Environmental (Bio)Tech for the Global Bio-Economy :
About hypes & mavericks

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The actual societal mindset about environment

Meadows et al. 1972, MIT:

The Limits to Growth

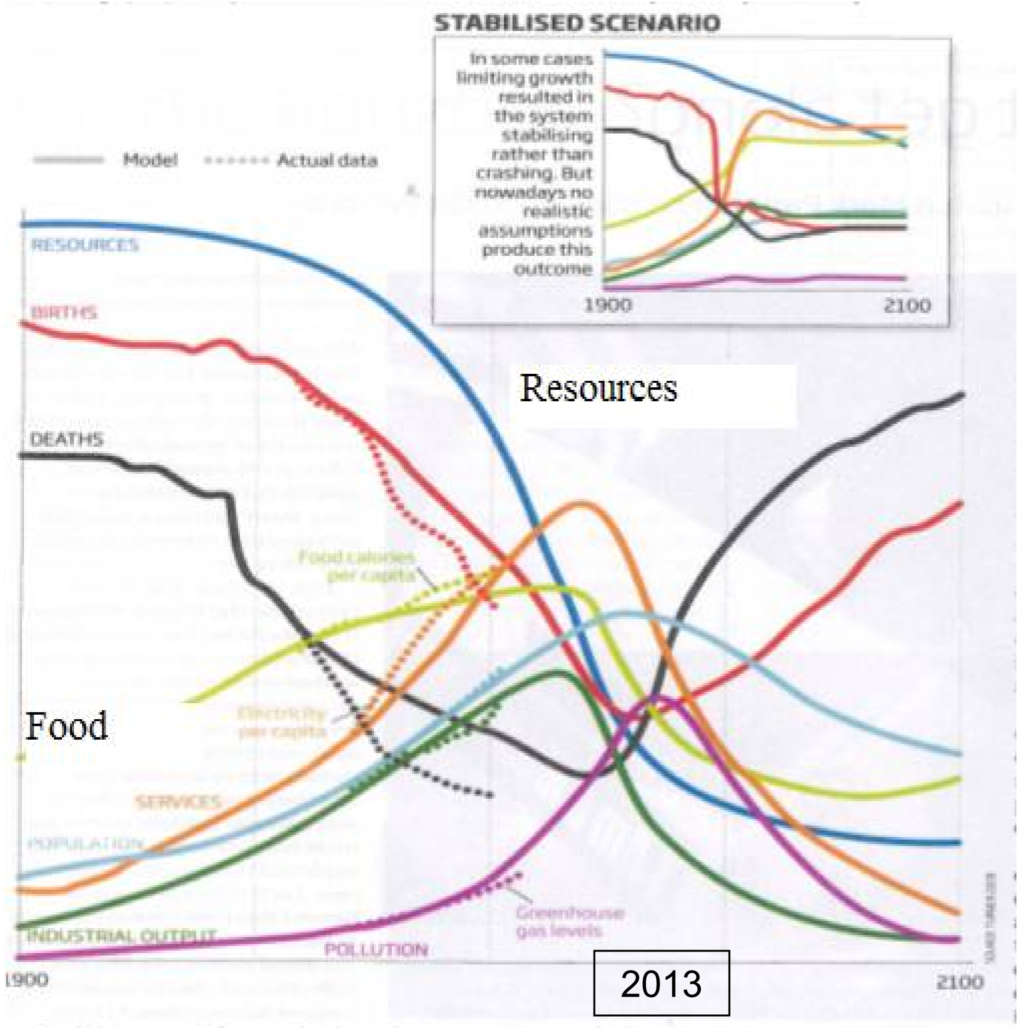
→ The first use of a computer model to explore the possible future

→ The message : a boom would be followed by a bust , unless we would take action

Today we ask : Have we taken the right action ?
(New Sci , jan 2012)

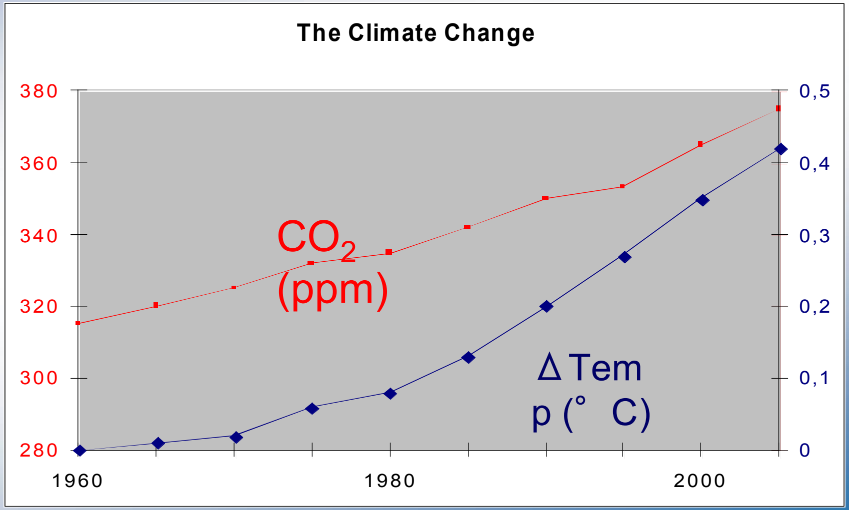
We are in
a zone of
transition

Resources
and Food
need to
re-examined
strongly

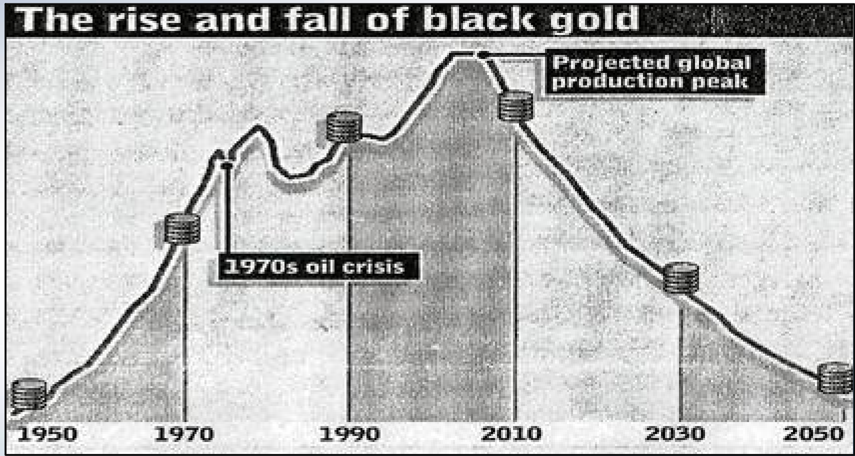


FOUR SUPERCHALLENGES OF THE 21st CENTURY

- **Climate change:**
  - → Dramatic ecological changes



- **Energy supply**
  - → The depletion of fossil fuel



Cambell and Laherre, 1999: The coming oil crisis

FOUR SUPERCHALLENGES OF THE 21st CENTURY

- Health & Diseases : Bird flu, Asian flu,…
  - Pandemics, MAR/ESBL, …
- Sustainable environment
  - Major wars for drinking water to be expected about 2020 (Pentagon report 2004 ; NASA 2013)
  - Rare Earth Metals /Food : protein !

Question: What has environmental technology to offer in these domains?

Outline

- **Hypes :**
- *The fossil fuel shortage

  *The algae

  *Synthetic biology

Mavericks :

* Soil rehabilitation
* The bio-economy /the biorefinery
* Nano catalysts/materials
* Microbial upgraders of the urban society
* Microbial protein

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Hype 1: Fossil fuel shortage

Facts

- **The fossil fuel production reserves are still huge !**

  → **New equipment will open massive reserves**

  e.g. in the USA

  Iraq

  Brazil

- **Gas reserves are much larger than expected**

Hype 1 : Fossil fuel shortage

<u>Consequences</u>

- **The EU has set the 20 – 20 – 20 policy**

  i.e. by 2020

  → minus 20% greenhouse gas levels

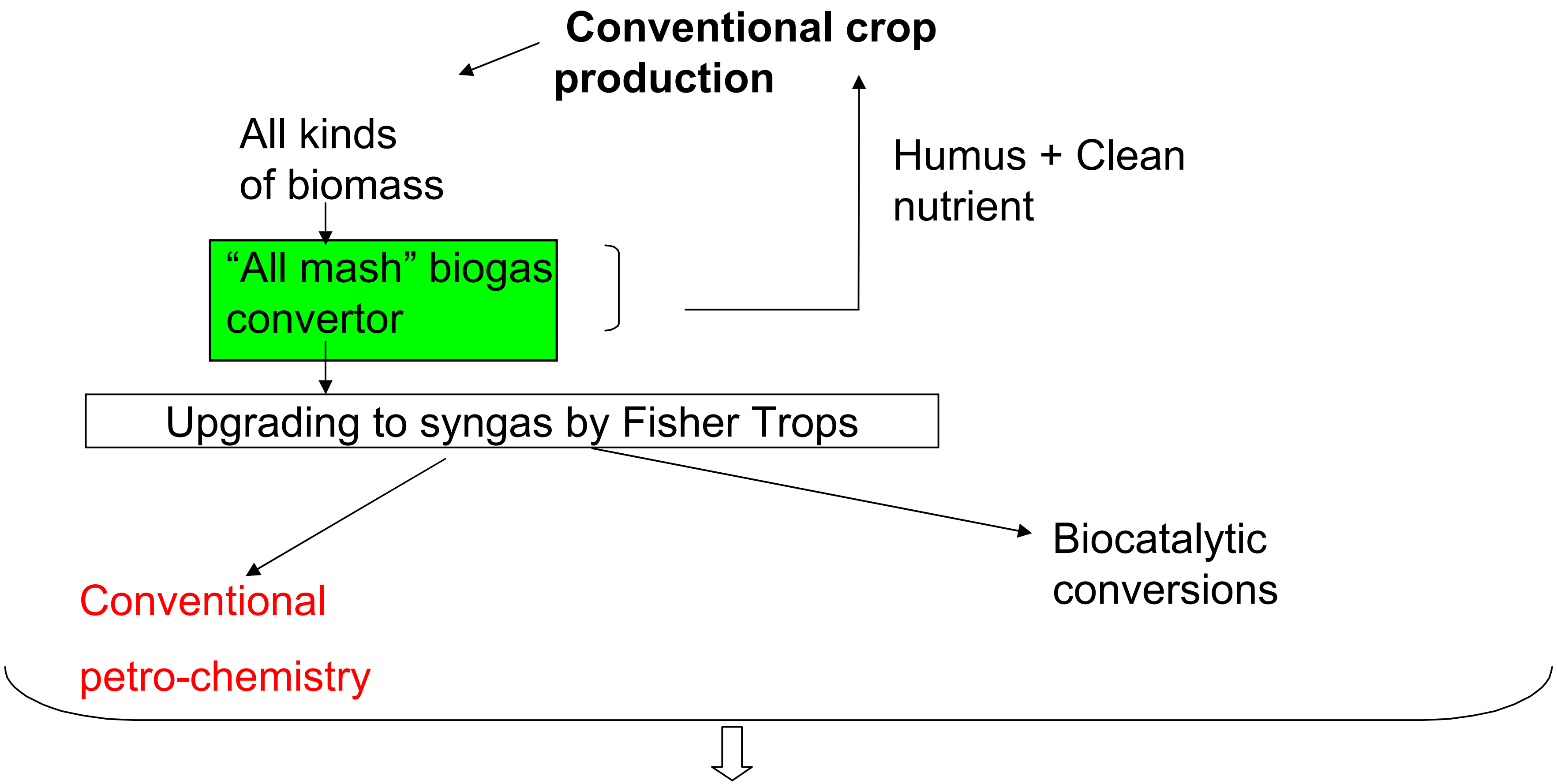
  → minus 20% energy consumption

  → plus 20% renewables in energy mix

BUT there is so much fossil fuel <u>that the market will not soon be asking for</u> <u>R</u>enewable <u>E</u>nergy <u>S</u>ources (RES) ; it will only ask for a 'face lift'

Repositioning of the fossil fuel and the environment

<u>Biogas lining up with petro-chemistry</u>



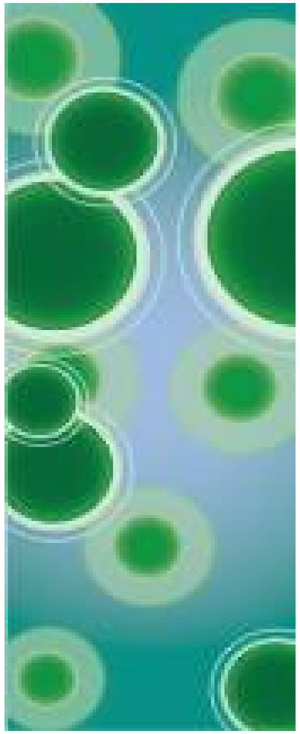
AD as a <u>first</u> <u>line</u> "all round " biomass supplier to facelift the petro-sector

(Yeuneshi et al., 2005; Biochem. Eng. J. 27: 110-119)

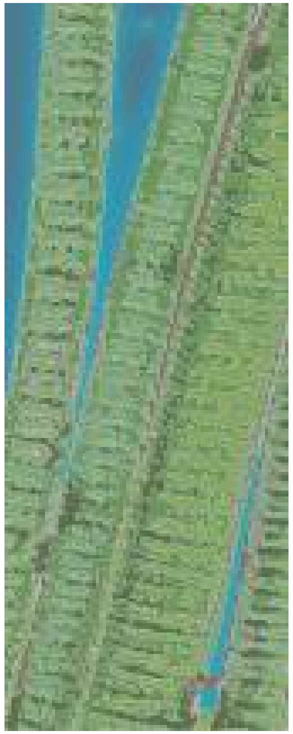
(Datar et al., 2004; Biot. Bioeng. J. 86: 587-594)

Hype 2: Algae feedstock

- Photosynthetic organisms
- No competition for food crops
- No need for freshwater
- No pesticides and herbicides
- Varying concentrations of carbohydrates, lipids, proteins...
- Biomass free of lignin



Microalgae
(5 – 50 µm)



Cyanobacteria
(5 – 50 µm)

Macroalgae
(multi cellular + tallus)

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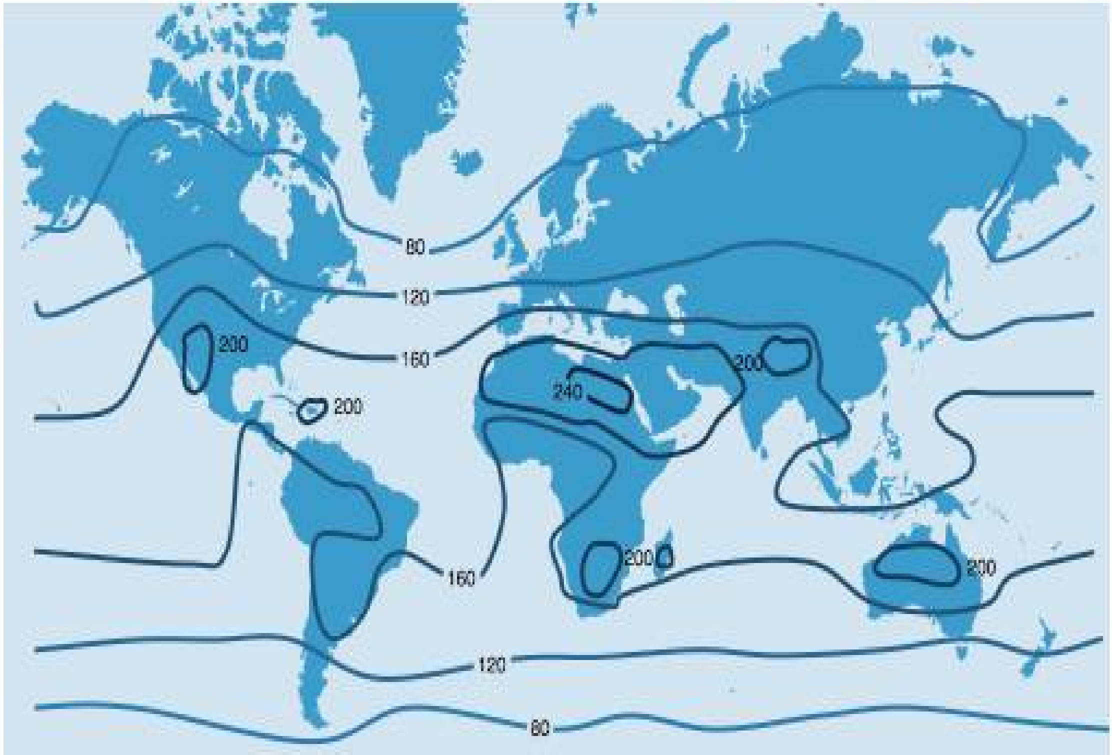
Productivity

- Algae photosynthetic efficiencies in practice close to 4-5% vs 3% for terrestrial crops
- Outdoor productivities achieved between 40-80 ton DM ha^{-1} a^{-1}
  (Richmond, 2004, ISBN: 0632059532; Sheehan et al., 1998; US NREL)
- **Unreasonable** targets: 100-227 ton DM ha^{-1} a^{-1}
  (Schenk et al., 2008; Bioenergy Res. 1, 20-43; Stephens et al. 2010; Nat. Biotechnol. 28, 126-128)



World map of estimated algae productivity (ton DM ha^{-1} a^{-1}) at 5% photosynthetic efficiency

(Tredici , 2010; Biofuels 1, 143-162)

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Players & Products (C&EN 2011; nr. 29)

Firm	Technology	Product
Solazyme	Heterotrophic dark algal production on sugarcane feedstock	*Biodiesel *Skin cream (alguronic acid) *Algal flour with Roquette *Fine chemicals with Bange (Br)
Cellena	Photobioreactors & Ponds	*Neutraceuticals *Oleo chemicals
Algenol (Dow)	Photobioreactors	*Ethanol and propylene in headspace
Sapphire Solajet Exxon Mobile-Synthetic Genomics; BP-Energy Bioscience	Open ponds with synthetic biology	*Fuel oil

The only money makers thus far are the “dark algal” producers

Conclusion hype 2: The algae

- We need to search for:
  - Algae which float better
  - Algae which harvest and process easily

(Van den Hende et al. 2012; Biotech Adv 30:1405-1424; LabMET)

- Serendipity is key!!

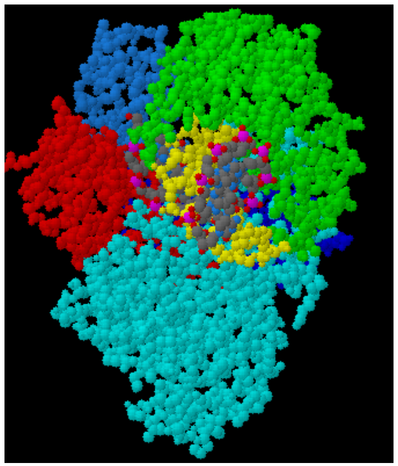
Hype 3: Synthetic biology

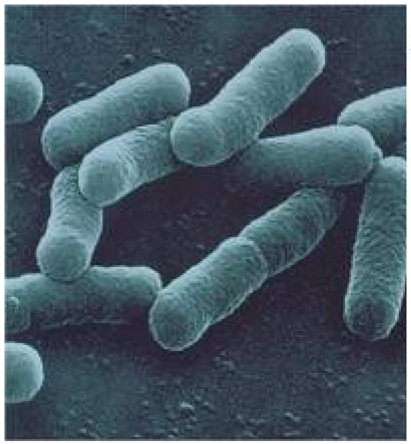
- Today, we can create new-to-nature synthetic genes, enzymes, microorganisms and plants
- Metabolically engineered plants and microorganisms can be better suited for our needs

Synthetic genes

Metabolically engineered microorganisms and plants

Synthetic enzymes





Hype 3: The synthetic biology

- **The syngas route :**

Crops / Waste ➡ Pyrolysis

↓

via (GMO) Clostridia based co-cultures

↓

Various chemicals such as caproate , …

The carboxylate platform

(Agler et al. 2010 Trends in Biotech 29:70-78)

Take home : Very high technical barriers in producing high quality endproducts

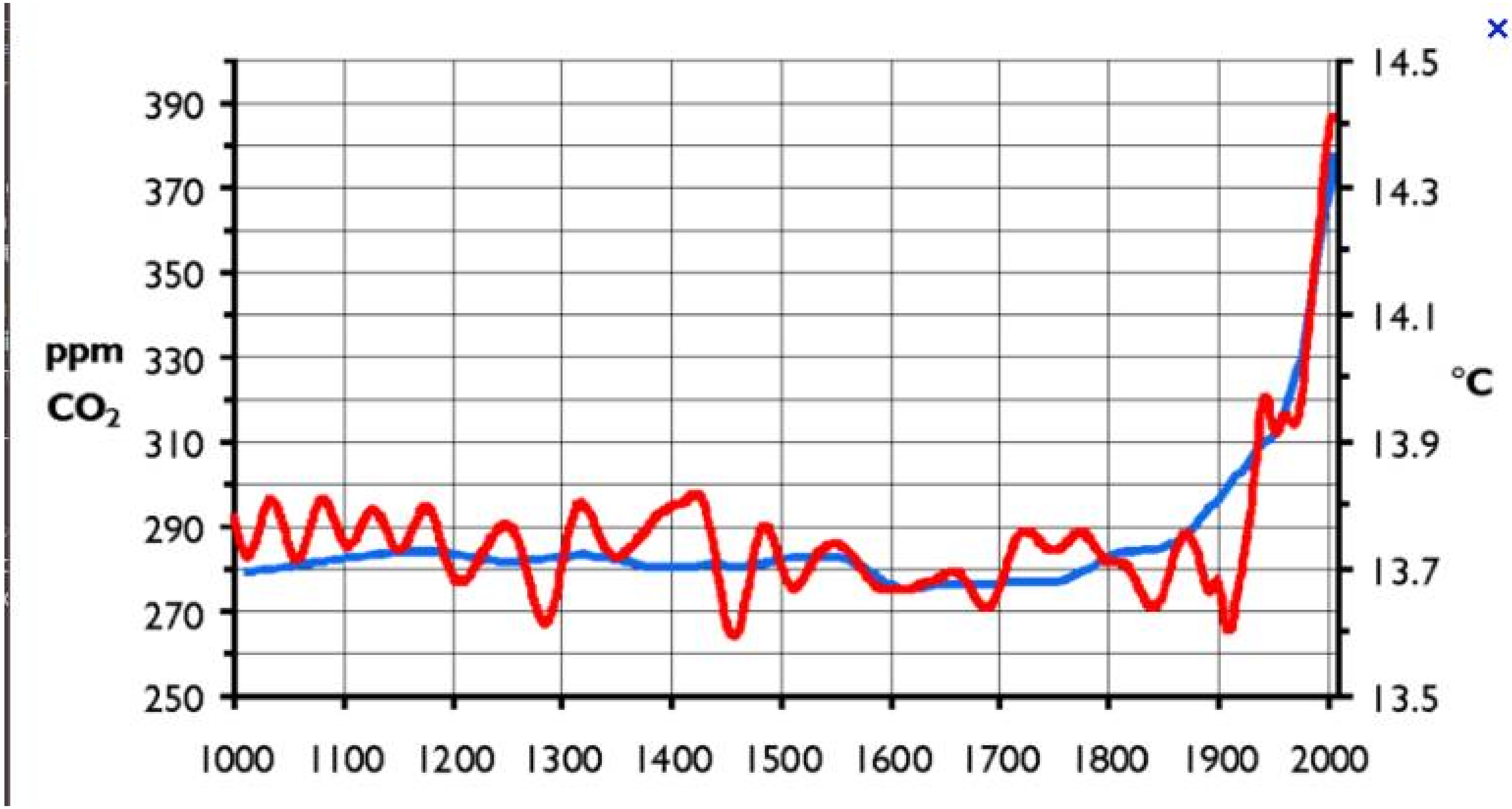
RECAP :

Environmental Biotech ; About HYPES & MAVERICKS

* THE HYPES ↔ | Energy supply
Algae
Synthetic biology

* THE MAVERICKS ???

The inconvenient truth



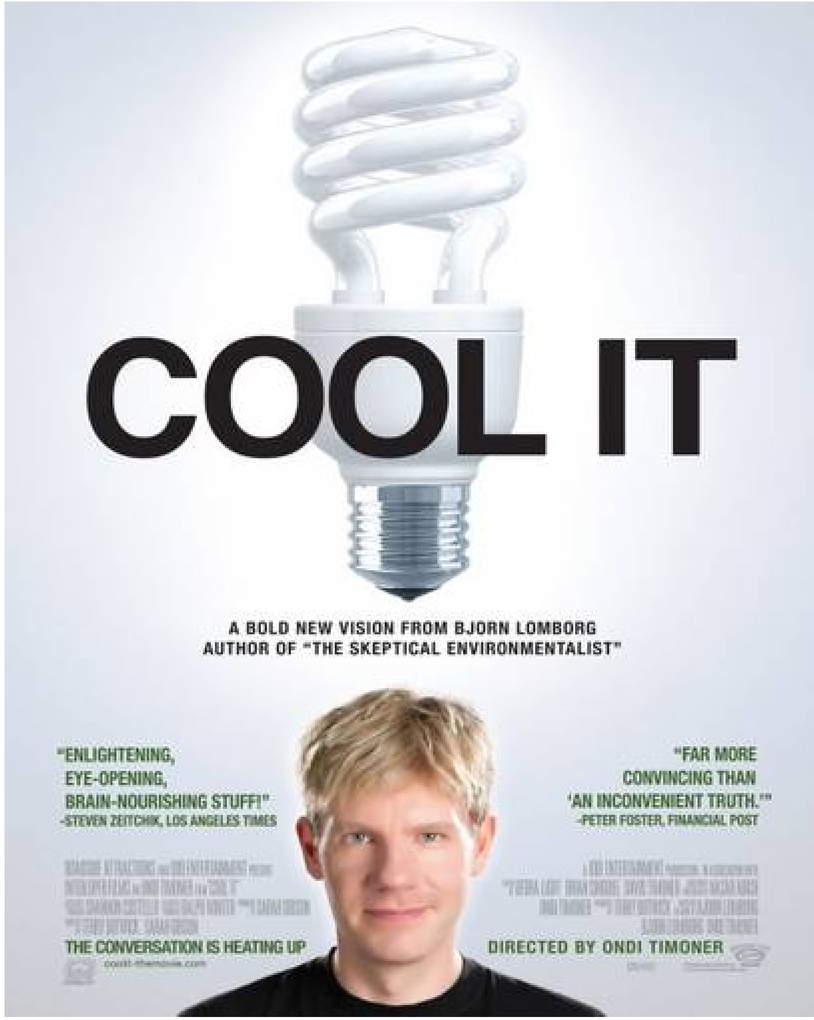
CO_2 captation/storage technology

- Bjorn Lomberg 2010:
  Cool it!

- "We must wisely invest for climate changes"

  ↓

  Put money where it has effect !



Maverick 1: Soil rehabilitation

Quantities :

- The total amount of fossil fuel used thus far + the amount known = 170x 10exp 9 tons
- The latter equals the total amount of biomass produced on Earth each year ; at present only 5% of this is used

Surfaces

- 2 x10 exp 9 ha under agricultural production
- 2 x 10 exp 9 ha can be rehabilitated for production

  (World Resource Institute)

Economics :

- *Price of agricultural soils is increasing factor 2-3 in the last decade
- *Return on investment for rehabilitation of soils increases to range of 10-70% (Ferwarda 2012 ; IUCN Comm. Ecosystem Management , Rotterdam Erasmus Univ)

• Maverick 1 : Soil rehabilitation

- ***The ecosystem services** of the soils are plenty eg removal of 1.0 ton methane gas from the air (= 20 ton CO_2) per ha per year (Boeckx et al. 1997 ; Soil Sci Soc Am J 61:5892-5899)

  The ecosytem services by the soil ecosytem are of the order of

  3 000-7 000 Euro per person per year (ie of the Bruto National Income per person per year world average (UNEP 2012)

- * **Soil management offers major possibilities** .The amount of CO_2 produced by soils totals 10x that of all traffic emissions ; plenty of options to modulate the former (Denman et al. 2007; IPCC)

A special tool in this context is the use of **biochar** in agriculture (Lehmann et al. 2007; Nature 447:143-144)

RECAP :
BIORESOURCES & BIOENERGY: ABOUT HYPES & MAVERICKS

* THE CHALLENGES / THE HYPES

* THE MAVERICKS

→ SOIL REHABILITATION

→ **THE BIOREFINERY**

→ **THE BIO(NANO)CATALYSTS/MATERIALS**

→ **MICROBIAL UPGRADING**

→ **MICROBIAL PROTEIN**

Maverick 2: The Biorefinery

Agriculture:
Primary production of biomass

Plant (green) biotechnology

Biorefineries:
biomass conversion

Industrial (white) biotechnology

Bioproducts
Biomaterials
Biofuels

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Products of the biobased economy

- Bioplastics
- Biofuels
- Biodetergents
- Bulk chemicals
- Fine chemicals
- Cosmetics
- Farmaceutical ingredients
- Vitamins
- Food ingrediënts
- Flavours and fragrances
- …

Biofuel Production Processes

Fuel	Unit processes	Wastestream	Reliability
Pure Plant Oil	Pressing, chemical extraction, extra refinery	Pressed cake	High
Biodiesel	Esterification	Glycerol residue	High
Bio-ethanol	Fermentation, distillation,…	Distillery slops direct Evaporation condensates	High
Fisher-Tropsch Diesel	Gasification, FT synthesis	Light oils	High
Biogas→ kWh-*electric* + kWh-*thermal*	Anaerobic digestion	None!!!	**Thus far: poor** **Now: OK**

Take home : To be sustainable, take care of the wastestreams !

- Second generation ethanol is still too expensive (ie of the order of some 0.4 USD per L ethanol) to be competitive with grain ethanol .

- YET , second generation bio-energy is now perfectly feasable via the biogas route

AD of energy crops

Energy crop

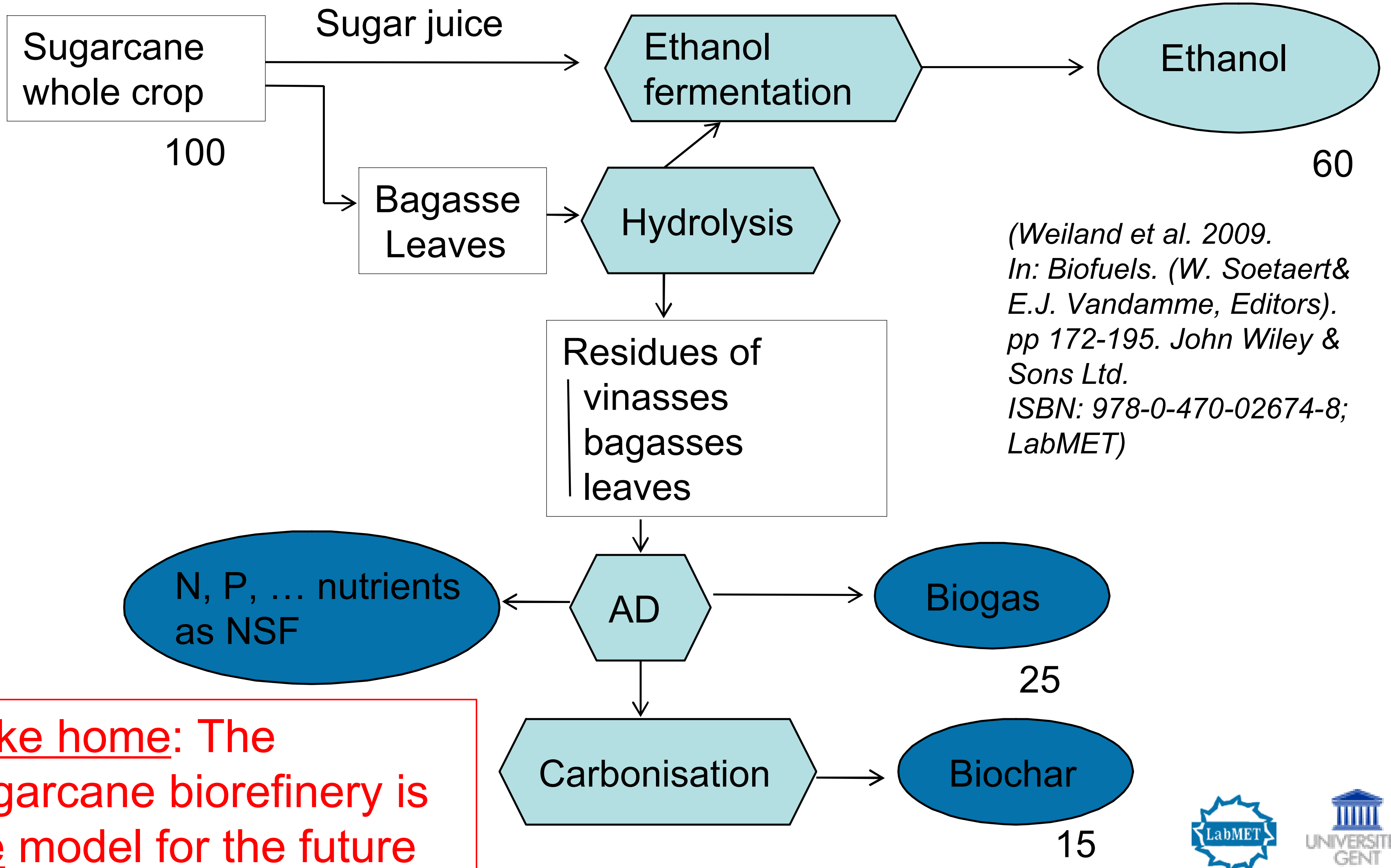
Lignocellulose → Chopper to < 1 cm→ DRANCO → Residue to land

Endpoints:
- **kWhe*l*   40 % netto output**
- **Clean nutrients + Humus**

Nüdstedt **4000 t DM/y**

Nuhrenberg **100 000 t DM /y ; 10 MW**

The sustainable sugarcane system



(Weiland et al. 2009. In: Biofuels. (W. Soetaert& E.J. Vandamme, Editors). pp 172-195. John Wiley & Sons Ltd. ISBN: 978-0-470-02674-8; LabMET)

Take home: The sugarcane biorefinery is the model for the future

The 'zero waste' / ' circular' biobased economy
The Ugent MRP

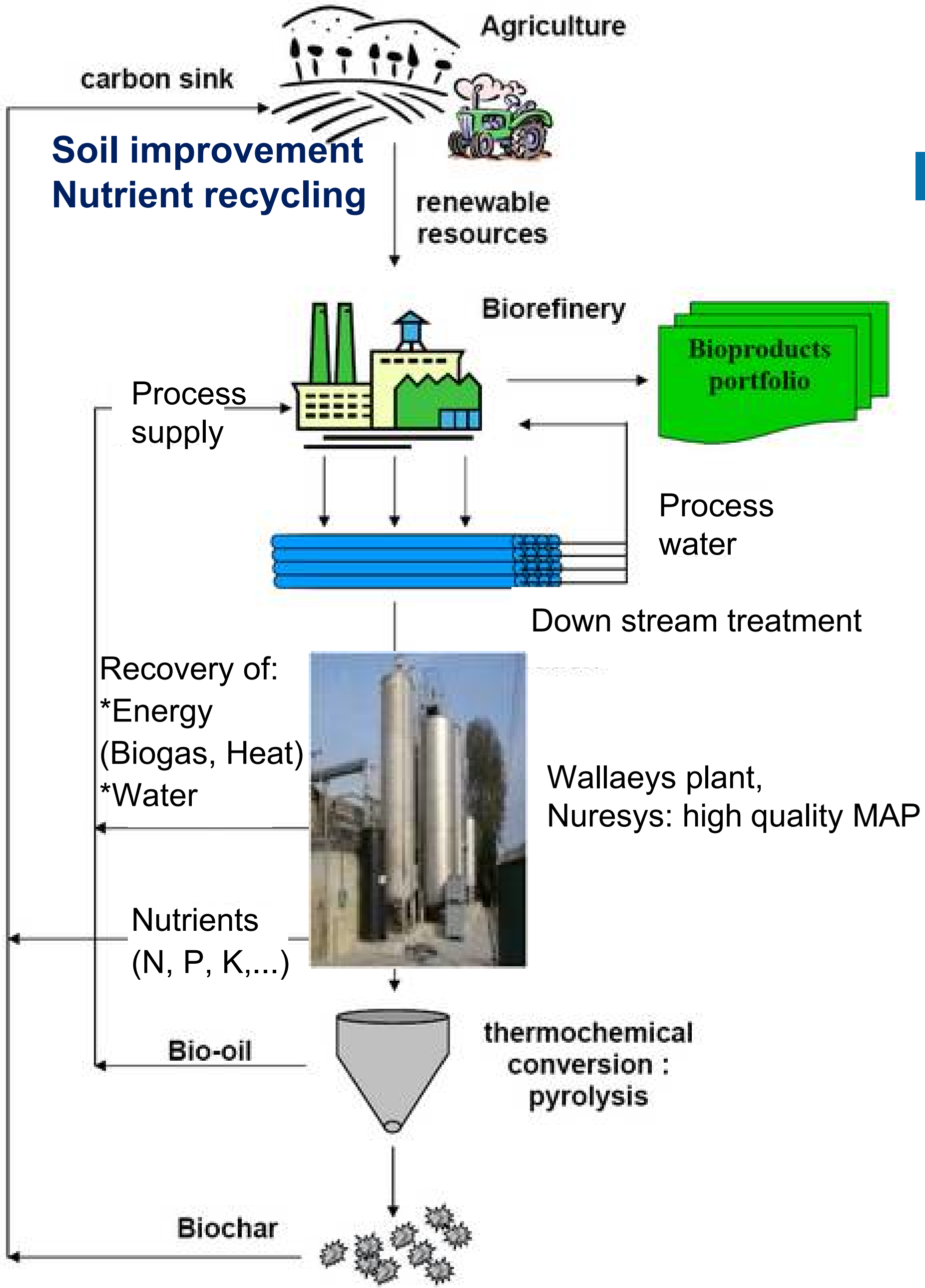
Plant biotechnology

Industrial biotechnology

Environmental biotechnology

Nutrient recycling
is essential

Thermochemical conversion



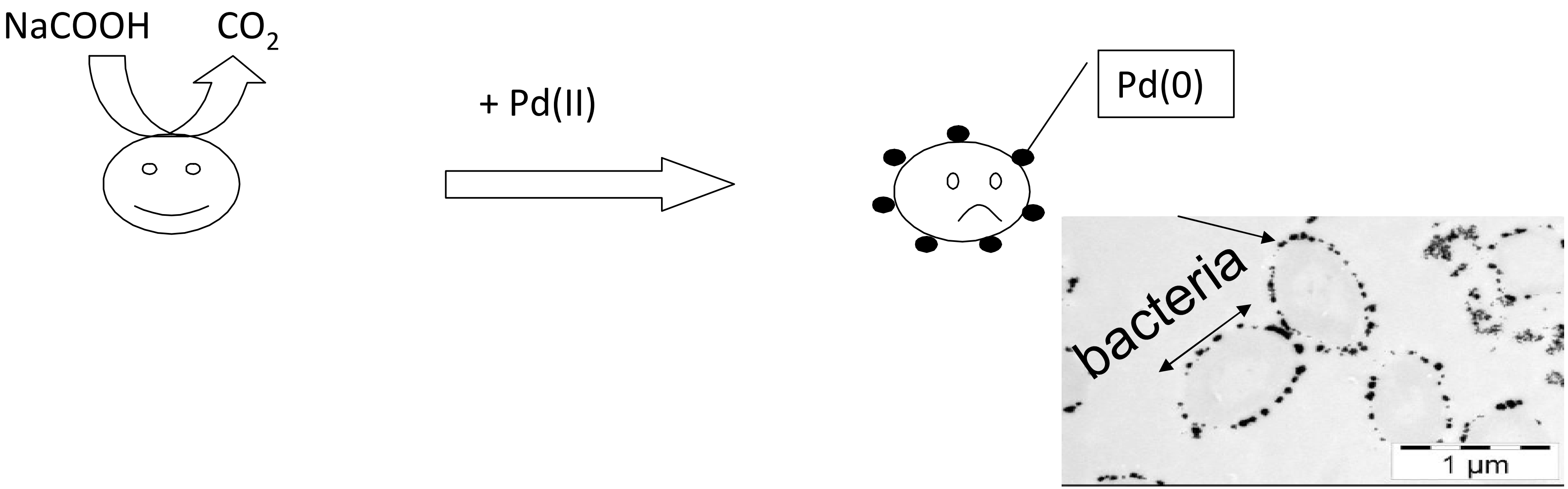
Conclusions Maverick 2: Biorefinery

- Sustainable provided adequate integration of
  - Anaerobic Digestion
  - Nutrient recovery
  - Maintenance of full "soil ecological services"

- Depends heavily on the "political foresight " , particularly in the context of climate change

Maverick 3: Nano Particles

Production of Pd nanoparticles by bacteria



- *Shewanella oneidensis* cells couple the reduction of soluble Pd(II) to the oxidation of an electrondonor
- Deposition of this biogenic Pd as nanoparticles on the cell wall and periplasmatic space

(De Windt et al., 2005; Environ Biotechnol, 90:377-389; LabMET)

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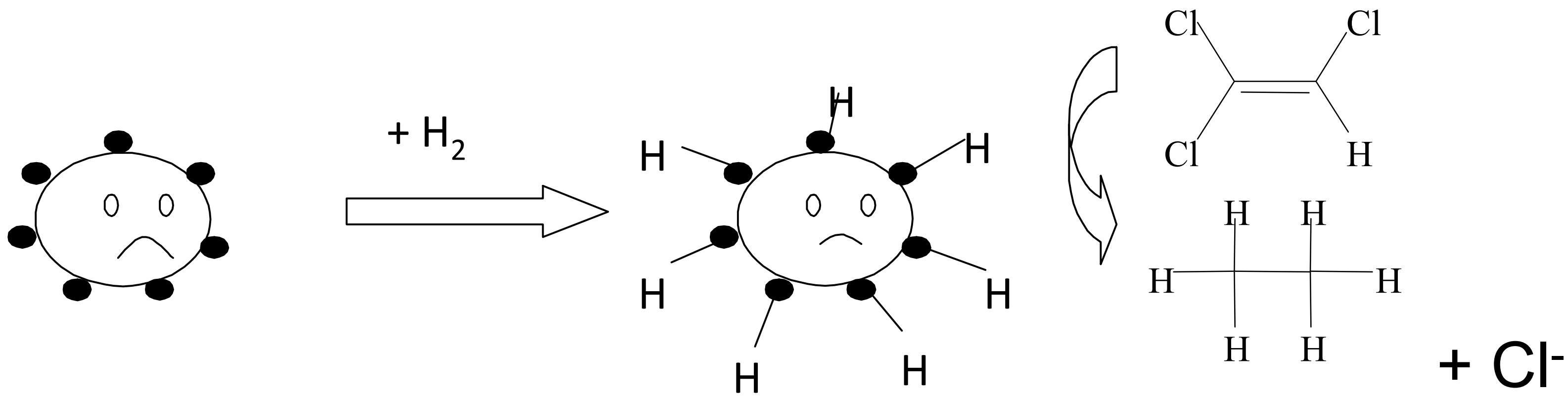
Application of BioPAD as catalyst

- Loading the bio-Pd with H_2/formate=> strong reductive capacities



- Applicable for chlorinated solvents, PCB's, micropollutants, pesticides (lindane), nitrate, perchlorate, Cr(VI) , even dioxines !!!

(Mertens et al., 2007; Chemosph, 66: 99-105; LabMET, Hennebel et al., 2009; Chemosph 76(9): 1221-1225; LabMET, Hennebel et al., 2010; Wat. Res.44(5): 1498-1506; LabMET Chidambaram et al., 2010, ES&T:44: 7635-7640; LabMET; Hennebel et al., 2009; Biotechnol and Bioeng,102: 995-1002; LabMET)

Take Home : Some potentialities for advanced Clean Tech with Nano Materials

RECAP :

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* THE CHALLENGES / THE HYPES

* THE MAVERICKS

→ SOIL REHABILITATION

→ THE BIOREFINERY

→ THE BIO(NANO)CATALYSTS/MATERIALS

→ **MICROBIAL UPGRADING**

→ **MICROBIAL PROTEIN**

Maverick 4: Microbial upgraders of the urban society

- Generic observation :The urban society is a fact !! Environmental Technology must focuss on the Urban Mining

- Two topics :

A. Rare earth metals

B. Domestic organic wastes /sewage/fecal matter

New Urban Metabolism

Most precious metals are already in our urban societies !

- Our cell phones , … contain these metals in concentrations ca 40 times higher than in the best natural ores

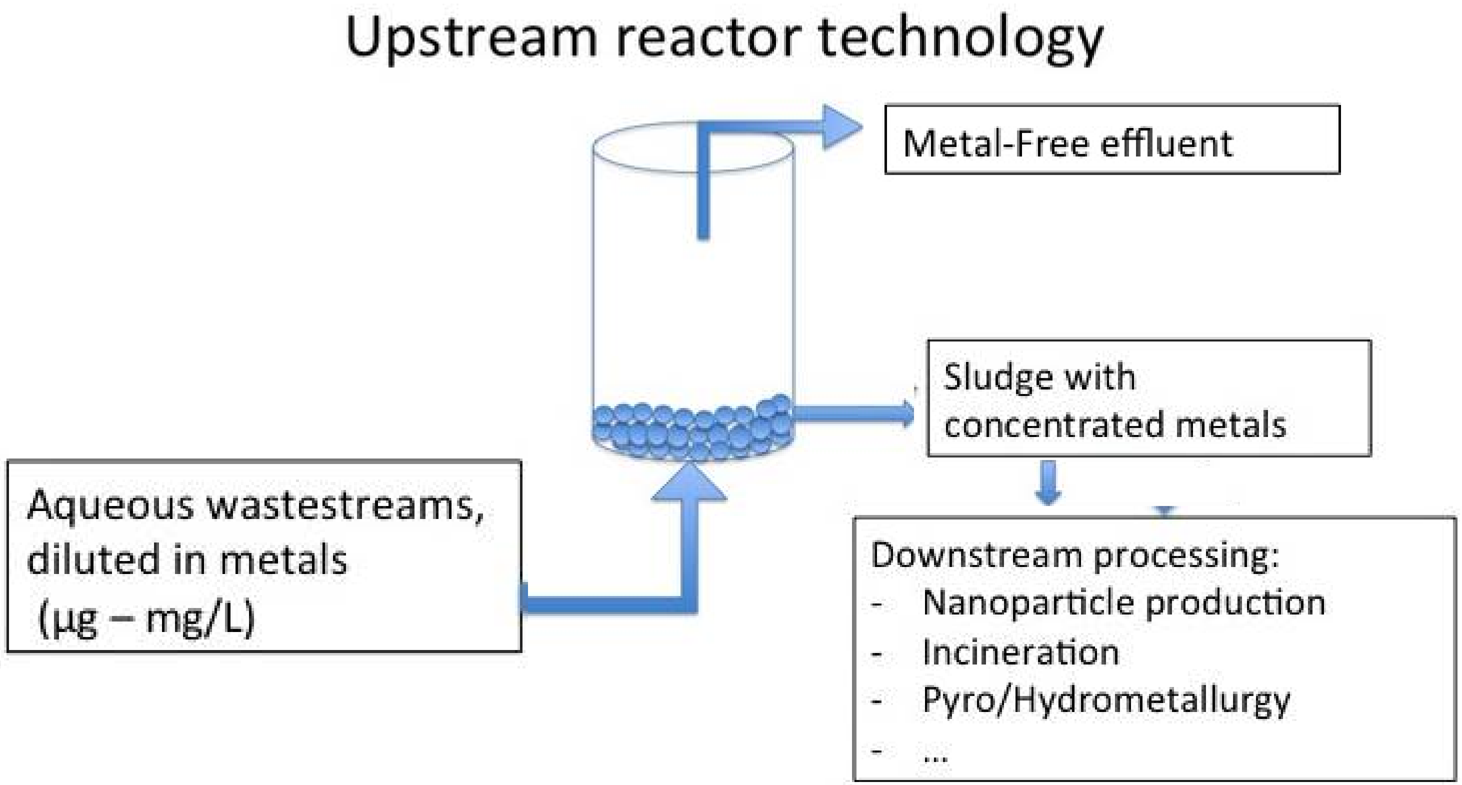
Take home:

- We must use our ‘secondary resources ‘ and recover these precious metals / rare earth elements
- Plenty of pyro- and bio-technological methods need to be developed in this context
- **Sewage sludge : processing via incineration must be complemented by harvesting the P , Fe ,Al and Rare Earths**

Maverick 4 : Microbes as upgraders

Metals /Rare Earths (Gadd 2010;Microbiology SGM 156:609-643)

*Granulated bacteria for upconcentration of metals, present at very low concentrations (µg – mg/L) in water streams:



New Urban Metabolism

<u>Food wastes are not properly re-used</u>

- Food consumes 15% of the US overall energy budget
- About 20% of food is wasted, i.e. 2-3% of the total energy budget *(Webber & Cuellar, 2010; EST; DOI 10:1021)*

<u>Take home:</u>

- Co-digestion can recover a major part of this energy
- Food and kitchen wastes can be the driver of a new type of wastewater treatment

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Maverick 4 : Microbial upgraders / the water cycle

Conventional activated sludge (CAS) design

- Capex + Opex: 17 - 40 EUR IE^{-1} $year^{-1}$
- Energy use: **20-35 kWh_{el} IE^{-1} $year^{-1}$**
- Energy recovery via sludge digestion is limited
  - ◊ Theor.: 30-40 kWh IE^{-1} $year^{-1}$
  - ◊ Pract.: 15-20 kWh IE^{-1} $year^{-1}$
- N, P, K → no recovery ; sludge ashes are mainly 'dumped'!!!!
- All organic C via biology + sludge incineration to CO_2
- Water → hardly re-used

Take home: The centralized wastewater treatment must be redesigned entirely!

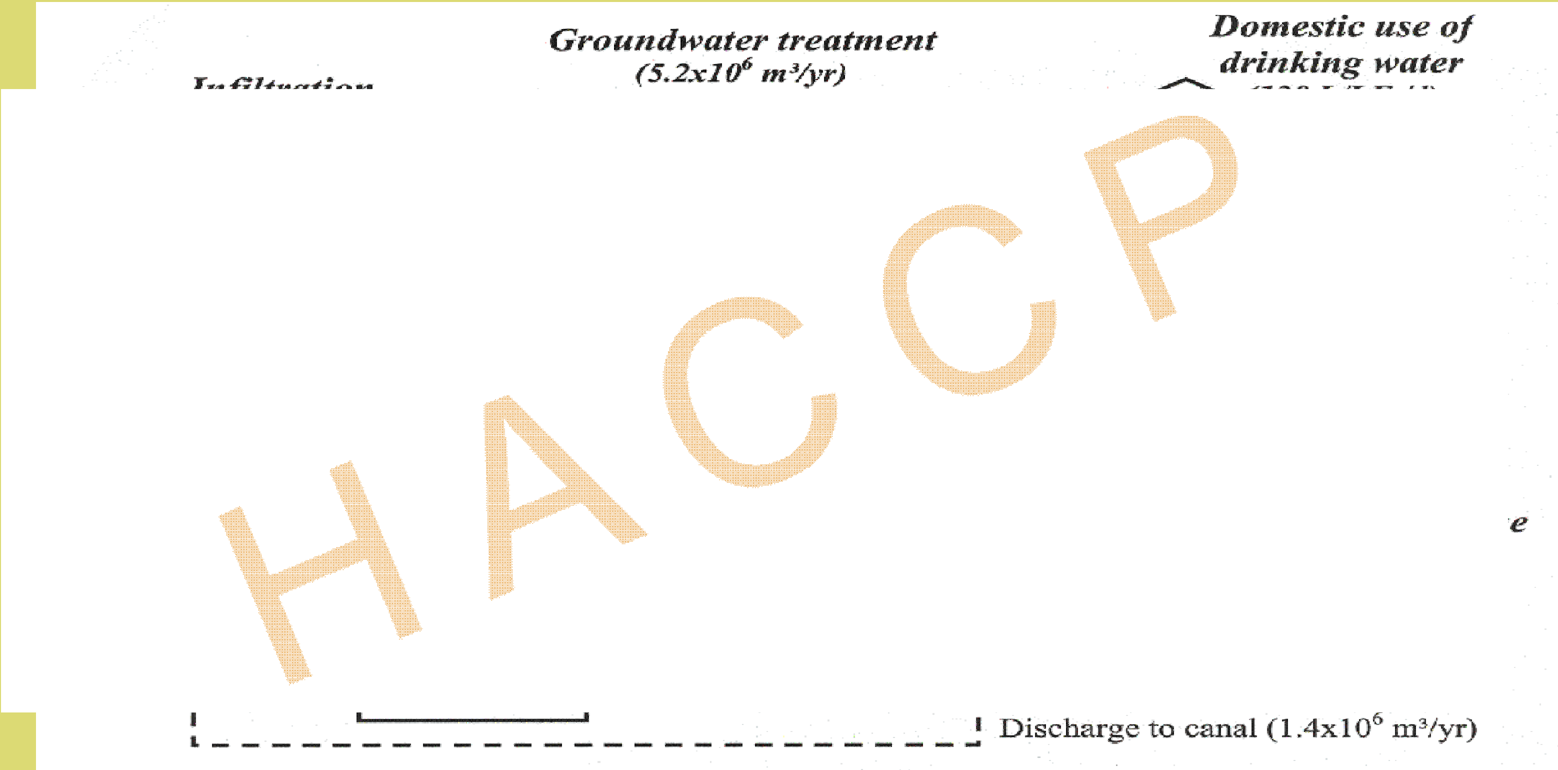
Sewage as a resource

Resources	Production IE^{-1} $year^{-1}$		Market price	Value (EUR IE^{-1} $year^{-1}$)	
	Sewage	Kitchen waste		Sewage	Sewage + Kitchen waste
Potable water	54 m^3		1.2 EUR m^{-3}	65.4	65.4
Heat recovered (5° cooling) • Electricity consumption • Heat recovered	 -179 kWh_{el} 496 kWh_{th}		 0.10 EUR kWh_{el}^{-1} 0.05 EUR kWh_{th}^{-1}	6.9	6.9
Anaerobic digestion • Electricity produced • Heat generated	 23 kWh_{el} 24 kWh_{th}	 16 kWh_{el} 17 kWh_{th}	 0.10 EUR kWh_{el}^{-1} 0.05 EUR kWh_{th}^{-1}	3.5	5.9
Biochar production	5.7 kg	3.9 kg	0.14 EUR kg^{-1}	0.8	1.3
Recovered nitrogen	2.4 kg	0.2 kg	1.15 EUR kg^{-1} N	2.7	2.9
Recovered phosphorus	0.82 kg	0.66 kg	1.35 EUR kg^{-1} P	1.1	2.0
			Overall	**80.4**	**84.5**

(Verstraete & Vlaeminck 2011, Int J. Sustainable Development and World Ecology 18: 253-264 ;LabMET)

Sewage as a resource of water

Case study: Koksijde, Belgium (IWVA)



(Dewettinck et al., 2001; Water Sci. Technol. 43: 31-38; LabMET)

Take home: This technology was upscaled in Singapore ➔ NEWater

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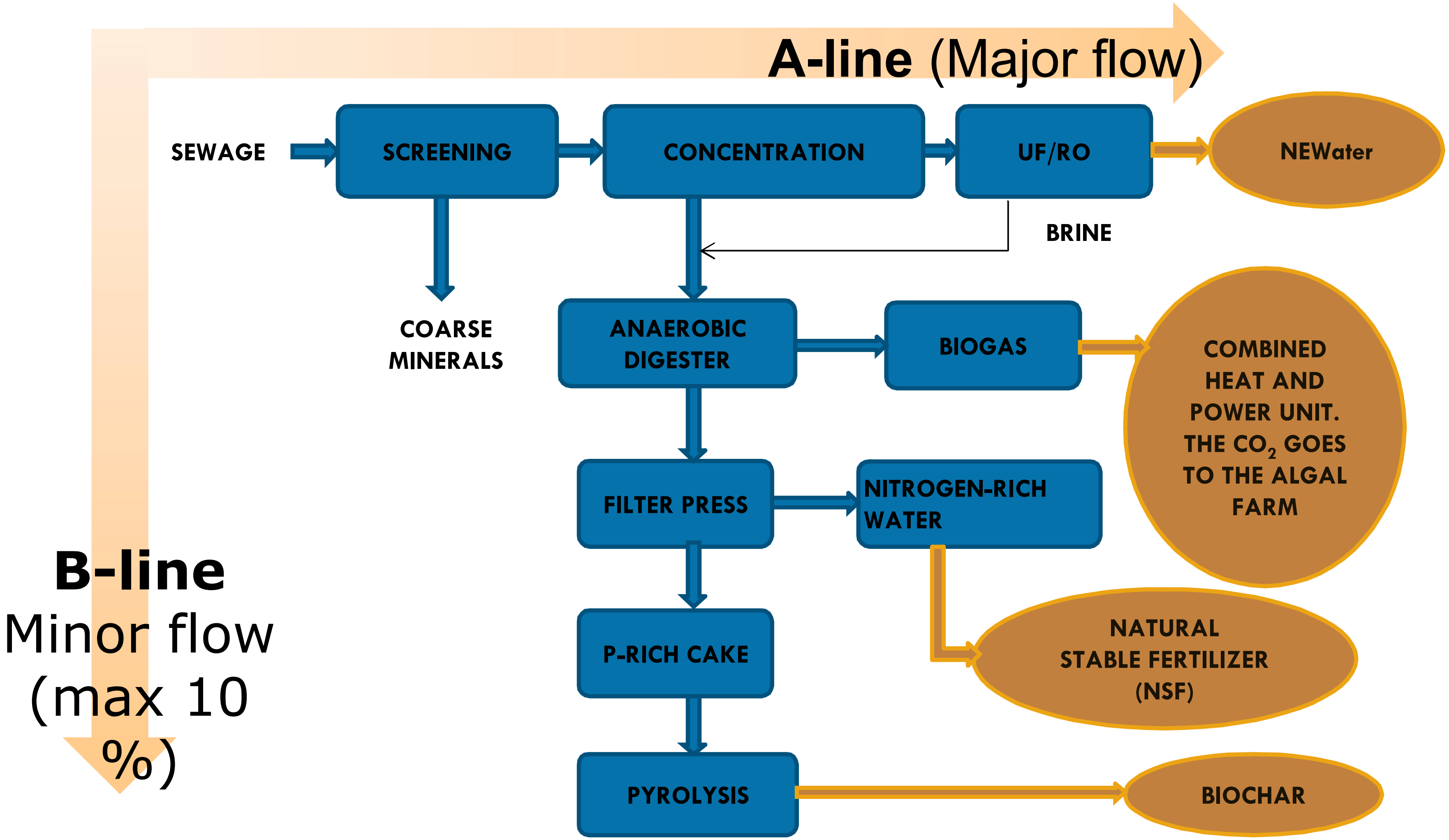
The "Zero Waste" Water Technology



(Verstraete et al. 2009; Bioresource Techn. 100, 5537-5545; LabMET)

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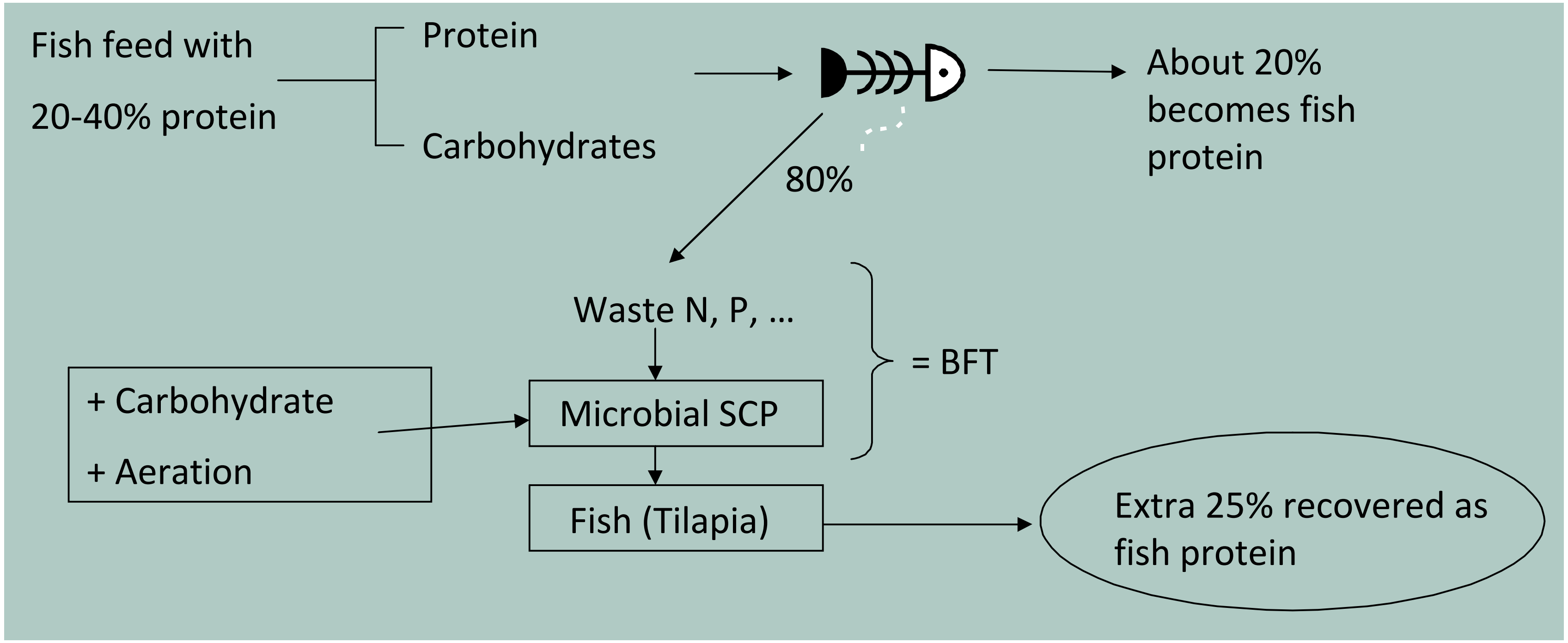
Fecal cycles in short loop can work

Production of SCP in intensive husbandry aquaculture

Direct recycling of fecal N as feed in aquaculture



(Crab et al., 2007; Aquaculture 270: 1-14; LabMET)

(De Schryver et al., 2008; Water Res. 42: 1–12; LabMET)

Valuable biomas polymers from wastes :

*Plenty of bacteria have ca 20% PHA on dry matter under anaerobic conditions ; Can be increased to 60% under micro-aerophilic conditions

(Salehizadeh & van Loosdrecht, 2004; Biotechnol. Adv. 22: 261-279)

*PHB :- Use to produce plastics (Veolia/Brussels)

- Use as a prebiotic for animal feeds

(Patent Ugent / LabMET)

(Defoirdt et al. 2007; FEMS Microbiol Ecol 60: 363-369; LabMET)

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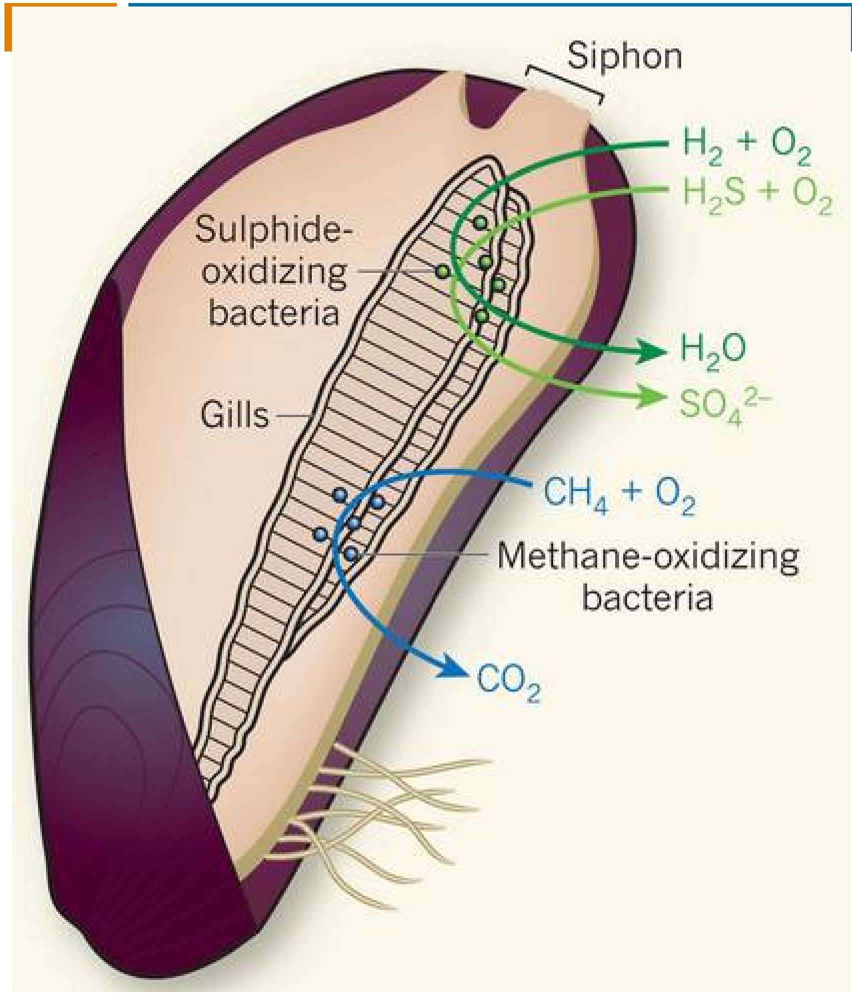
Microbial Protein :**Hydrogen for dinner**



(Petersen et al. 2011, Nature 476, 176-180)

Hydrogen + CO2
to higher forms
of food , eg to be used
in aquaculture

Note:
*The rumen of the cow thrives on microbial H_2

Microbial Protein :Chemo-autotrophs

- Convert CO2 to Organic carbon in the form of microbial cells :

Oxidize hydrogen

$H_2 + ½ O_2 \rightarrow H_20$

Energy

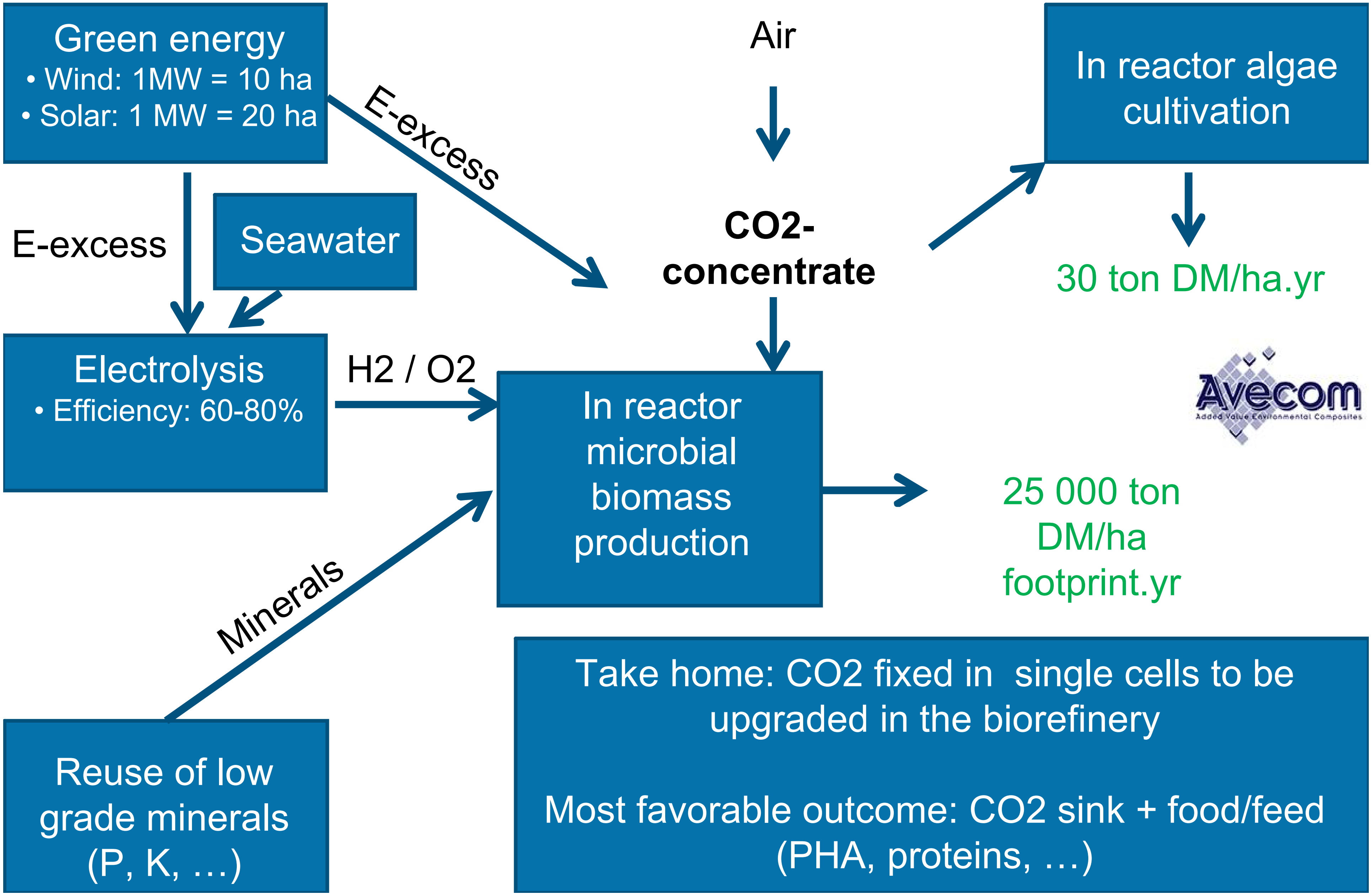
CO_2 ⟶ **Microbial products**

- Proteins (SCP)

- Oils ,Fats(PHB)

Take home: very short route to new food ; this route can be fitted to the urban society

Abatement of Climate Change – Biotech for carbon capture



Microbial Biomass for Cultured Meat

Microbial cells grown green and clean !!

↓

Lysate

↓

Muscle cell growth by *in vitro* tissue engineering

↓

Cultured meat

	Decrease relative to conventional meat
On energy use	Factor 2
On greenhouse gas emission	20
On water use	20
On land use	100 !

(Tuomisto and Texeira, 2011, Envir. Sci. Technol. 45:6117-6123)

Concluding remarks about Bioresources & Bioenergy

- **The "bio-maverick" technologies of the future probably will be:**
  - Based on improved soils & conventional cropping systems
  - Based on novel biocatalysts/materials
  - Based on clever urban mining
  - Based on direct coupling of novel variants of existing environmental processes with clever microbial biotech e.g. to make PHB, microbial protein , cultured meat, …

Concluding remarks about Env (Bio)Tech and Bio-Economy

The challenges :

*__Climate:__ We must really invest in CO_2 captation ; the rehabilitation of soils is the key

*__Sustainable environment / Cities of the future :__ We must fully invest in **urban mining** of all wastes in terms of energy, nutrients, rare metals , and water as such .

*__Resource recovery__ :We must not only activate the push but particularly the **pull side**

Concluding remarks about Bioresources & Bioenergy

The current <u>driver</u> for environmental technology and bio-economy is not

- **Fear for fossil fuel shortage**

BUT rather

- **Forsight to abate climate change , to recycle limitting resources and to thus assure a sustainable planet**