Biofuels and bioenergy from organic solid waste

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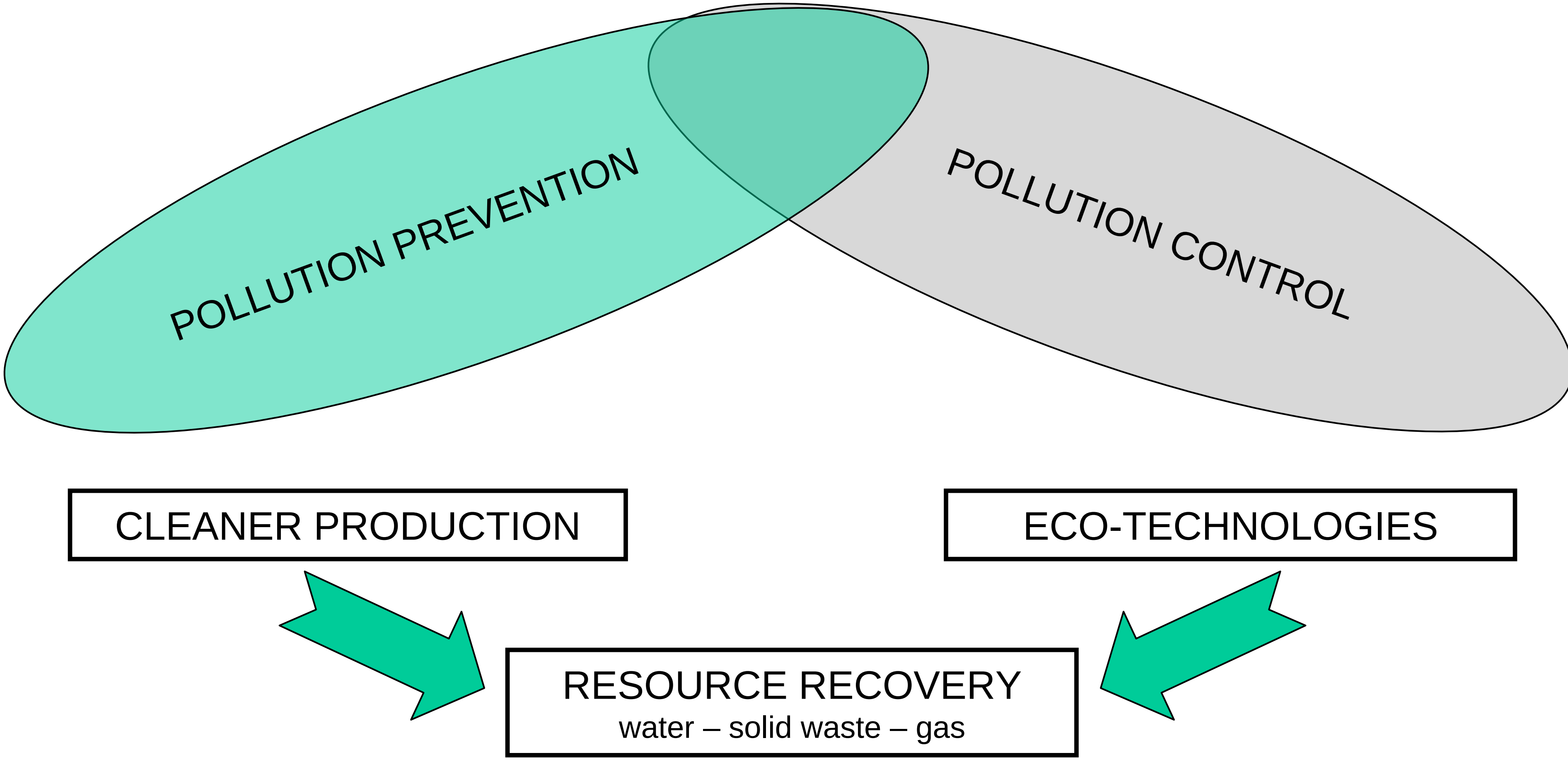
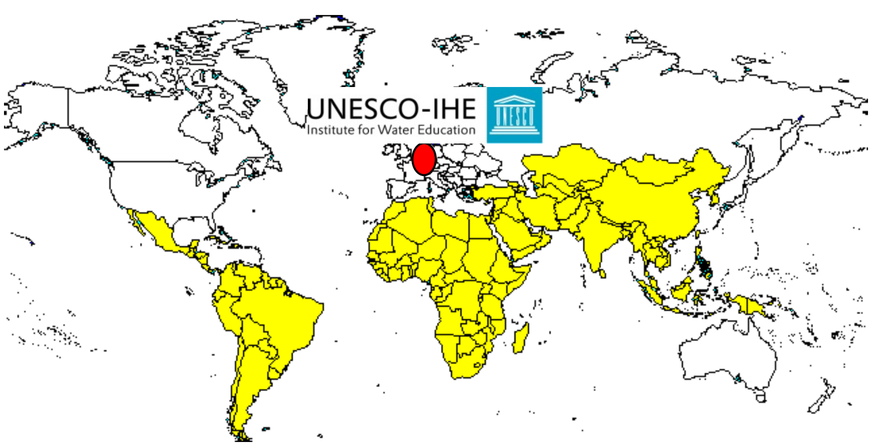
UNESCO-IHE





Key topics:
- nutrient cycle, removal of micropollutants, disinfection
- constructed wetlands, waste stabilization ponds, photobioreactors
- source separation, solid waste management
- …

Pollution Prevention and Control

Cleaner Production

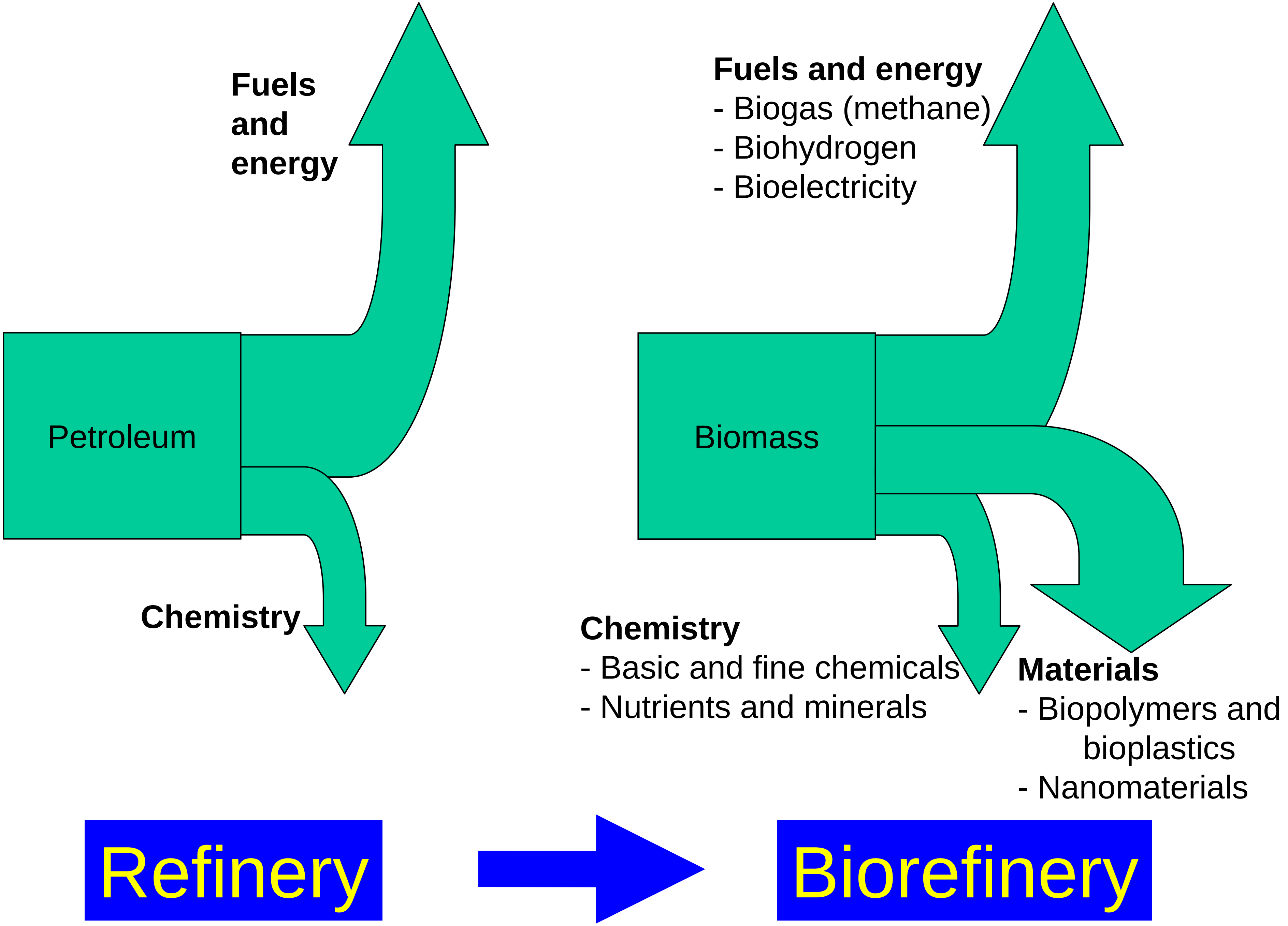
- Green chemistry
- Integrated wastewater and solid waste management
- Biorefinery concepts

Eco-technologies

- Natural treatment systems (Wetlands, ponds, …)
- Anaerobic digestion
- Photobioreactors
- Phytobioremediation
- Ecological engineering

Resource recovery

- Reuse of water
- Biorecovery of nutrients, minerals and metals
- Bioenergy (H_2, CH_4, electricity)
- Nanomaterials and chemicals

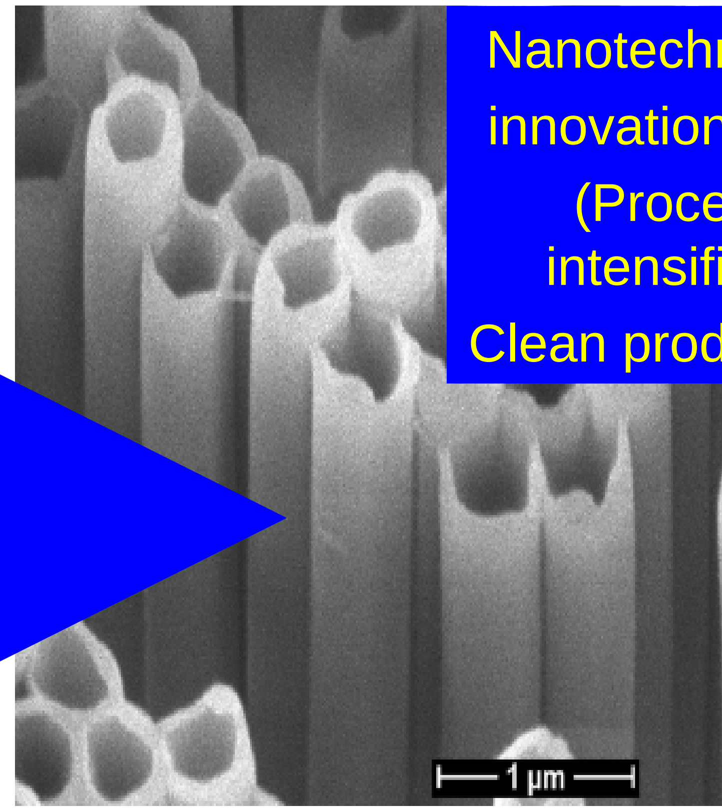

Fuels and energy
Petroleum
Chemistry
Fuels and energy
- Biogas (methane)
- Biohydrogen
- Bioelectricity
Biomass
Chemistry
- Basic and fine chemicals
- Nutrients and minerals
Materials
- Biopolymers and bioplastics
- Nanomaterials
Refinery
Biorefinery

Mining

Biomining

Metals
Metalloids
Rare Earth elements

Sustainable development/ Need for paradigm shifts



Biogenic synthesis of nanomaterials

Create options for new technologies

(Cleaner Production)

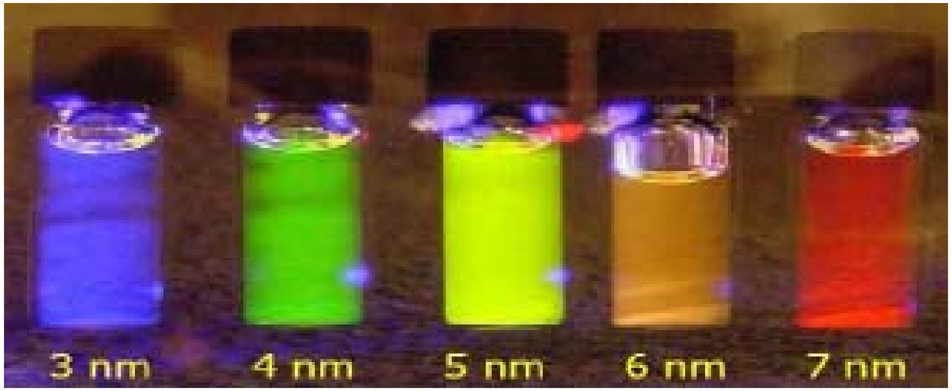
- Green production processes synthesis nanoparticles
- Process intensification

Resource recovery

(Concentrated) waste streams

Emerging Opportunities

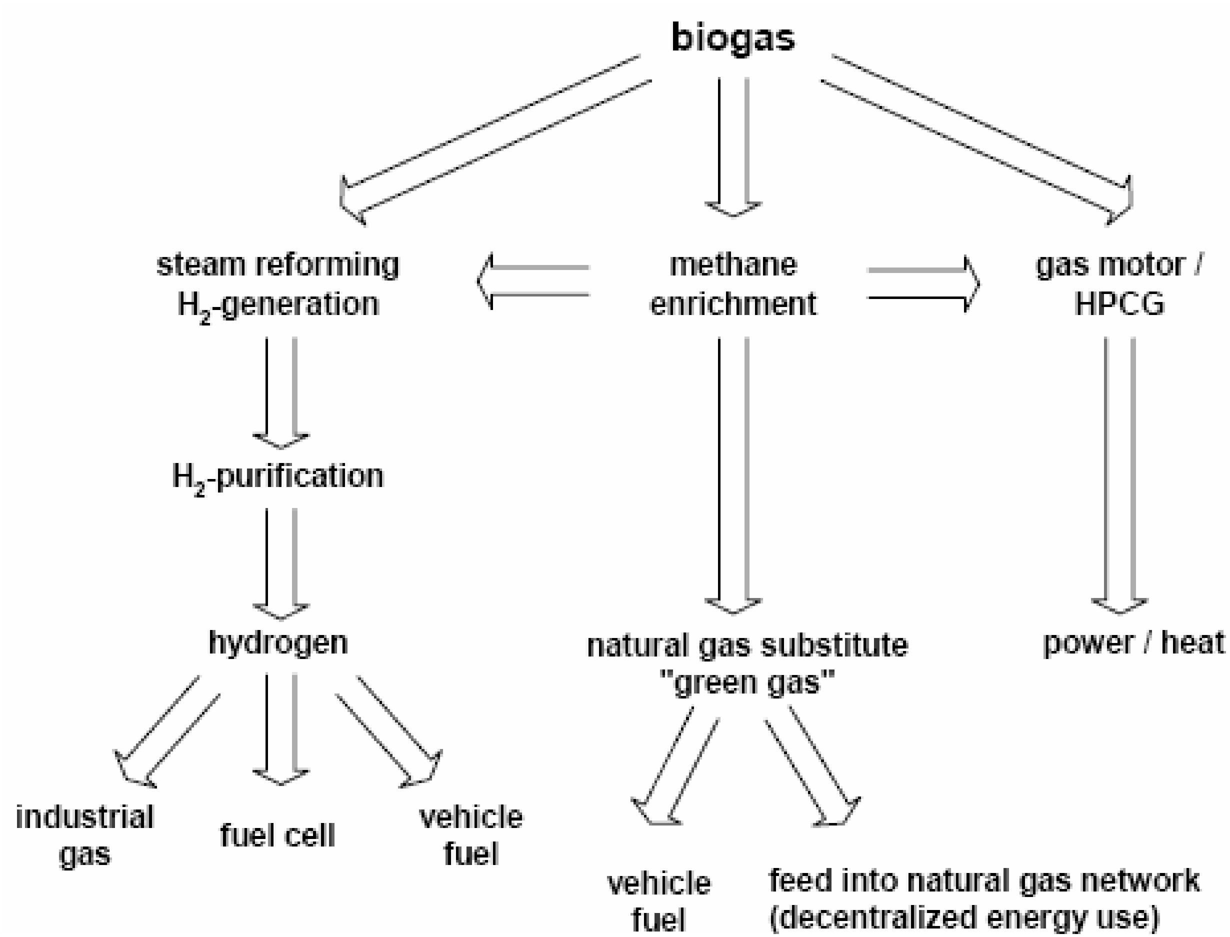
- Sorption pollutants
- Sensors



Contents

- **Biofuel production**
- The biogas fuel cell chain
- Partial gasification (CO – Biochar)

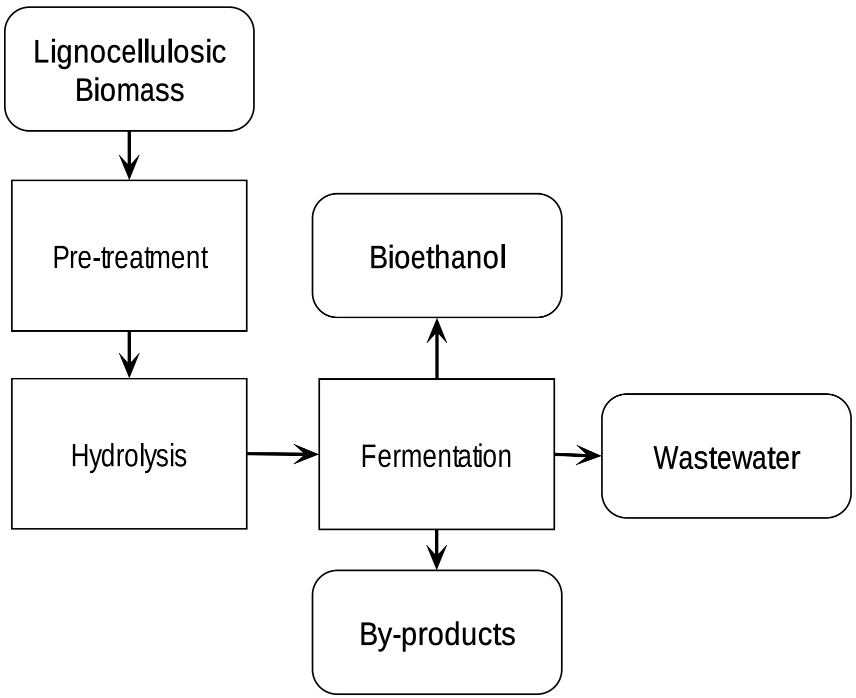
Utilisation of biogas



Biogas plant of FAL
Braunschweig, Germany

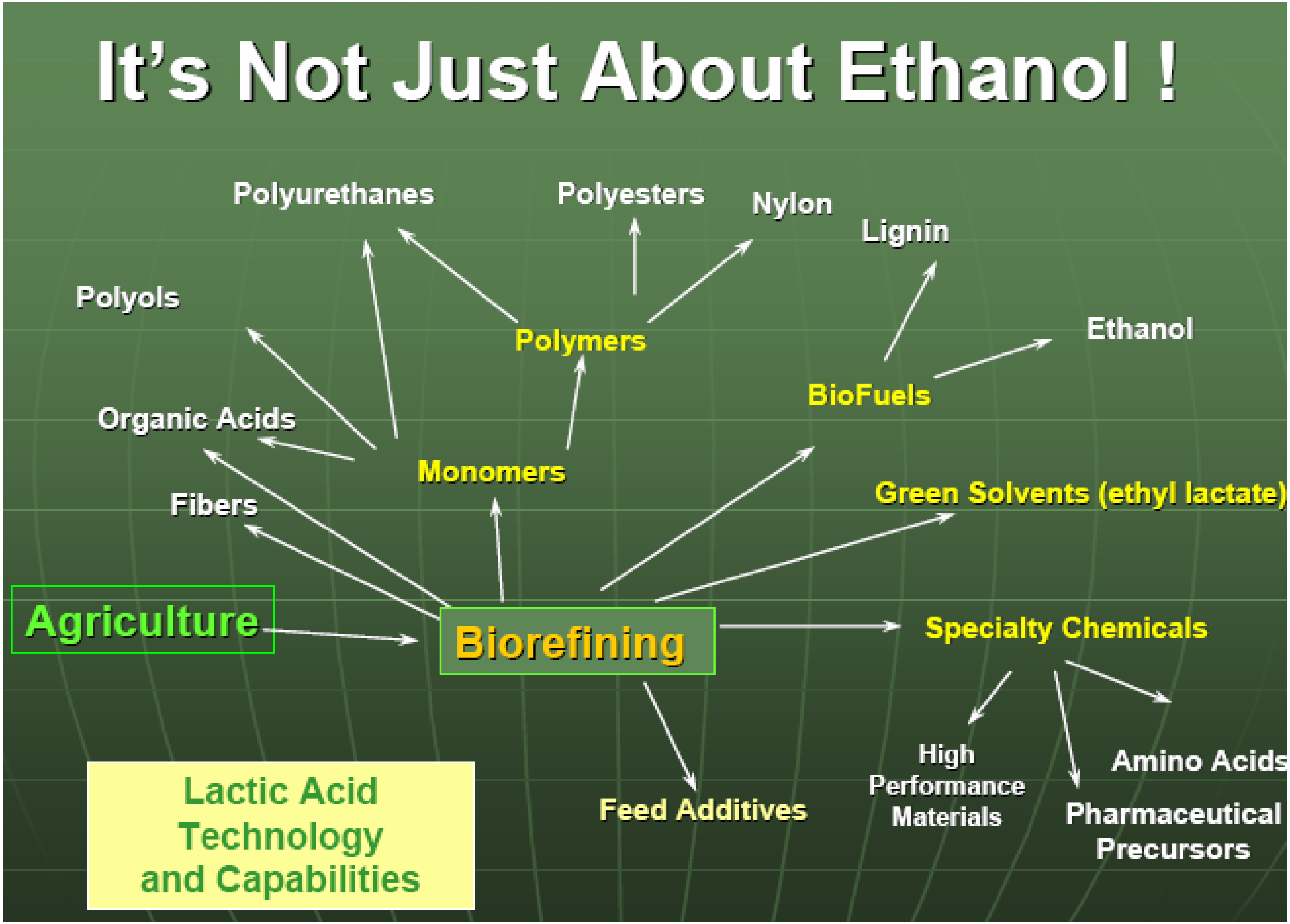
Bioethanol

General outline of lignocellulose-based bioethanol production

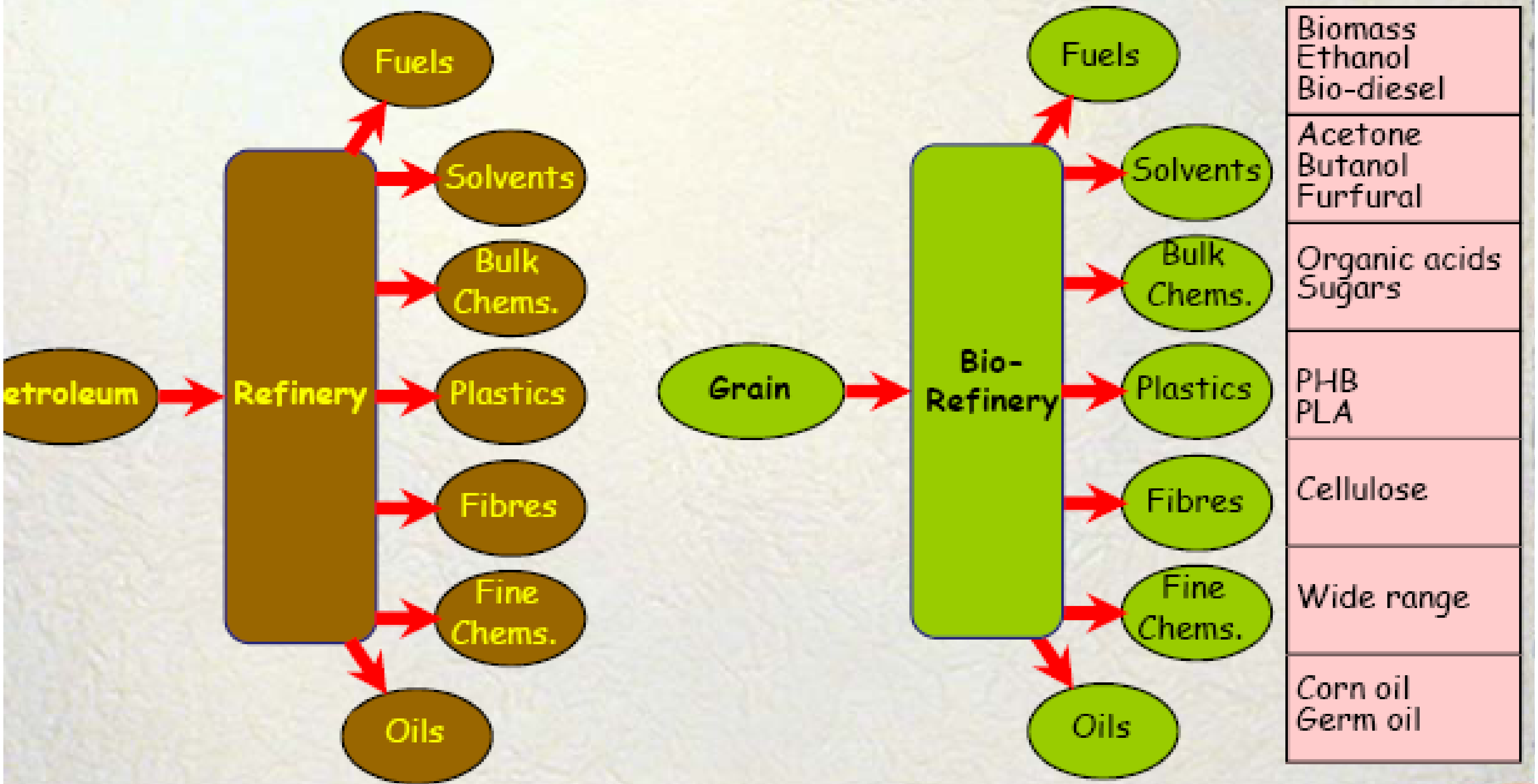


Lignocellulosic biomass material used for bioethanol production

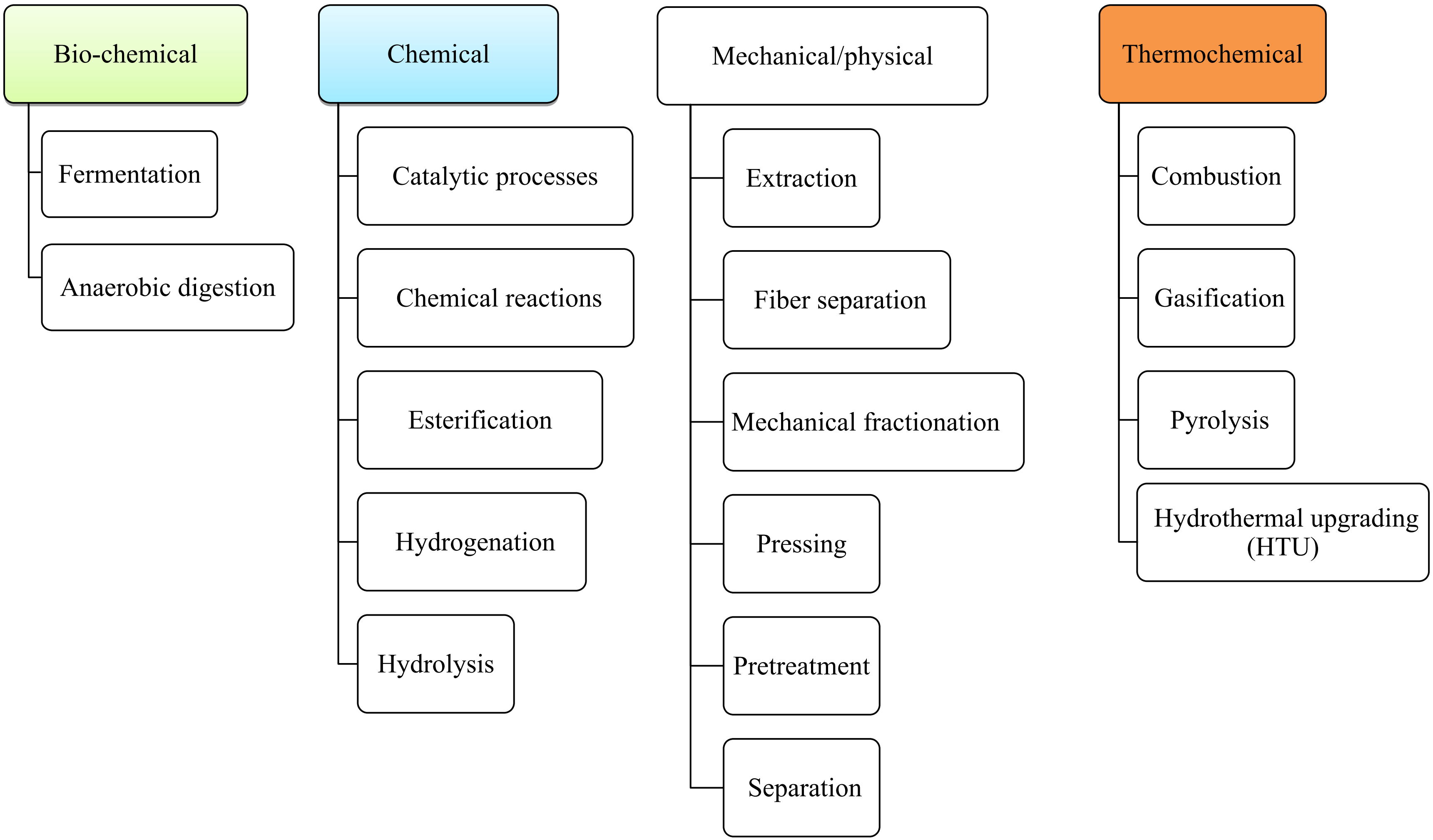
Primary crop or product	**Biomass residue**
Corn	Corn stover, cob, etc.
Sugarcane	Bagasse, barbojo[a]
Grain (wheat, barley etc.)	Straw
Rice	Rice straw, hulls, etc.
Green Coffee	Husks (wet or dry)
Softwood (spruce, pine, etc.)	-
Hardwood (willow, aspen, etc.)	-
Energy Crops (switch grass etc.)	-

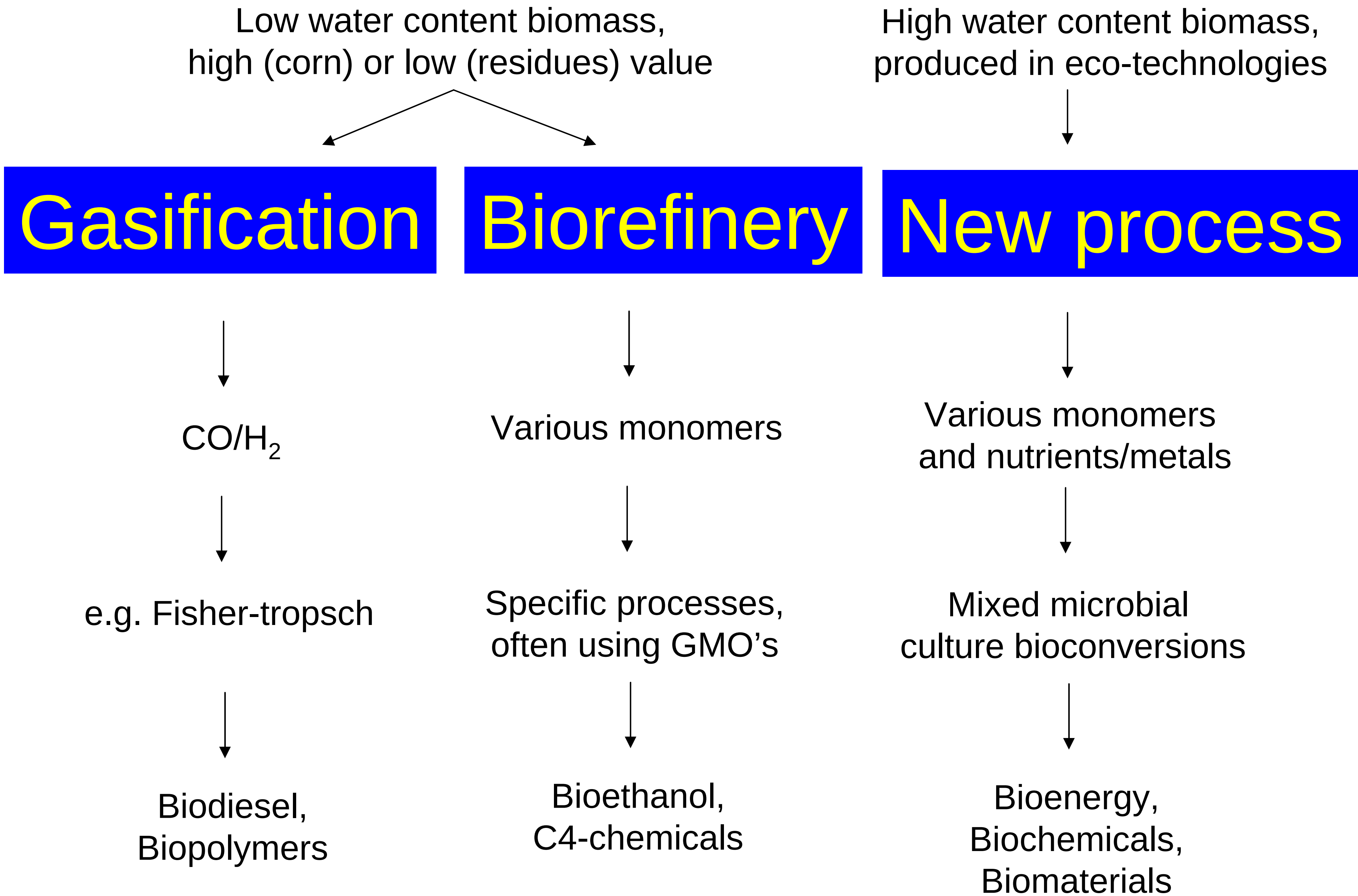

It's Not Just About Ethanol !
Polyurethanes
Polyesters
Nylon
Lignin
Polyols
Polymers
Ethanol
BioFuels
Organic Acids
Monomers
Fibers
Green Solvents (ethyl lactate)
Agriculture
Biorefining
Specialty Chemicals
High Performance Materials
Amino Acids
Lactic Acid Technology and Capabilities
Feed Additives
Pharmaceutical Precursors

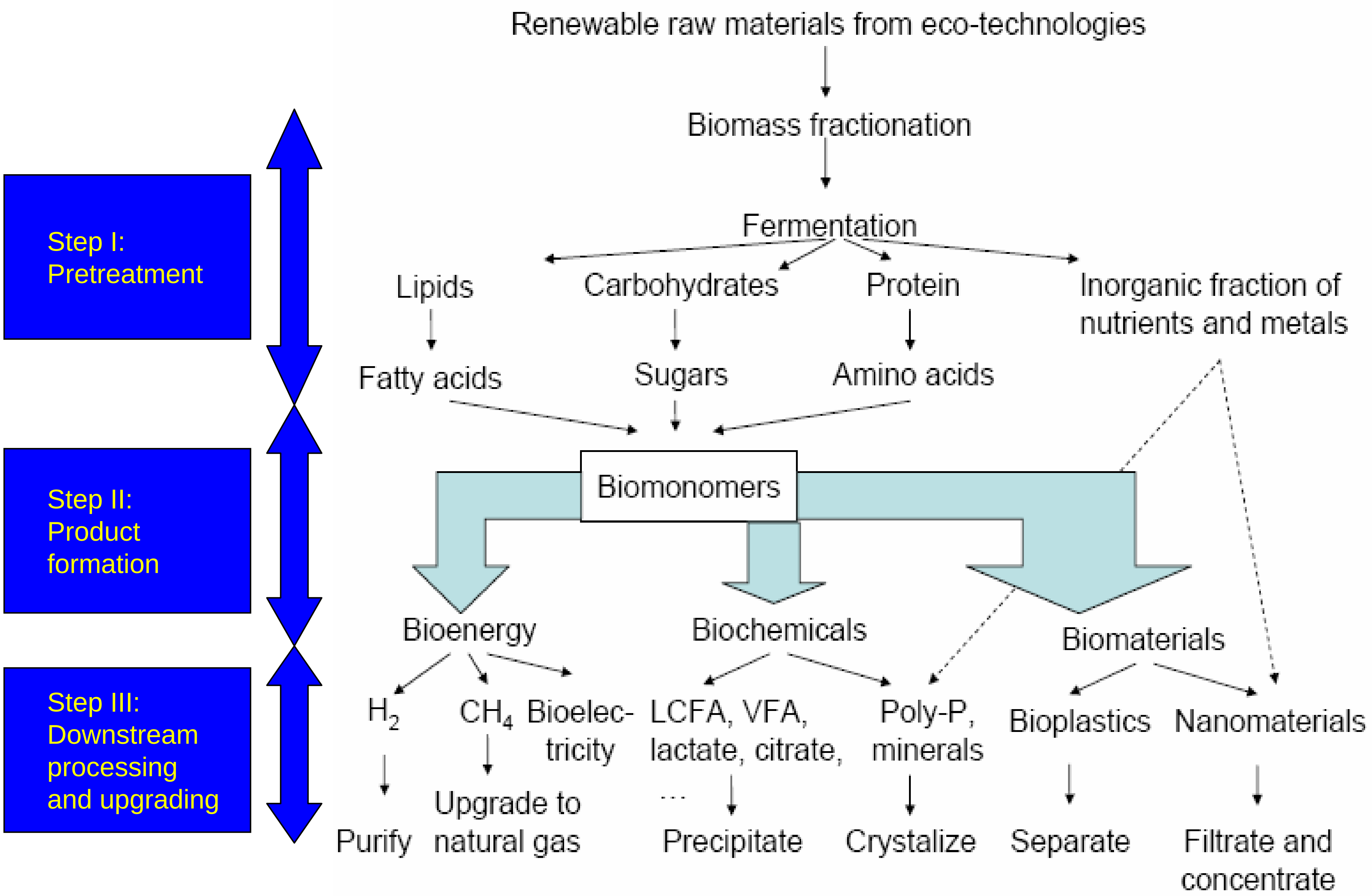
Most types of chemical produced from petroleum can be produced from cereals



Many of these can be produced through bioprocessing (fermentation) of the grain.


Bio-chemical
Fermentation
Anaerobic digestion
Chemical
Catalytic processes
Chemical reactions
Esterification
Hydrogenation
Hydrolysis
Mechanical/physical
Extraction
Fiber separation
Mechanical fractionation
Pressing
Pretreatment
Separation
Thermochemical
Combustion
Gasification
Pyrolysis
Hydrothermal upgrading (HTU)


Low water content biomass,
high (corn) or low (residues) value
High water content biomass,
produced in eco-technologies
Gasification
Biorefinery
New process
CO/H_2
Various monomers
Various monomers
and nutrients/metals
e.g. Fisher-tropsch
Specific processes,
often using GMO's
Mixed microbial
culture bioconversions
Biodiesel,
Biopolymers
Bioethanol,
C4-chemicals
Bioenergy,
Biochemicals,
Biomaterials


Step I:
Pretreatment
Step II:
Product
formation
Step III:
Downstream
processing
and upgrading
Renewable raw materials from eco-technologies
Biomass fractionation
Fermentation
Lipids
Carbohydrates
Protein
Inorganic fraction of
nutrients and metals
Fatty acids
Sugars
Amino acids
Biomonomers
Bioenergy
Biochemicals
Biomaterials
H_2
CH_4
Bioelec-
tricity
LCFA, VFA,
lactate, citrate,
...
Poly-P,
minerals
Bioplastics
Nanomaterials
Purify
Upgrade to
natural gas
Precipitate
Crystalize
Separate
Filtrate and
concentrate

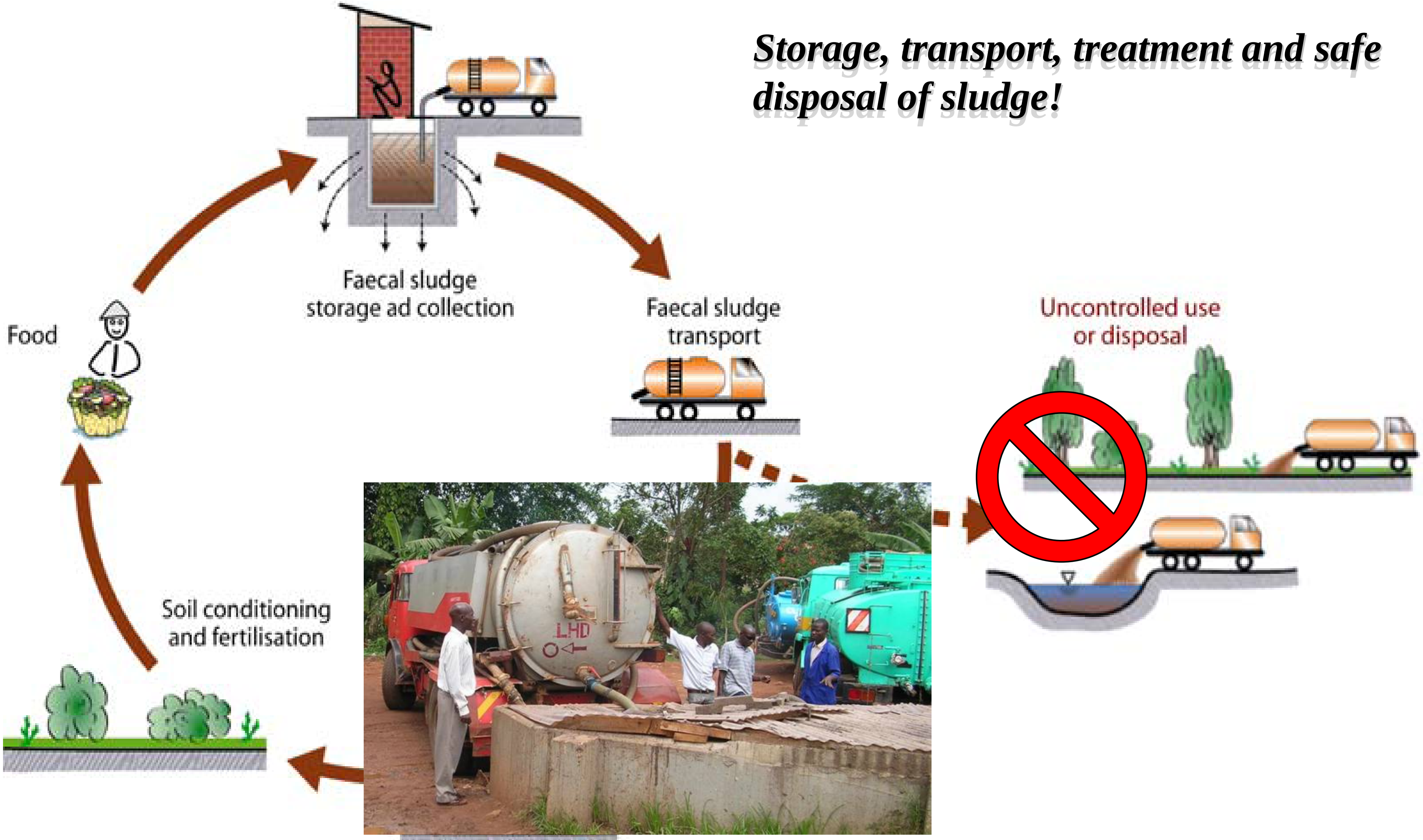
Contents

- The biogas fuel cell chain
- **Partial gasification (CO – Biochar)**
- Biofuel production

Existing situation in Bwaise III – Kampala, Uganda (Alex Katikuzi)

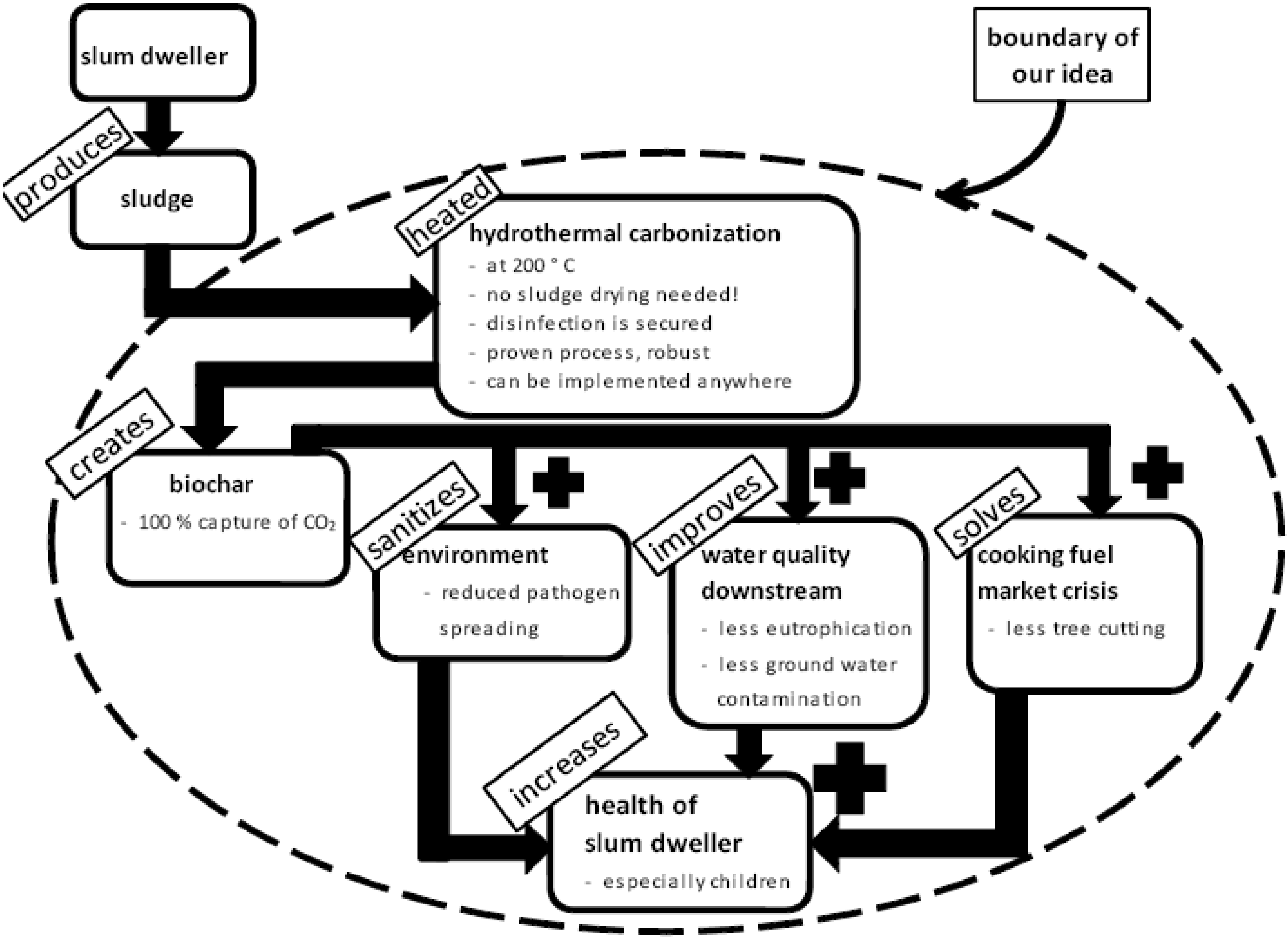
Challenge in Feacal sludge management

Storage, transport, treatment and safe disposal of sludge!



Existing Ecosan toilets in peri-urban Kampala

Katukiza et al. 2010 *Science of The Total Environment* **409(1)**, 52-62.


slum dweller
produces
sludge
boundary of our idea
heated
hydrothermal carbonization
- at 200 ° C
- no sludge drying needed!
- disinfection is secured
- proven process, robust
- can be implemented anywhere
creates
biochar
- 100 % capture of CO2
sanitizes
environment
- reduced pathogen spreading
improves
water quality downstream
- less eutrophication
- less ground water contamination
solves
cooking fuel market crisis
- less tree cutting
increases
health of slum dweller
- especially children

Production of syngas

from cokes:

$$C_{(s)} + H_20 \rightarrow CO + H_2$$

from natural gas:

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

Introduction

Purification of synthesis gas currently performed in chemical catalytic shift converters

$$\mathbf{CO + H_2O \rightarrow CO_2 + H_2} \qquad (\Delta G^{0\prime} = -20\ \mathrm{kJ/mol})$$

Disadvantages: high T, high P, sensitive for H_2S

and relative high exit CO concentration

Introduction

Therefore interest in a biological alternative:

- Phototrophic organisms convert CO to H_2
- Thermophilic CO converting bacteria (Hydrogenogens)

Key enzymes: CODH and hydrogenases widespread in nature

Biological CO conversion

Biological water-gas shift reaction

- Photosynthetic bacteria:
  - *Rhodobacter* sp.
  - *Rhodopseudomonas gelatinosa*
  - *Rhodospirillum rubrum*
- Methanogens:
  - *Methanosarcina barkeri*
- Chemoheterotroph:
  - *Citrobacter* sp.
- Carboxydotrophic (chemoautotroph)
  - *Carboxydothermus hydrogenoformans*
  - *Carboxydobrachium pacificum*

CO conversion pathways

$$\mathbf{CO + H_2O \rightarrow H_2 + CO_2}$$

$$CO + 3\ H_2 \rightarrow CH_4 + H_2O$$

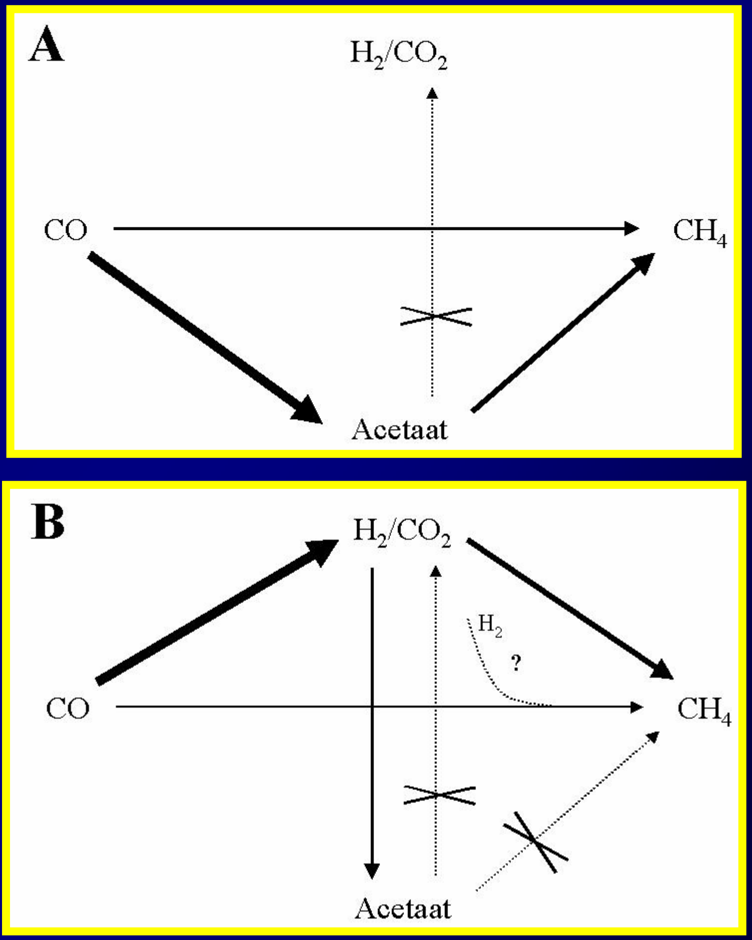
$$4\ CO + 2\ H_2O \rightarrow CH_4 + 3\ CO_2$$

$$4\ CO + 2\ H_2O \rightarrow CH_3COOH + 2\ CO_2$$

CO conversion by anaerobic granular sludge

30° C

55° C



At 55°C

H_2 production

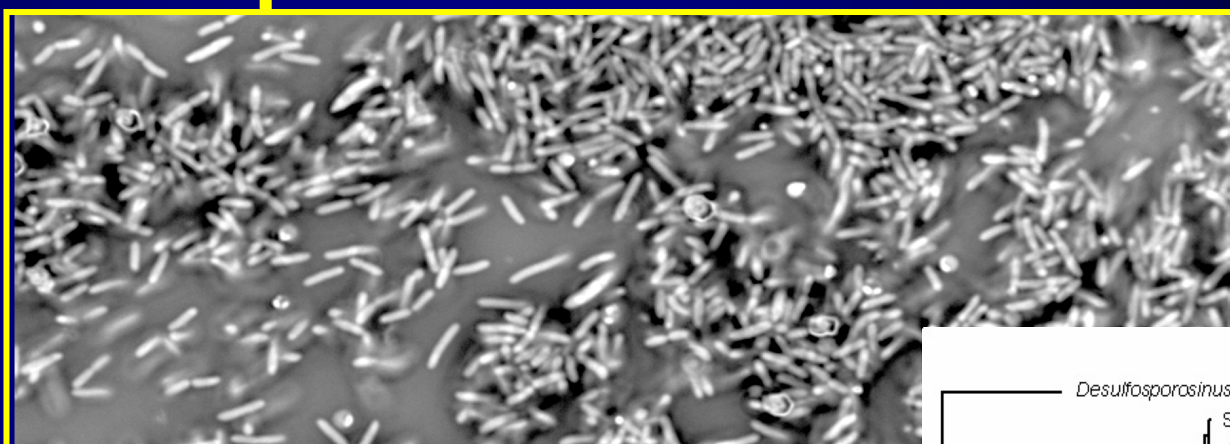
Sipma et al., 2003, FEMS Microbiol. Ecol. 44, 271-277

Specific CO converting microorganism

International Journal of Systematic and Evolutionary Microbiology (2005), 55, 2159–2165

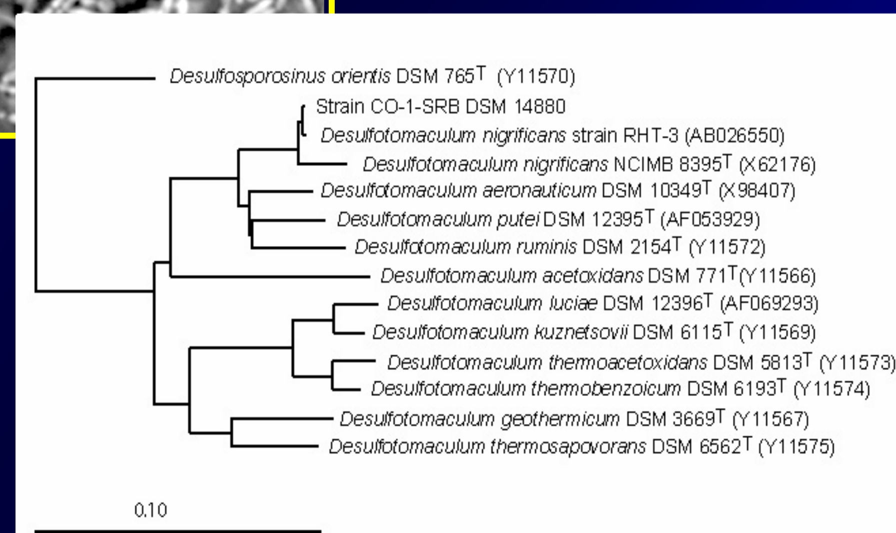
CO_2 & H_2

Desulfotomaculum carboxydivorans



55°C

CO & H_2O



Contents

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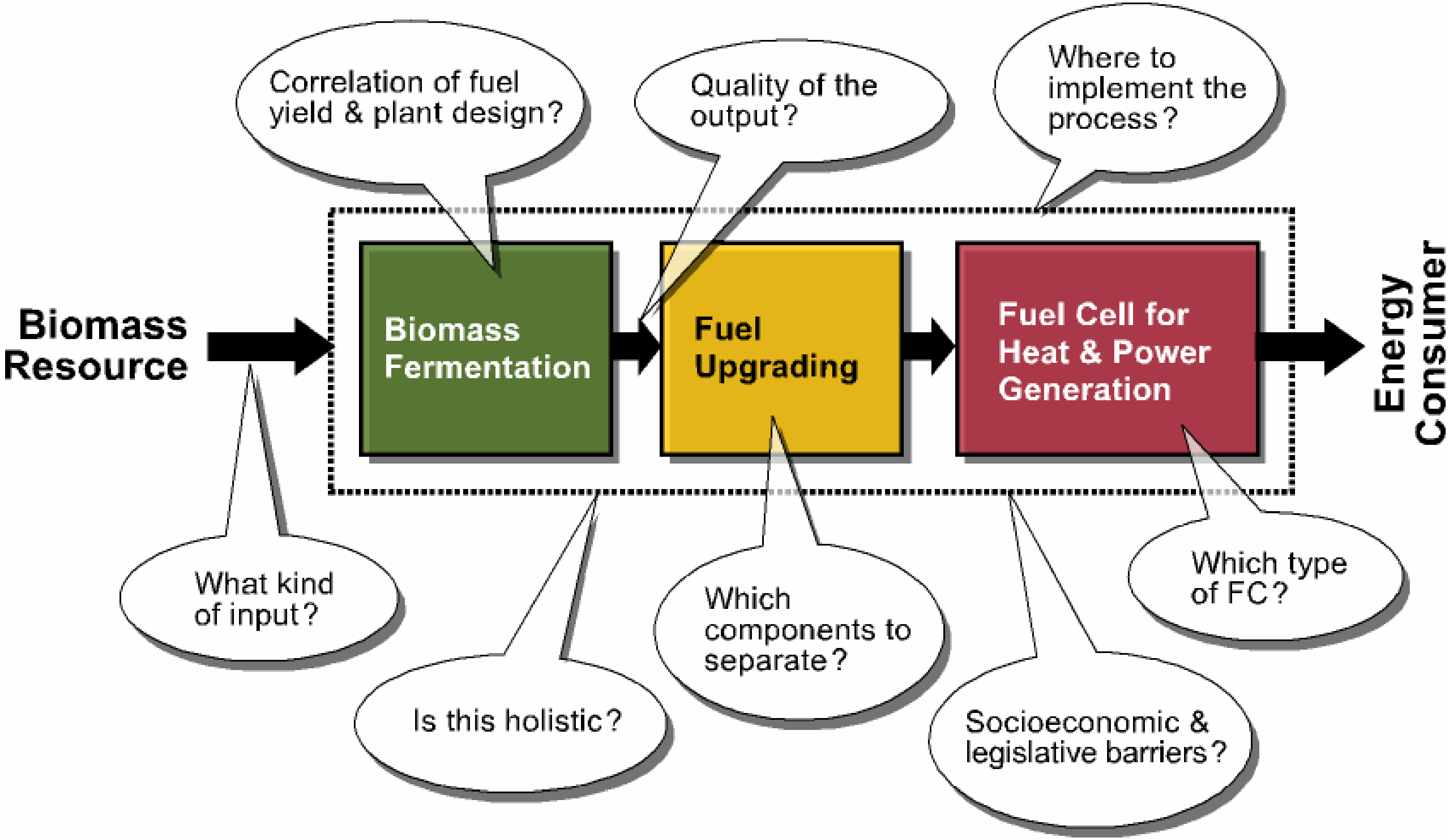
- Partial gasification (CO – Biochar)
- **The biogas fuel cell chain**

The biogas-fuel cell chain

A holistic appraoch



Fuel cell overview

Why high temperature fuel cells ?

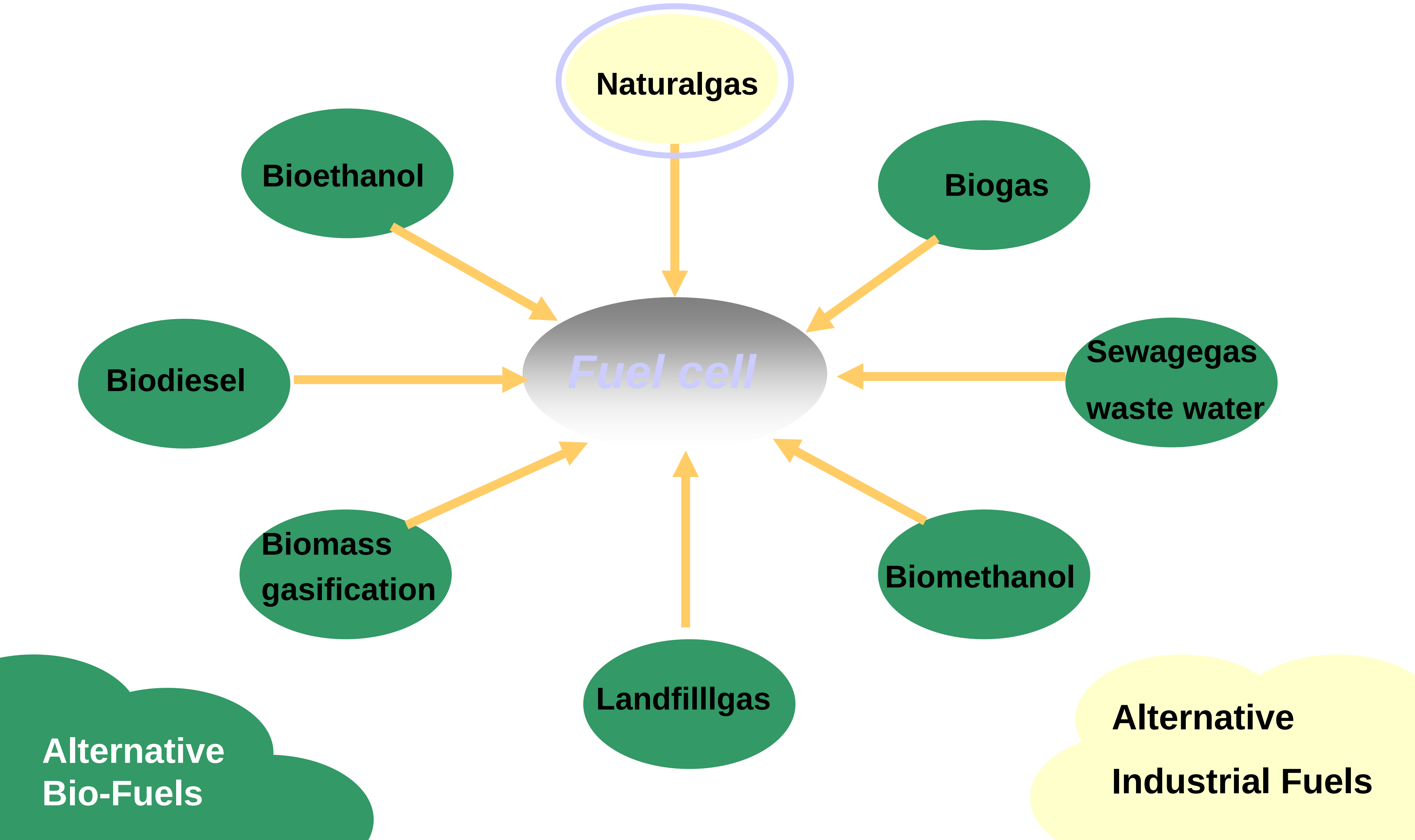
Low Temperature FC ← → High temperature FC

FC-Typ	**PEFC**	**AFC**	**PAFC**	**MCFC**	**ITSOFC**	**SOFC**
Gas comp. **Temp.°C**	80	100	200	650	800	1000
H_2	F	F	F	F	F	F
CH_4, CnHm	IG	poison	IG	IG/F	F	F
CO_2	IG	poison	IG	React.	IG	IG
CO	poison (<50ppm)	poison	poison (<500ppm)	F	F	F
H_2S, COS	nd	poison	poison (<50ppm)	poison (<0.5ppm)	poison	poison (<1.0ppm)
NH_3	poison	F	poison	F	F	F

Analysis on siloxanes, halides, tar, dust, and other contaminants are missing!!!

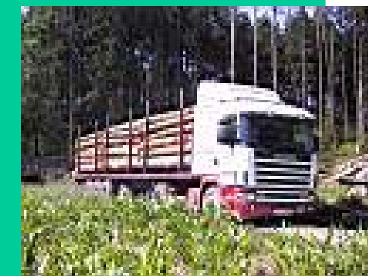
F.....Fuel, IG…. Inert gas, React. .... Takes part in electrode reaction

Fuel Flexibility



Variety of different Fuels within the EU

Landfill Gas



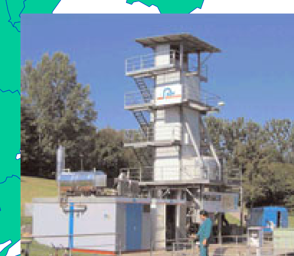
Gasification of Wood and Cardboard

Biodiesel and Bioglycerin

Regional distribution of Biogas Facilities Profiles

Biogas from Solidfermatation Process

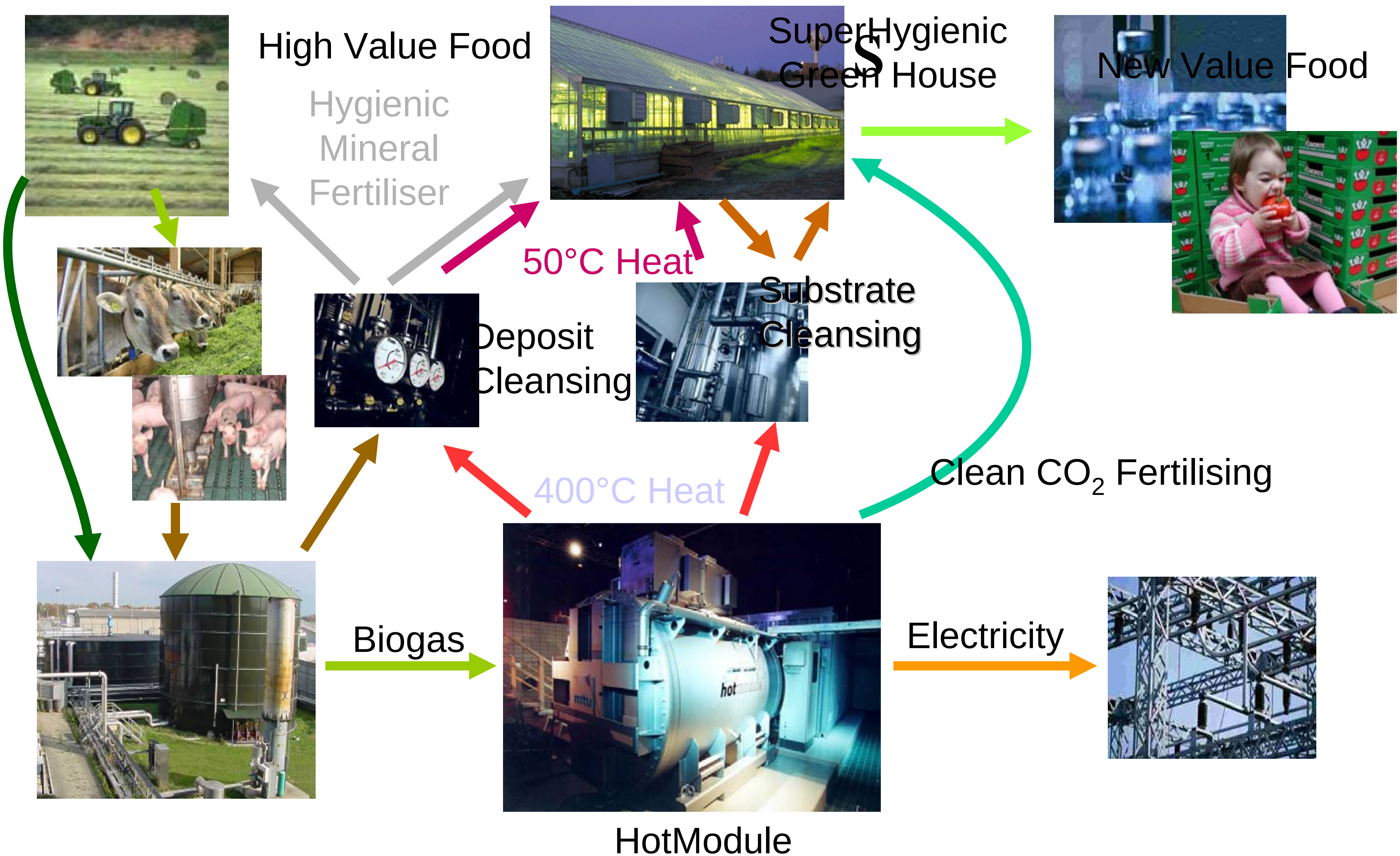
Oils



Gasficatioin of Solid Sewage Residues

Closing Energy Cycle – role of

S



Locations of Biogas – MCFC Testruns

Owschlag, **Germany**, 2.200 h operation (Industrial research center, Seaborne GmbH)

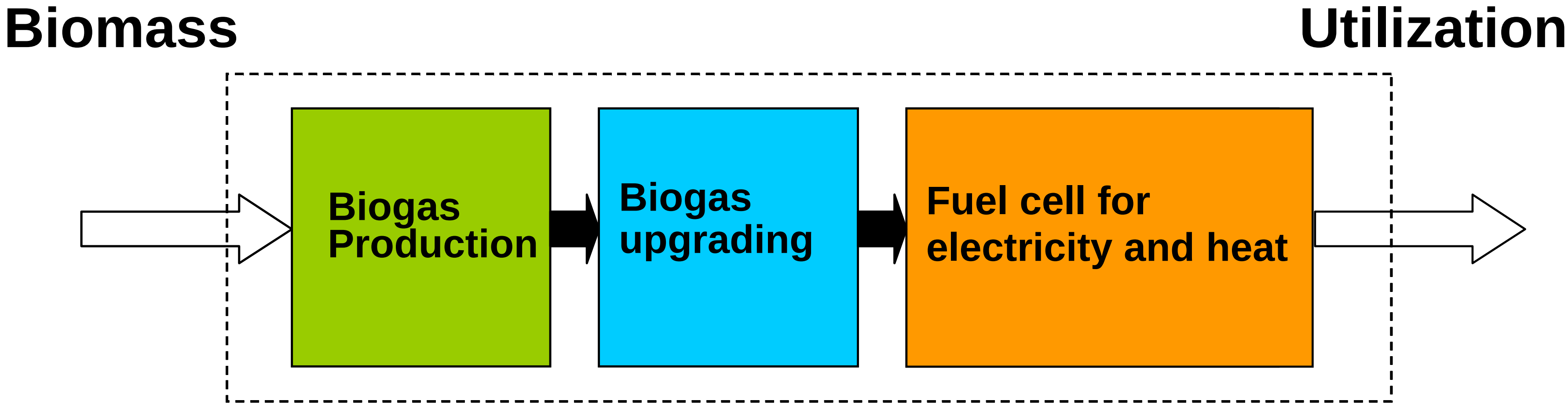
Linz, **Austria**, 1.500 hours operation (Waste water treatment plant in Asten, Linz AG)

Pinto, **Spain**, 2.000 hours operation (Waste treatment plant, Urbaser)

Nitra, **Slowak Republic**, 2.400 hours in operation in first cycle, over 3.300 hours in the 2nd (Agricultural Biogas plant at Uni Nitra) and 3.600h in the third cycle

- **Slovakia: Agricultural Biogas**
- **Germany: Biogas from Cattle Sewage and Co-Fermentation of industrial waste (Food)**
- **Austria: Sewage Gas from Waste Water Treatment**
- **Spain: Landfillgas**

Biogas upgrading



Principles of biogas upgrading

Removal of hydrogen sulphide

Gas type	H2 Vol%	CH4 Vol%	CnHm Vol%	CO2 Vol%	N2 Vol%	CO Vol%	H2S ppm	NH3 ppm	Others
Biogas from fermentation									
[1]Biogas from agricultural biogas plants	0	55-70	-	30-45	0-2	-	500	100	Siloxane, Oxigen
Waste water gas	-	65	-	35	-	-	1000	100	Siloxane, Oxigen
[2]Landfill gas	-	50-60	-	40-50	-	-	0-50	-	Aromates, Chlor comp., Siloxanes
Biogene gas from thermal gasification									
[3]Biomass-gasification	4,5	14,8	-	10,6	39,6	19,1	100	2000	Dust, Teer (3000ppm)
Fossil									
Natural gas	-	93	4,9	1	1,1	-	1	-	Inert gas

1 Jensen, J.K., Jensen, A.B.: Biogas and natural gas – fuel mixture for the future, 1st World Conference and Exhibition on Biomass for Energy and Industry, Sevilla, 2000

2 Christenson, T.H., Cossu, R., Stegmann, R.: Landfilling of Waste, Biogas, E&FN Spon, London 1996

3 Kivisaari, T., Björmbom, P., Sylwan, C.: Studies of Biomass MCFC Systems, Journal of Power Sources, 104 (2002) p. 114-124

Principles of biogas upgrading

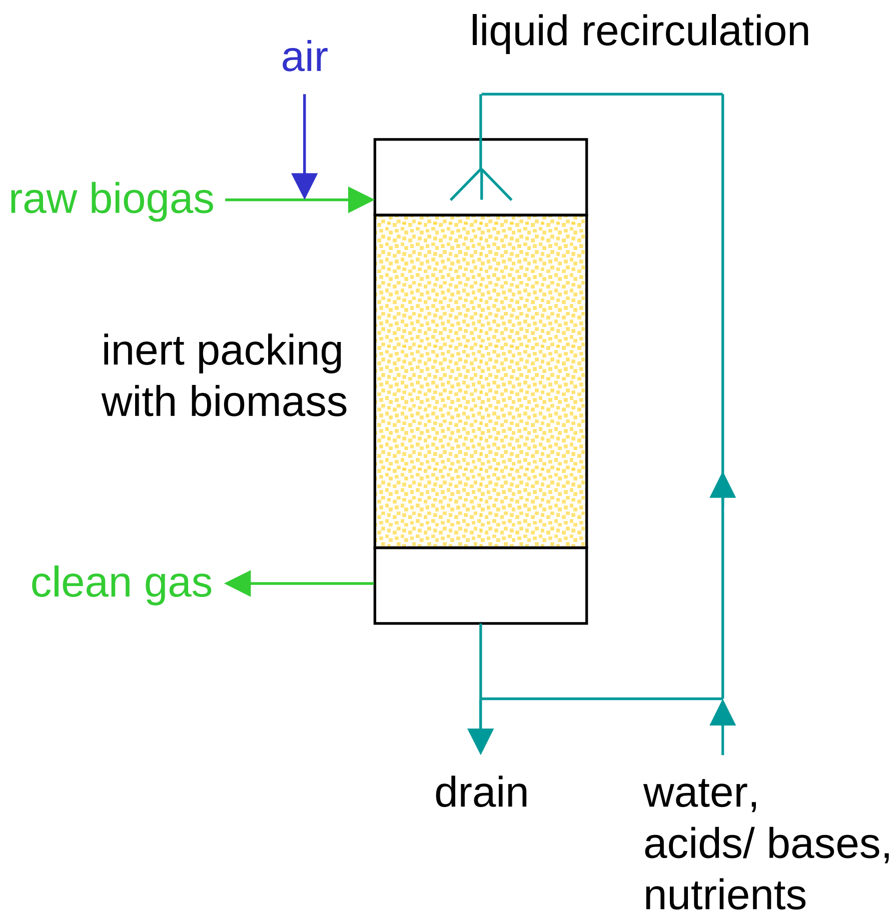
Removal of hydrogen sulphide

- **Physical – Chemical Methods**

- **Biotechnological Methods**
  - Biofilter
  - Bioscrubber
  - Biotrickling filter
  - High efficiency
  - Lower investment costs
  - Lead to savings on energy
  - Avoid catalysts
  - Avoid formation of secondary contaminants

Biotrickling filter concept

Removal of hydrogen sulphide



- **Microorganisms to degrade H_2S:**

  bacteria genus Thiobacillus

✓ Common bacteria.

✓ They do not oxidise CH_4.

✓ Their carbon source is CO_2.

✓ They obtain energy for growth from oxidising inorganic sulphur substrates.

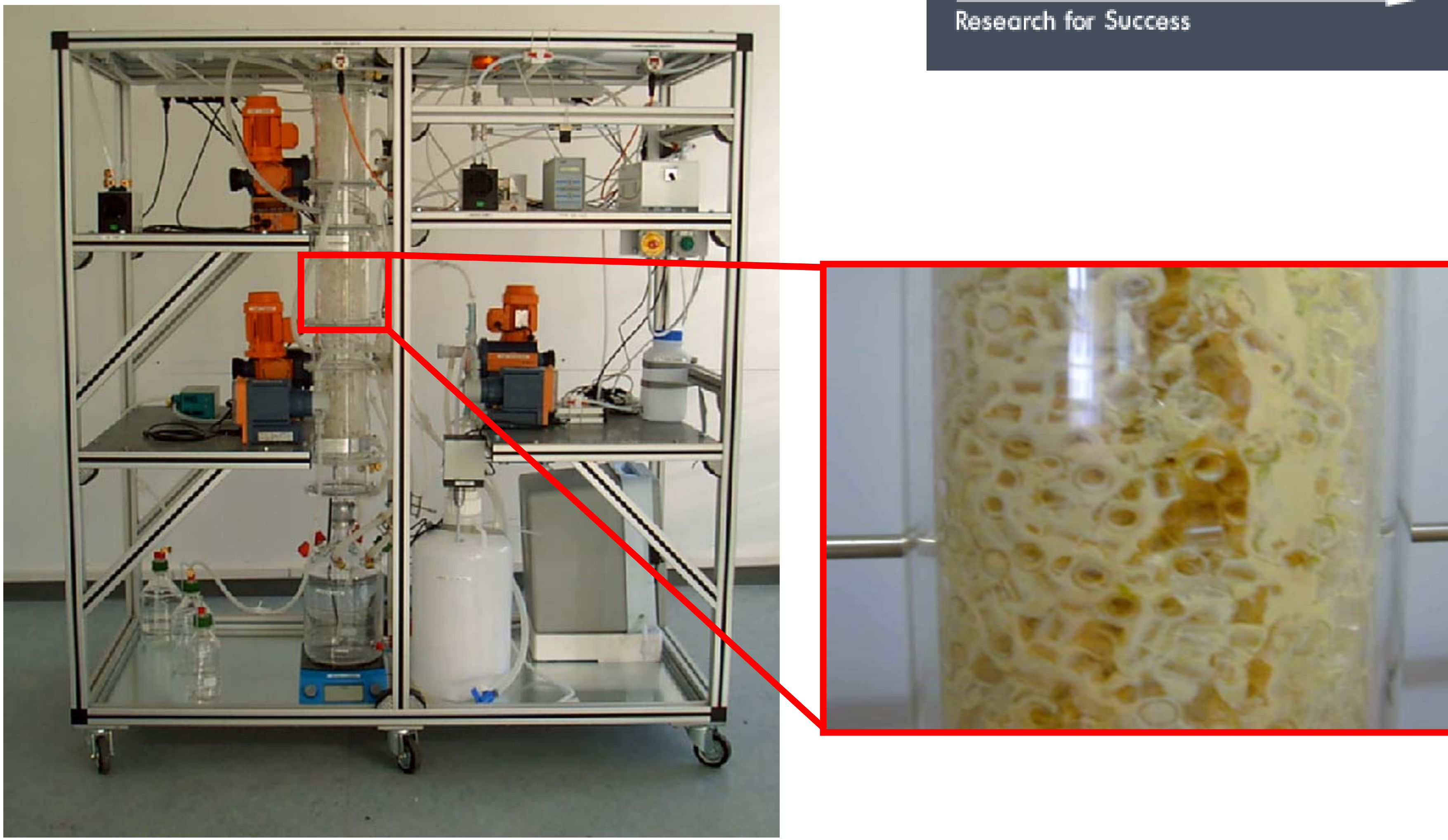
$$H_2S + 0.5\,O_2 \rightarrow S + H_2O$$

$$H_2S + 2\,O_2 + 2\,OH^- \rightarrow SO_4^{2-} + 2\,H_2O$$

Biotrickling filter concept

PROFACTOR®
Research for Success

Pilot plants

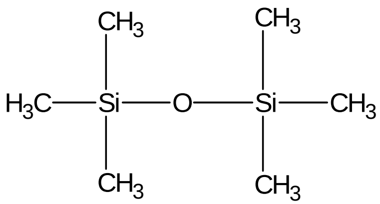


Principles of biogas upgrading

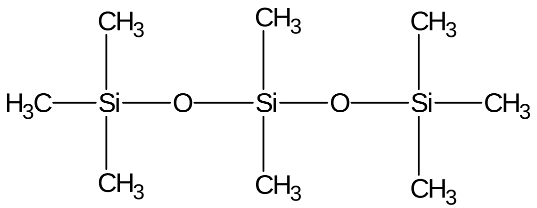
Siloxanes – problems in sewage and landfill gas

Silicon containing compounds

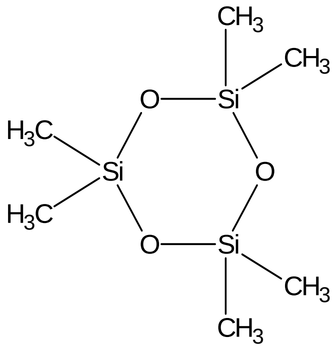
Linear and cyclic siloxanes



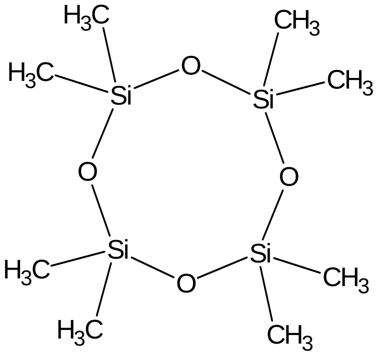
hexamethyldisiloxane (L2)



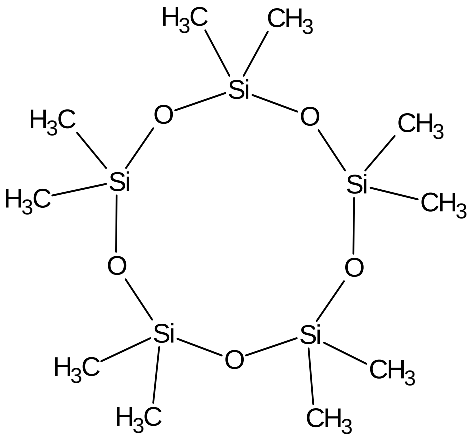
octamethyltrisiloxane (L3)



hexamethylcyclotrisiloxane (D3)

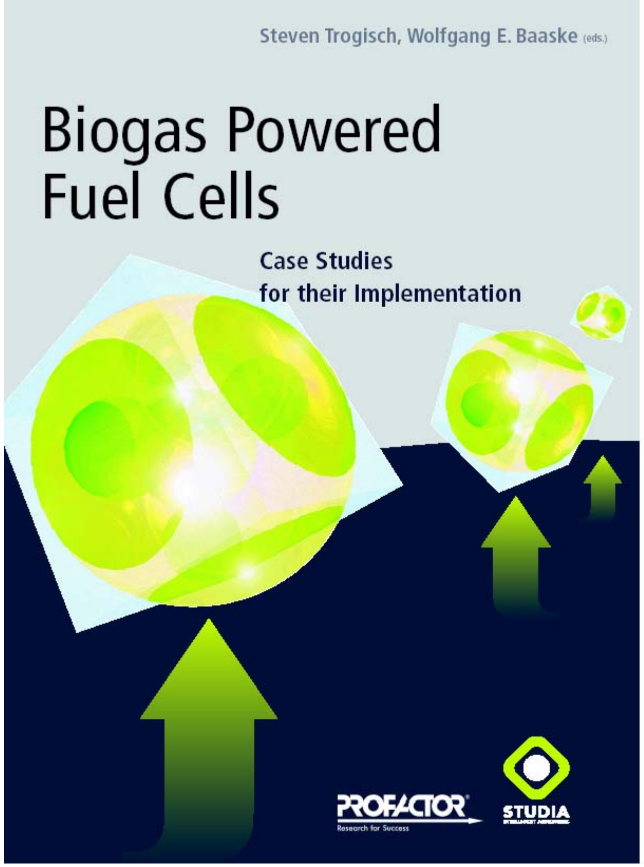


octamethylcyclotetrasiloxane (D4)



decamethylcyclopentasiloxane (D5)

Book about the Results of the EU-granted EFFECTIVE Project



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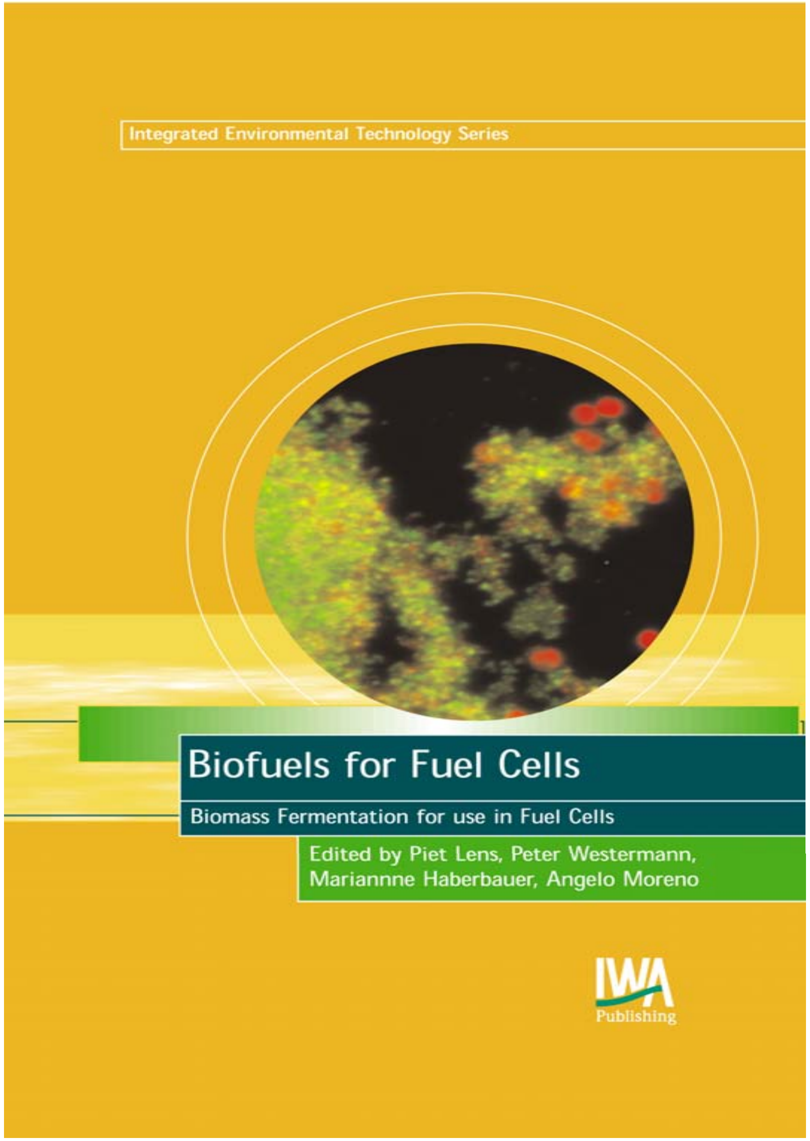
Joachim Hoffmann (MTU CFC Solutions)
Mogens Hedegaard (Seaborne)
Jesus Gil Diez (Urbaser)
Peter Berger (MTU CFC Solutions)
Piet Lens (Univ. of Wageningen)
Knut Stahl (RWE)
and many more……

ISBN 3-85487-626-2



Hard cover book

IWA Publishing

The integration of Biomass Fermentation and Fuel Cells (FC) technology creates a new and interdisciplinary research area. This book cross-links scientists of all fields concerned with Biomass Fermentation, Fuel Upgrading and Fuel Cells at European and World level.