distinct regions of red carotenoids (presumably astaxanthin esters), green photosynthetic chlorophyll, and clear paramylon carbohydrate granules (storage material).

A.C. Wilkie et al. 2011

Affect the biochemical composition and therefore bioproduct potential of microalgae

Microalgae : 3G biorefinery

Biorefinery

First Generation : edible crop
Sugarcane, rice, wheat, patato, sugar beet, etc

Second generation : wastes, lignocellulosic biomass
Sugarcane bagasse, forest residues, grass, cell biomass from fermentation, etc

Third generation : Algae
Botryococcus braunii, Crypthecodinium, Nitzschi sp., etc

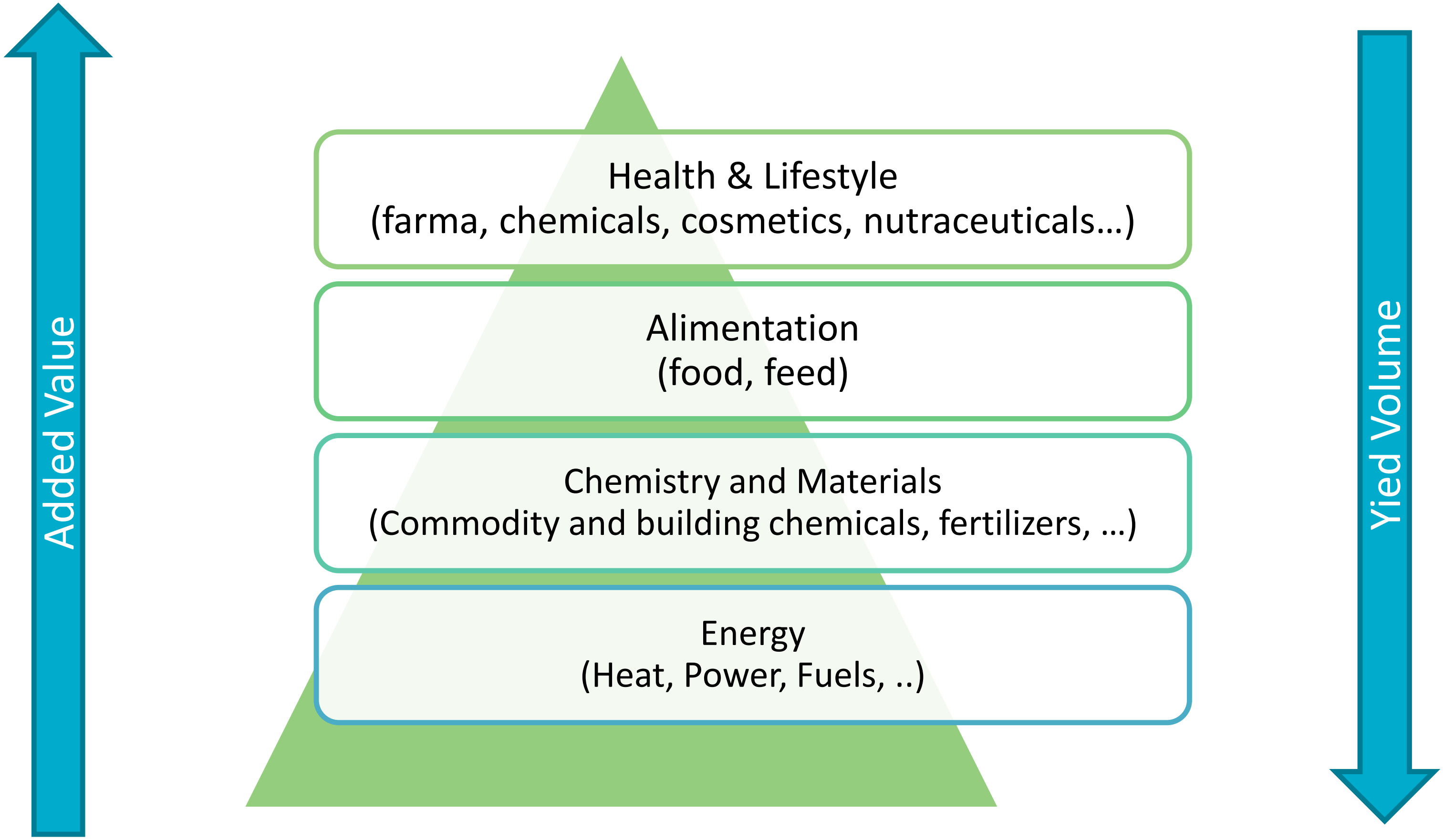
Forth generation : non-edible
$CO_{2,}$ Jatropha, Castor, Karanja

Low scale
Antioxidants, medcines, dietary

High scale
Biopolymer, biofuels, chemicals, food, biofertilizers

Adapted from Romeo-Garcia et al. 2017

Value pyramid of biomass in a biorefinery concept



Industrial fields potentially covered with microalgae ressources

L. Zhu / Renewable and Sustainable Energy Reviews 41 (2015) 1376–1384

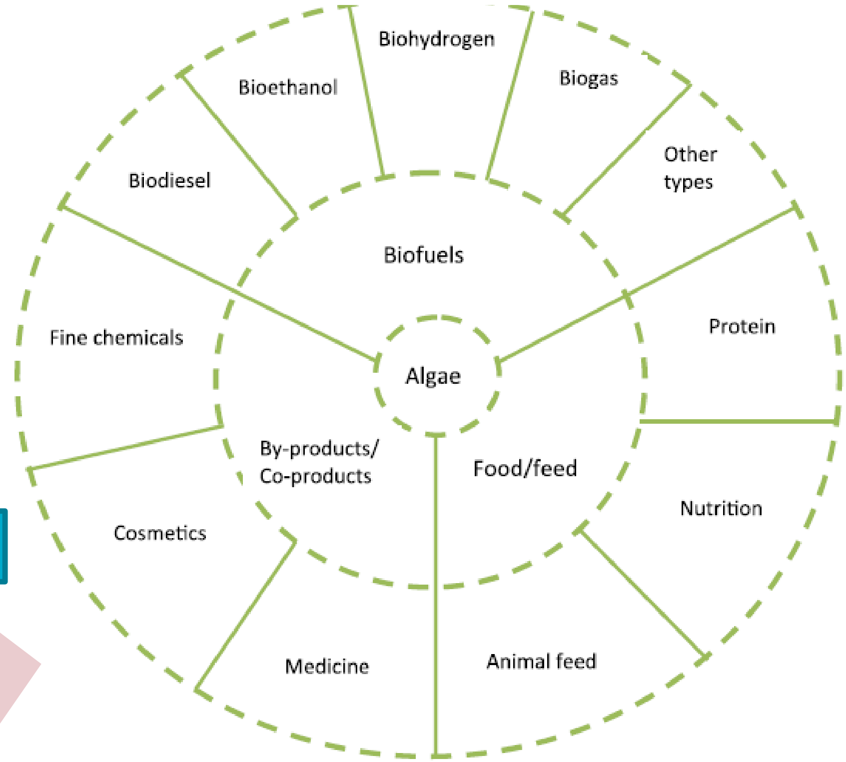
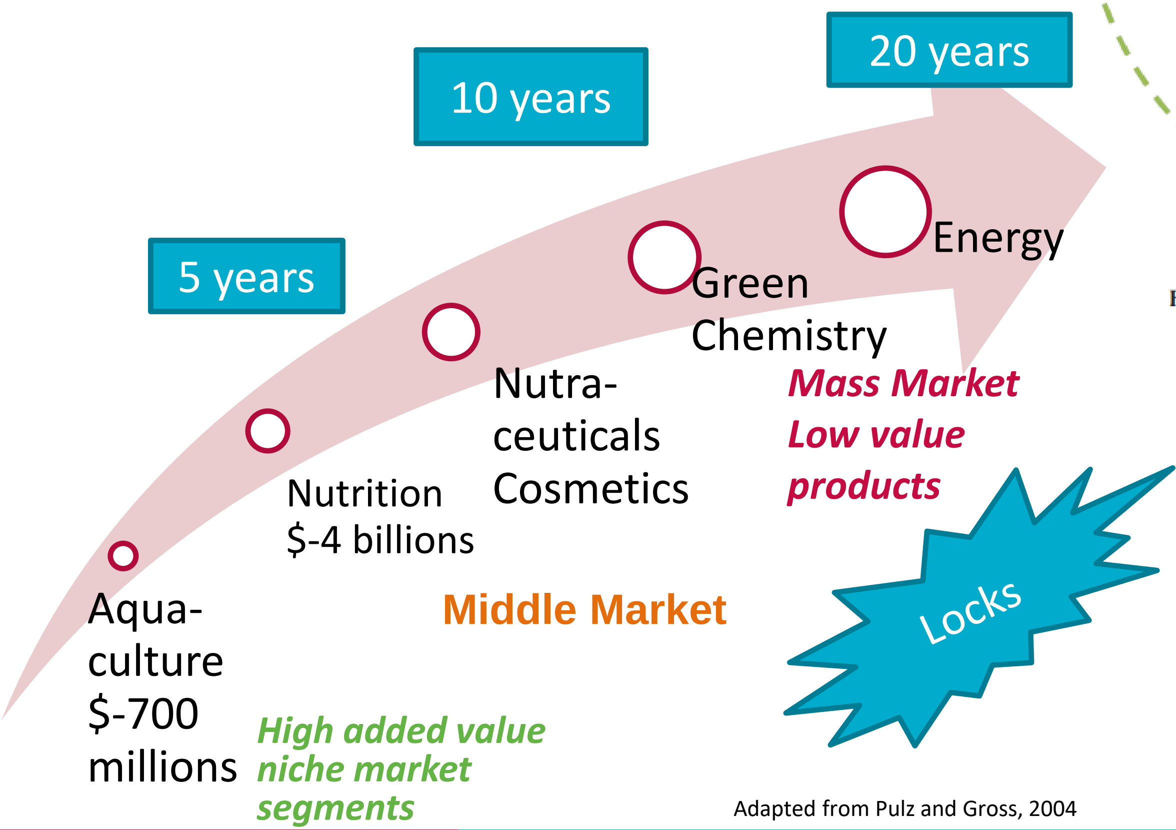


Fig. 4. Potential products from microalgae during biorefinery.

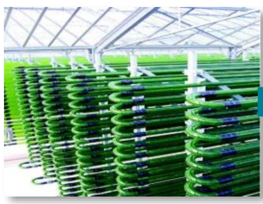


Adapted from Pulz and Gross, 2004

Mainstream Biorefinery with Microalgal Biomass
Cascad Principle

Sequential steps for optimal biomass use → Energy recovery stage at the end of the lifecycle

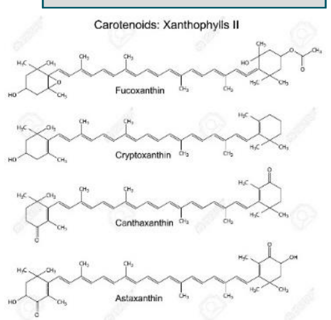
Fractions of biomass and utilization cascades



Production

Pre-treatment / Harvesting/Dewatering

Highvalue compounds



Carbohydrates/ lipides/ proteins

Crude extract/ fractions

Fermentations / Enzymatic reaction/ Chemical transformation

Energy

Coproducts valorization

Valuables compounds and molecules

Microalgae : Tool for waste treatment

Problem ↔ Process ↔ Products

Waste gases

Waste water

Benefitting Industries

Coal-fired Power Stations
Underground coal mines

Metal refineries

Waste water remediation

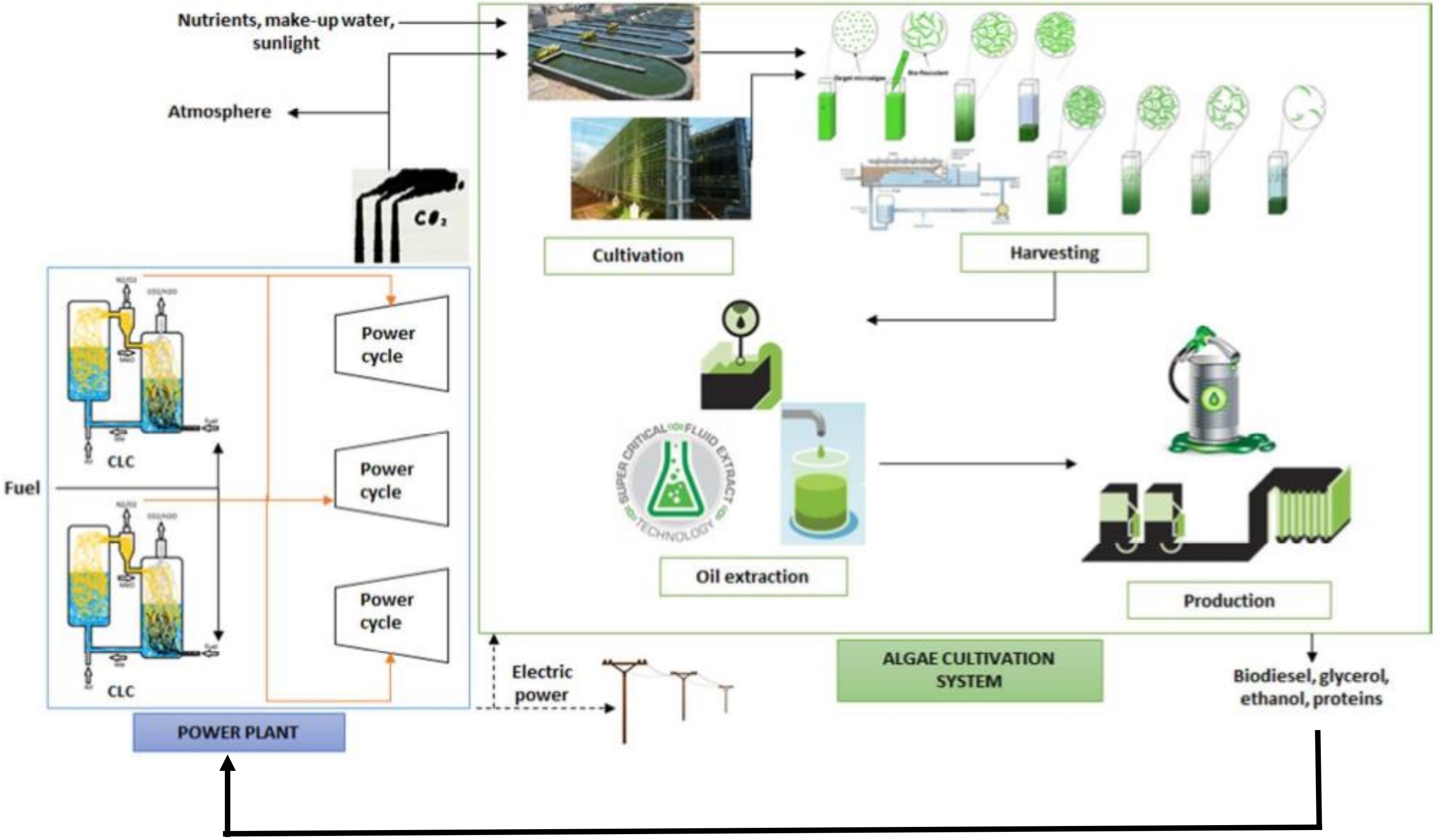
Algae Cultivation

Outcomes

GHG emission abatement
Water recycling
Nutrient remediation
Bioremediation (metals)

- Animal feeds
- Algal biofuels
- Fertilizer/Biochar
- Biorefining
- Nutraceuticals
  - → Carotenoids

CO_2 mitigation in a power plant using chemical looping combustion and microalgae cultivation for biofuel production



Mungui-Lopez et al. 2018

Nutriment rich Wastewater as feedstock

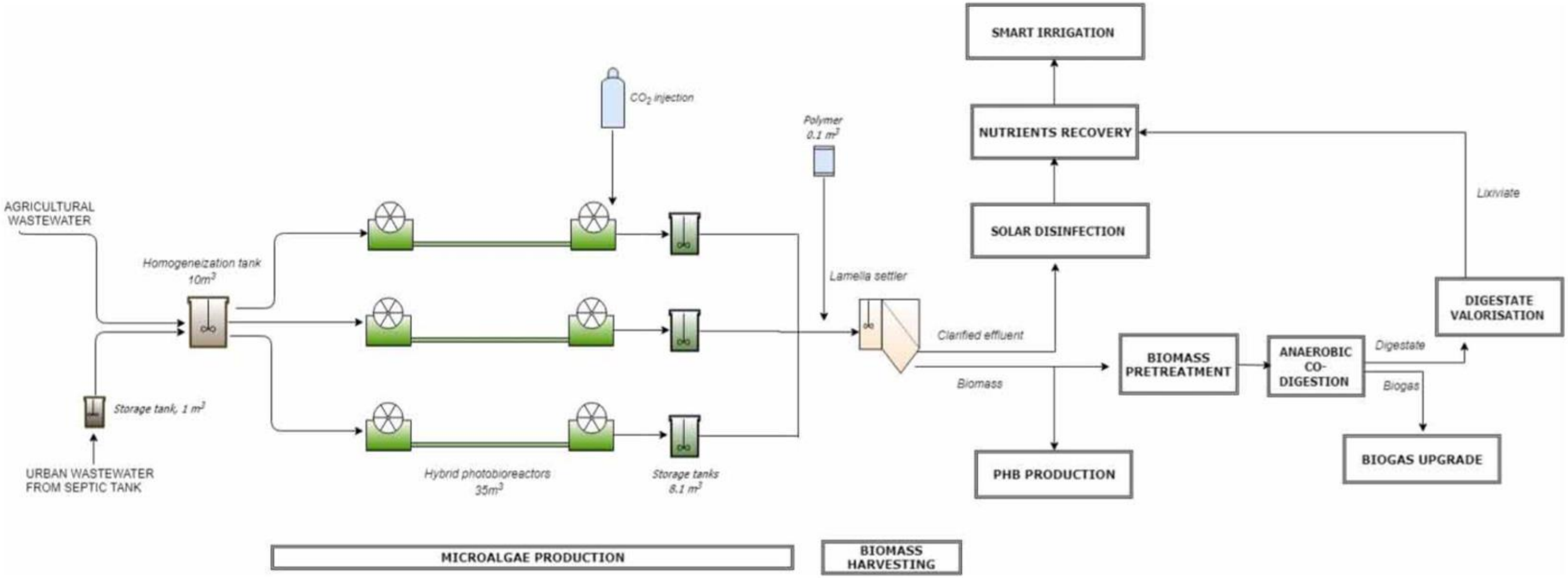


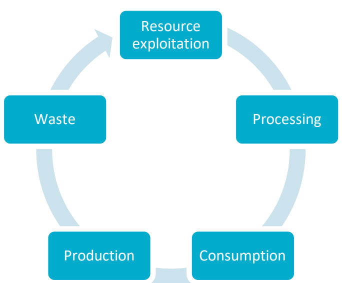
Figure 1 | Scheme of the INCOVER plant located at the Agròpolis campus, Viladecans, Barcelona.

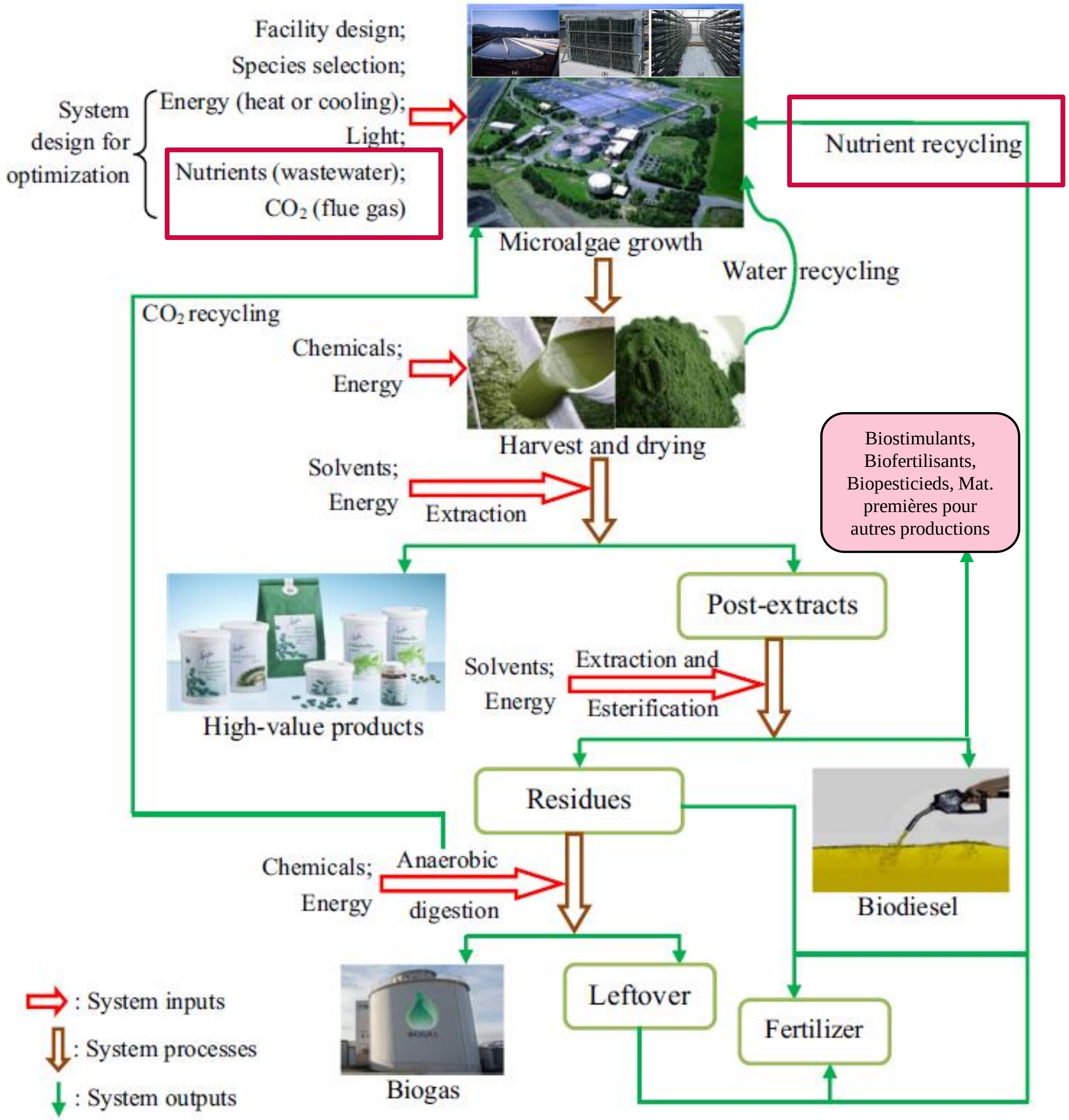
Uggetti et al. 2018

Microalgal biorefinery integrating recovery and recycling of gaseous and liquid effluents + by-products

Integrated environmental biorefinery

Waste treatment (human activities)





Adapted from Zhu 2015

Conclusions

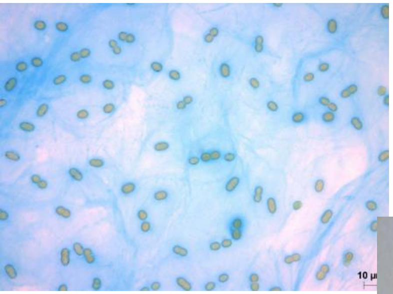
We need Circular economy for :

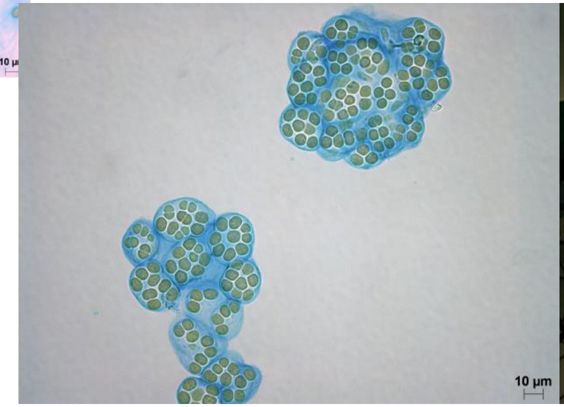
- Environment: inefficient use of resources has negative environmental impacts
- Access to raw materials: scarcity or depletion of resources, dependence of EU on imports from often politically unstable countries- question of price volatility
- Societal pressures: global middle class to double to nearly 5 billion by 2030, which will cause rise in consumption and increase pressure on resources
- Innovation and growth potential

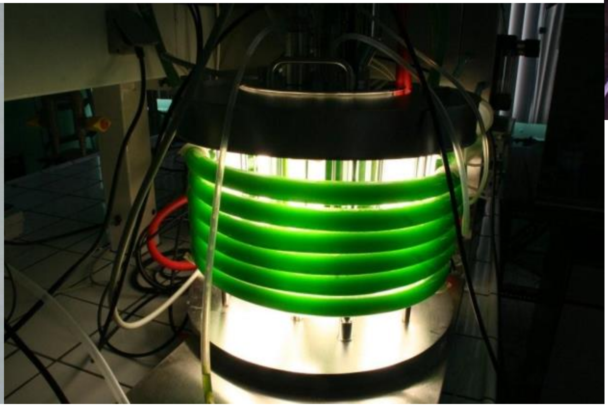
Environmental Microalgal Biorefinery

=

Real opportunity for circular econony







Hellweg and Milà i Canals 2014

Thank for your attention