Biogas technology

a key technology to adjust fluctuating renewable energy sources
and
to recycle scarce resources from bio-wastes and residues

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ZNES
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Universität | Fachhochschule Flensburg
Biomass

C.A.T.S.
Centrum für Angewandte Technologie
Green Process Enginnering

FH Flensburg

Who we are

Anaerobic digestion
Technology development
- Pre-treatment
- Fermenter Technology
- Products Upgrading
- Control

Closing nutrient loops
- Algae as nutrients collectors are digested
- Biogas in artificial food cycles (Hydroponics, Aquaculture, etc.)

Renewable Energy Systems Integration
- Methanation
- Methanol Synthesis
- Power to Chemicals

Process integration in Biorefineries
- Waste valorization in Food Industries
- Efficiency studies

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Innovative Fermentation Technologies

Adapt the reactors to the microbial processes

Make anaerobic digestion robust against sudden substrate changes (shock loads)

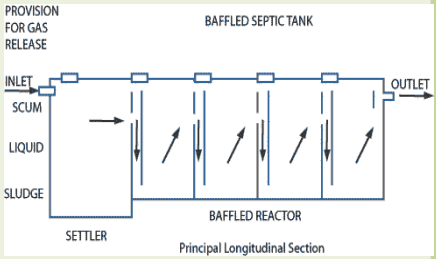
Increase concentrations of value added products in the reactor like the ruminants do

Keep the actors (catalysts or micro organisms) always in the fermenter

Transfer the whole feedstock into value added products

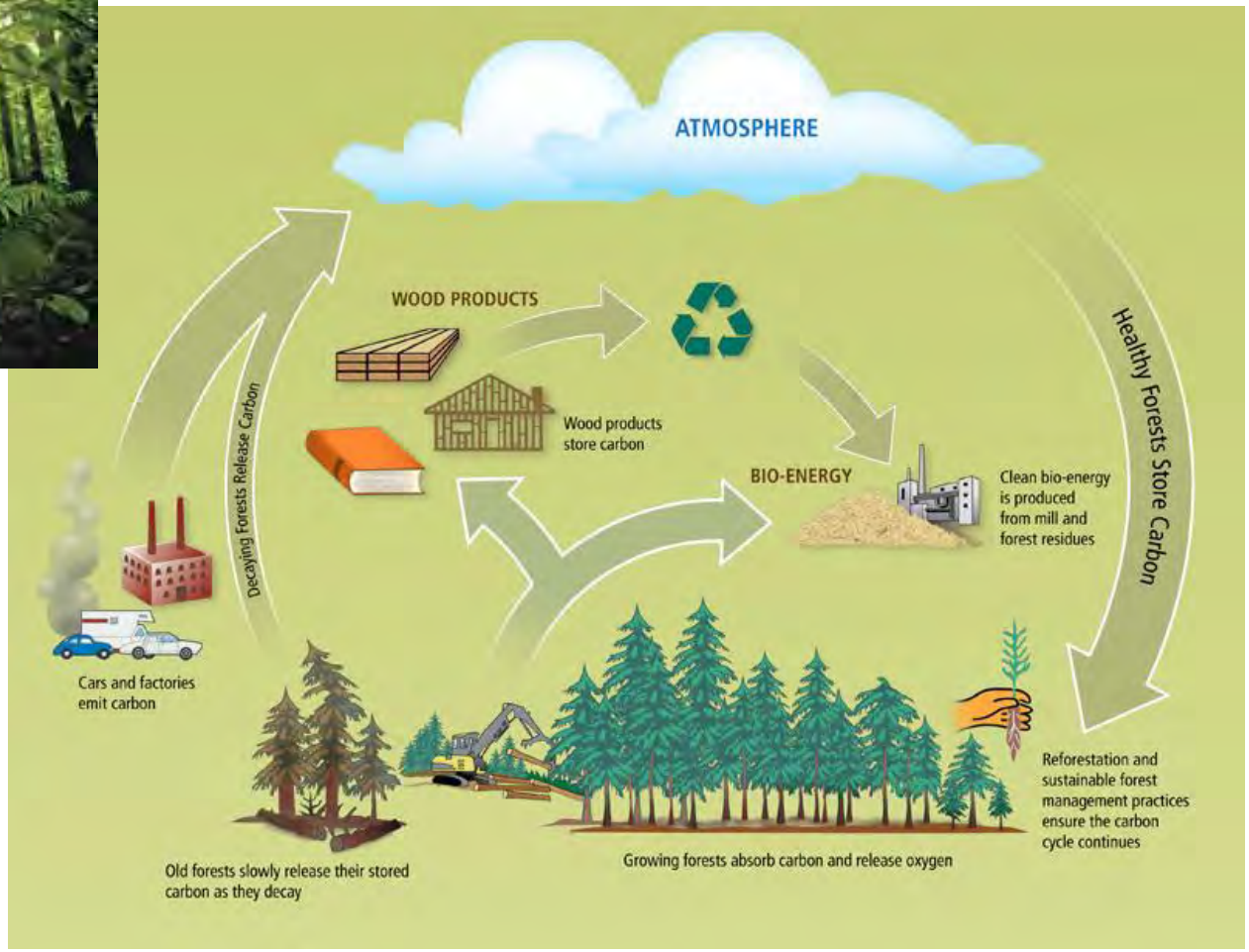
Make it simple and robust: fermentation in containers

(M)ABR Technology



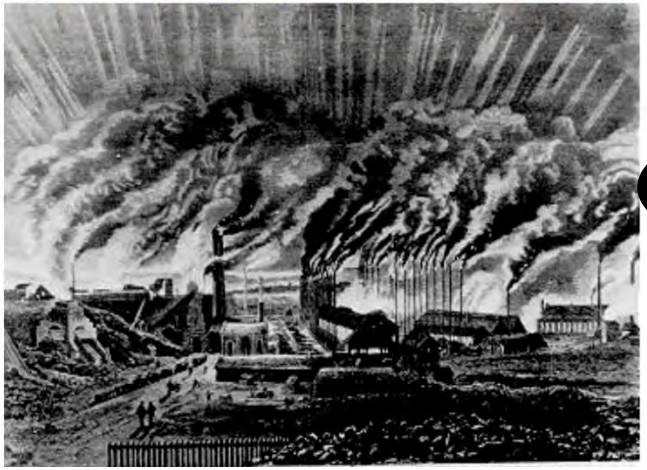
→ Start-Up Company Conviotec GmbH

Bioenergy is a Source of Renewable Energy



Climate Change Forces Paradigm Shift

Metal foundry refining in early industrial Germany, 1870s



From

Chemical Energy

To

Downtown Los Angeles, December 31, 1993

Electrical Energy

As

Primary Energy Source

Energy Efficiency of …

…. a fuel based internal combustion engine

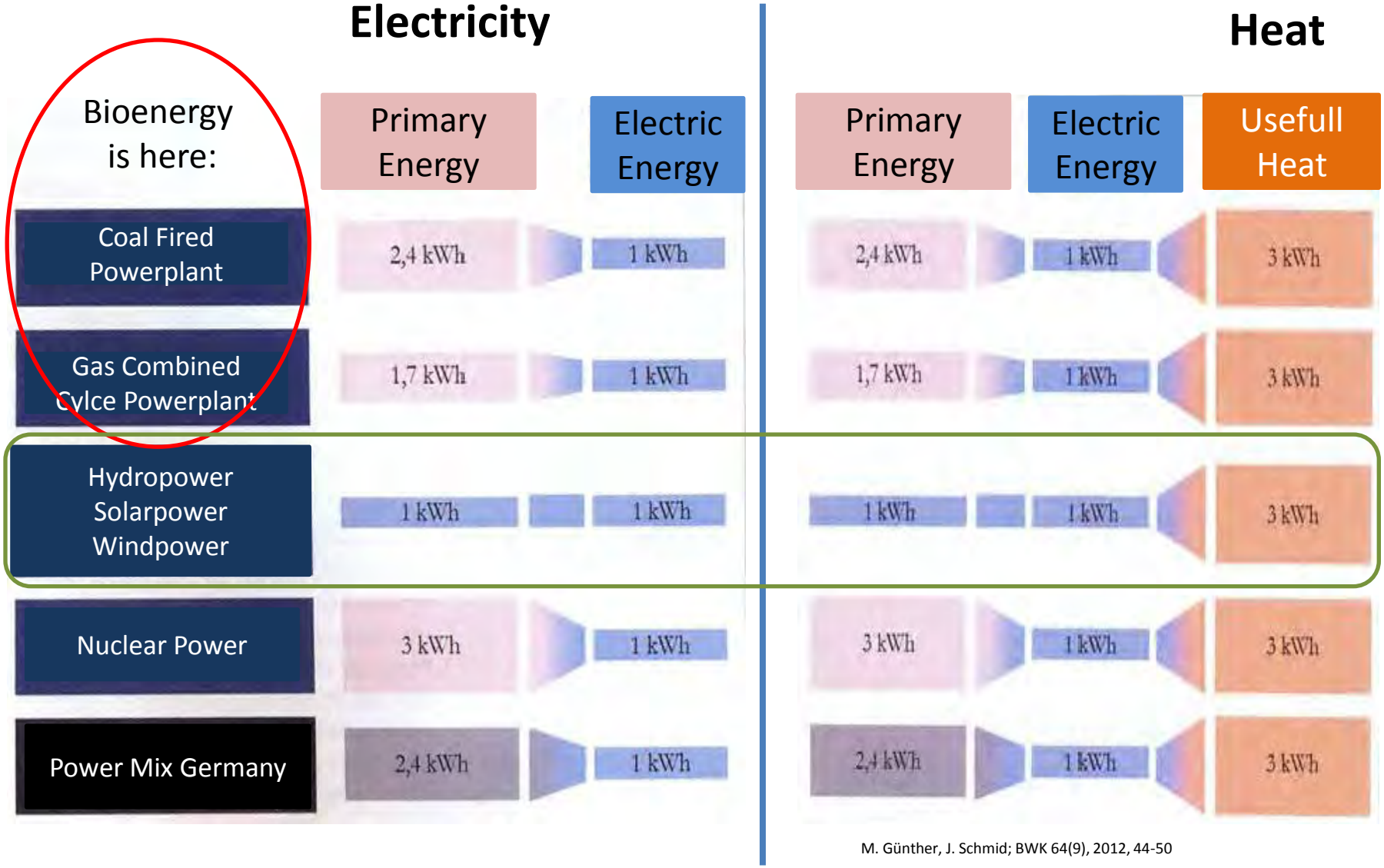
η = 25%

Biofuels are here

… an electrical engine

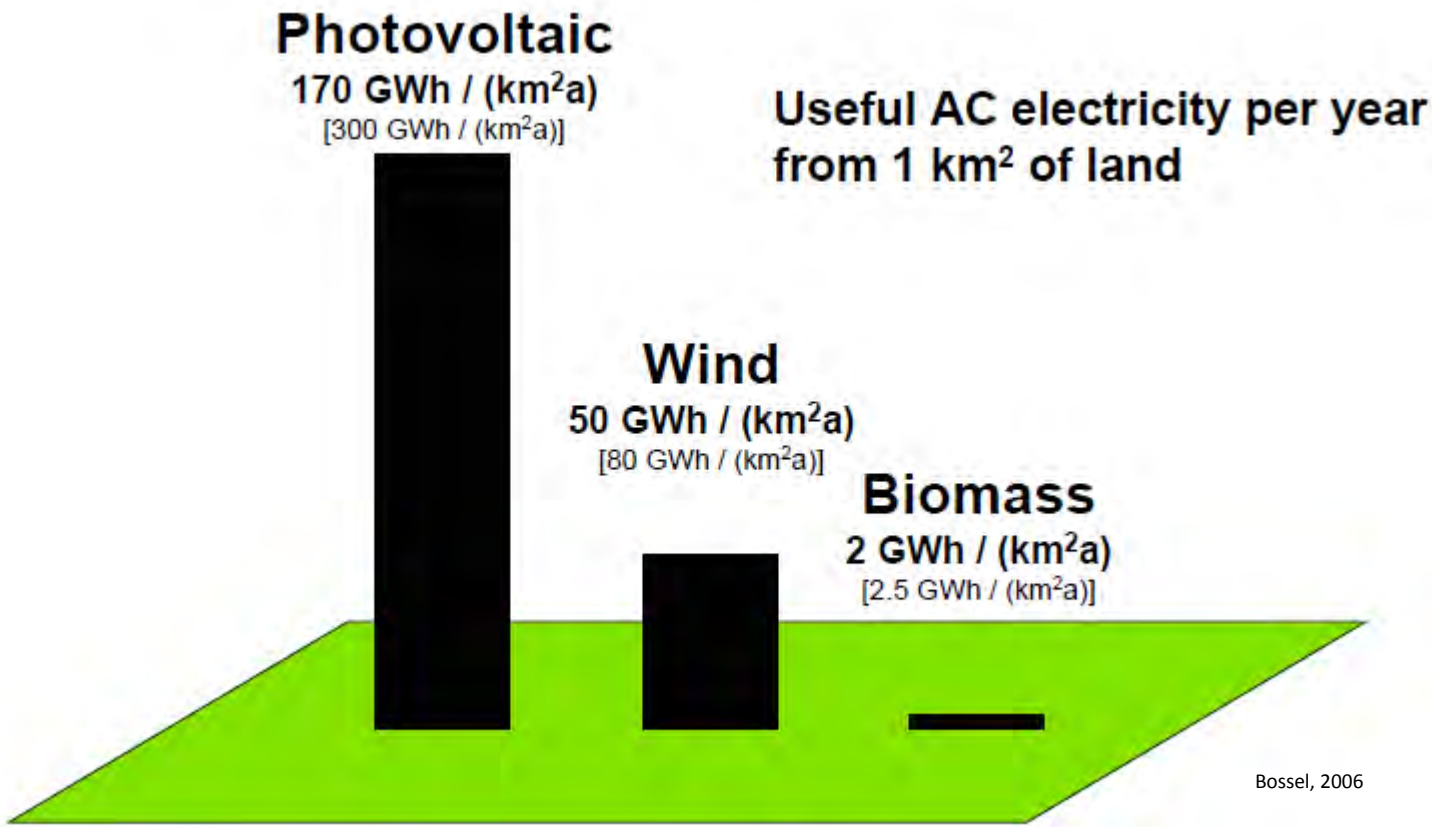
η = 90%

Energy Efficiency Potential > 40%



M. Günther, J. Schmid; BWK 64(9), 2012, 44-50

Space Efficiency
Biomass, Wind or Photovoltaics?



Photovoltaics and wind far superior to biomass

Supply Chains – Electrical Energy

	Photo-voltaics	Wind Power	Biomass (Fermentation)	Biomass (Gasification)	Crude Oil	Coal	Nuclear Power	Natural Gas
0	electric Power	electric Power	electric Power	electric Power	electric Power	electric Power	electric Power	electric Power
1	Inverter	Middle Voltage	Middle Voltage	Middle Voltage	Middle Voltage	Middle Voltage	Middle Voltage	Middle Voltage
2	Solarpanel	Generator	Generator	Generator	High Voltage	High Voltage	High Voltage	Generator
3		Windturbine	CHP	Turbine	Generator	Generator	Generator	Turbine
4			Fermentation	Gas/Steam	Turbine	Turbine	Turbine	Transport
5			Transport and Storage	Gasification	Gas/Steam	Gas/Steam	Gas/Steam	Purification
6			Harvesting	Pretreatment	Heat Gasification	Heat Gasification	Reaktor	Transport
7			Cultivation	Transport	Transport	Transport	Transport	Gas Production
8			Seeding	Harvesting	Raffination	Purification	Enrichment	
9			Fertilzer	Cultivation	Transport	Transport	Transport	
10			Pesticides		Oil Production	Mining	Ore Dressing	
11			Seed production				Transport	
12							Mining	

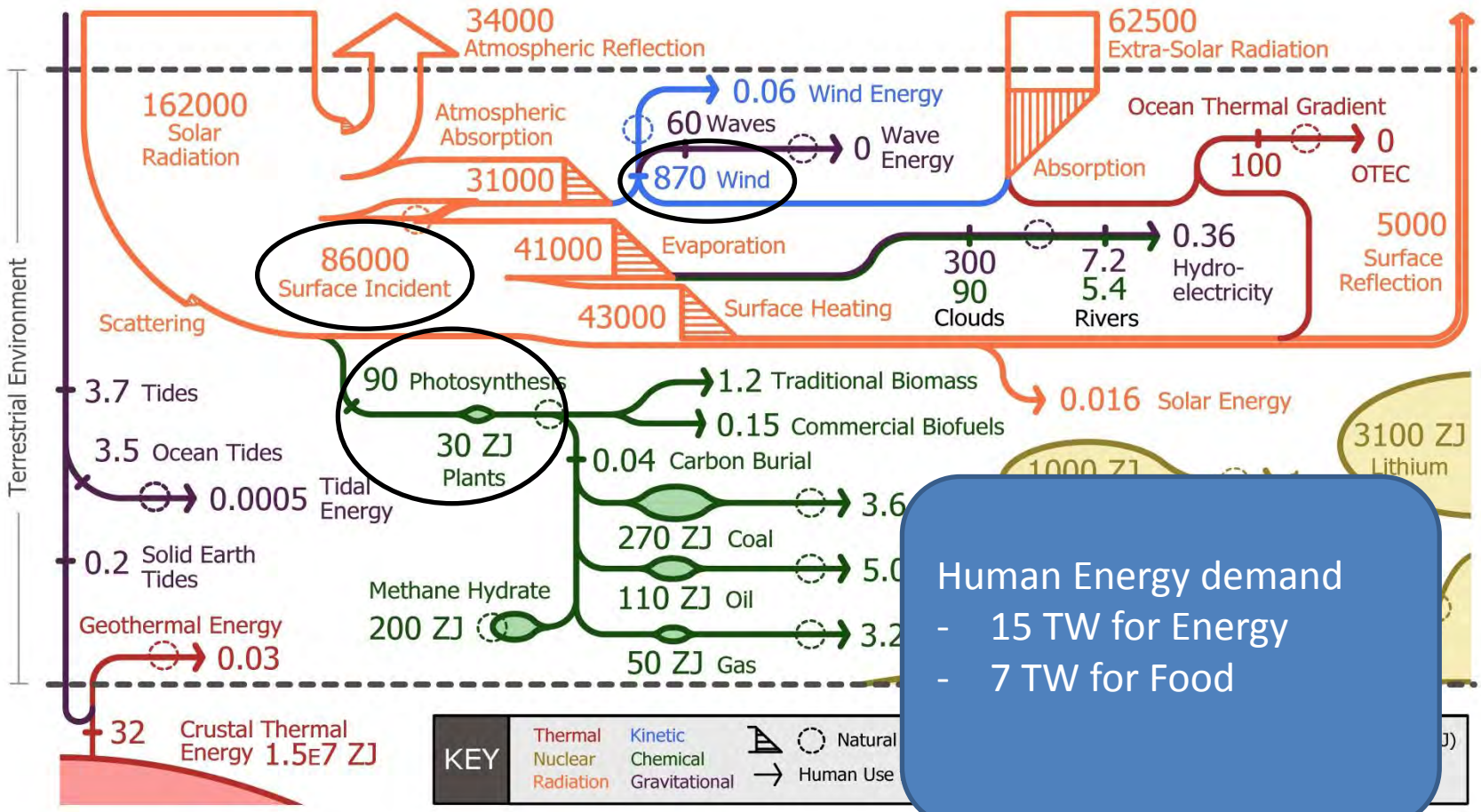
Fuel Production

Nach H. Scheer: Solare Weltwirtschaft; 2002; 5. Auflage

Reasons for Biogas Production: Portfolio of Products and Services

Substrate	Main Goal	Attractive Goal	Additional Goal
Wastewater	Disposal	Nutrients Recycling	Energy Production
Waste	Disposal	Nutrients Recycling	Energy Production
Manure	Disposal	Nutrients Recycling	Energy Production
Energy Crops	Energy Production		

Global Exergy Flux, Reservoirs, and Destruction



Human Energy demand
- 15 TW for Energy
- 7 TW for Food

Exergy is the useful portion of energy that allows us to do work and perform energy services. We gather exergy from energy-carrying substances in the natural world we call energy resources. While energy is conserved, the exergetic portion can be destroyed when it undergoes an energy conversion. This diagram summarizes the exergy reservoirs and flows in our sphere of influence including their interconnections, conversions, and eventual natural or anthropogenic destruction. Because the choice of energy resource and the method of resource utilization have environmental consequences, knowing the full range of energy options available to our growing world population and economy may assist in efforts to decouple energy use from environmental damage.

Prepared by Wes Hermann and A.J. Simon
Global Climate and Energy Project at Stanford University (http://gcep.stanford.edu)

Properties of Biomass

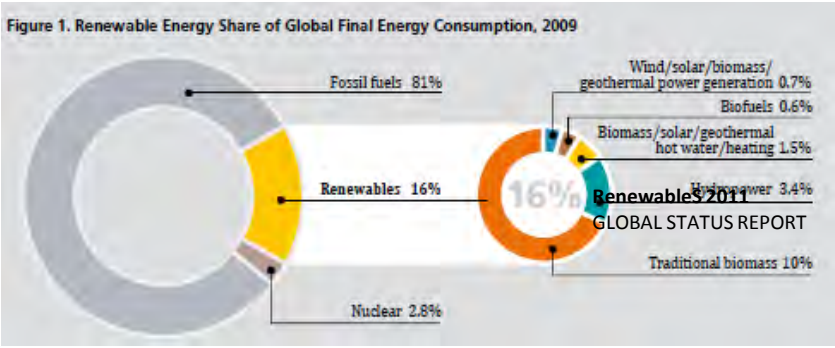
- Biomass is a distributed source and available all around the globe (like wind and solar energy)
- Multipurpose function of biomass
  - Natural product for food, construction material, textiles, paper and fuels …
  - Natural services in balancing water household and temperature, keeping soil quality stable, CO2 sink, bio-organic waste treatment …
- Biomass is stored solar energy in form of chemical energy with
  - long-term storage options (available every time)
  - low energy density

Logistic Aspects of Bioenergy

Pro‘s and Con‘s of Bioenergy

Pro

- Bioenergy matches into traditional and industrial energy systems
- Option for climate change mitigation
- Energy storage properties



Con

- Land-use competition
  food versus fuels versus natural ecosystems
- Human alteration of net primary productivity of ecosystems
- Long and complex supply chain
- Low energy density
- Matches not really into a renewable energy based energy system

Intermediate Conclusions

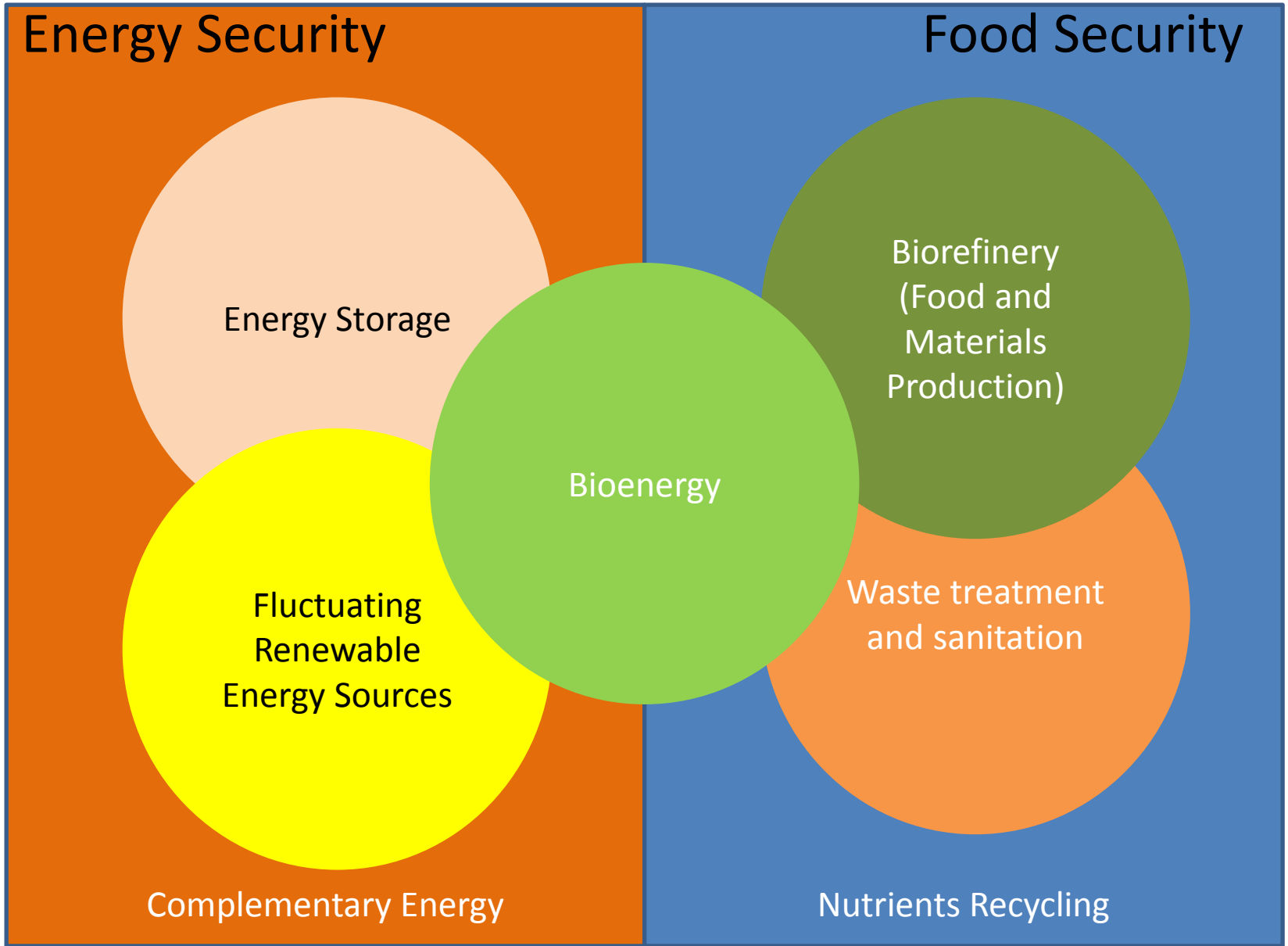
- Bioenergy fits well into traditional and industrial energy systems
- Biomass stores solar energy, but with low energy density
- Bioenergy production should be combined with the transfer of residues/wastes into nutrients for biomass production (based on solving environmental problems)

  => Biogas Technology is a solution of choice!!!

- The production of energy via energy crops is the most expensive way to produce renewable energy
- Land-use competition due to multipurpose role of biomasse and scarce availability of arable land

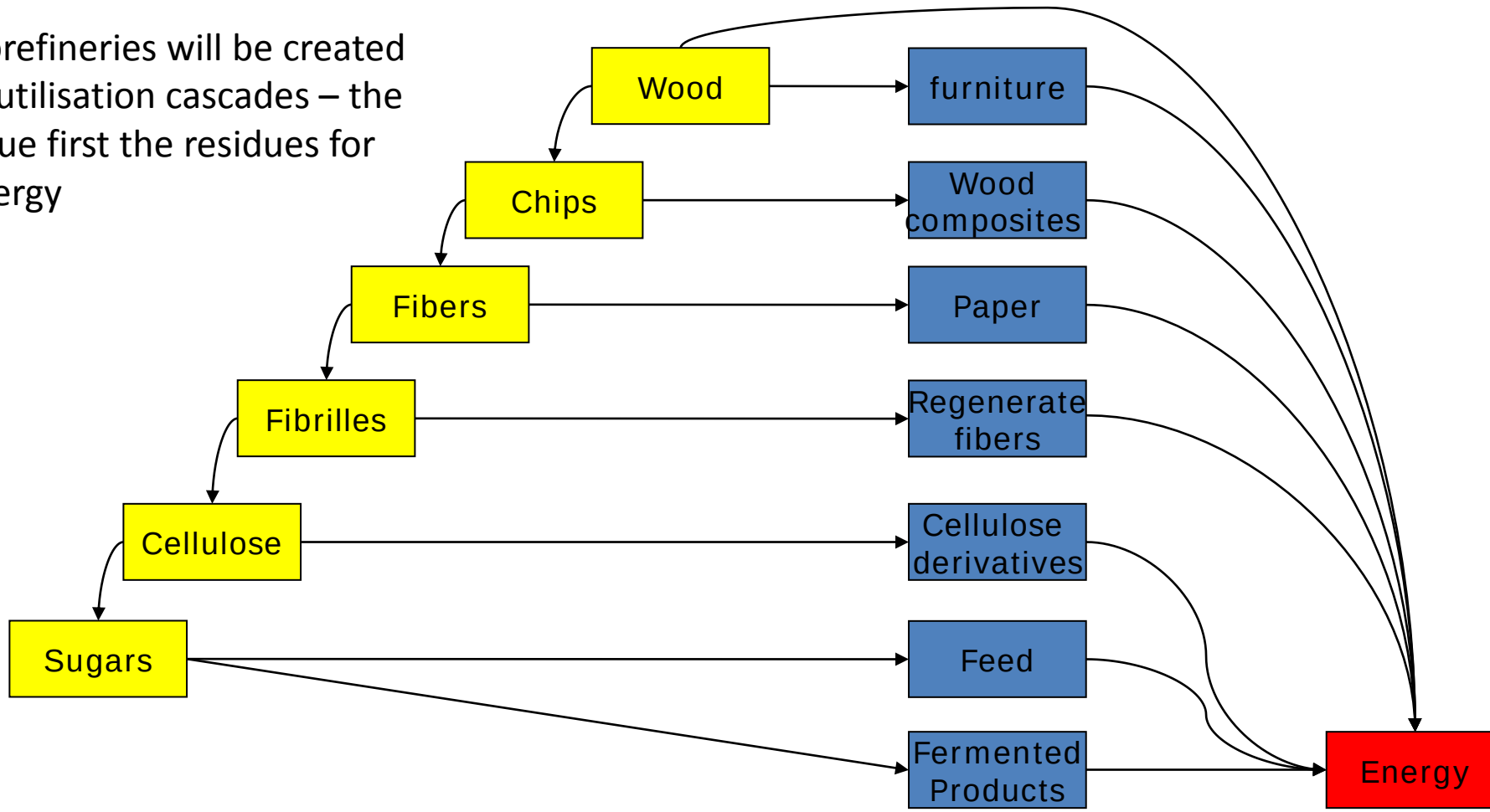
WHAT IS THE FUTURE ROLE OF BIOENERGY – BIOGAS TECHNOLOGY?

The Future Role of Bioenergy



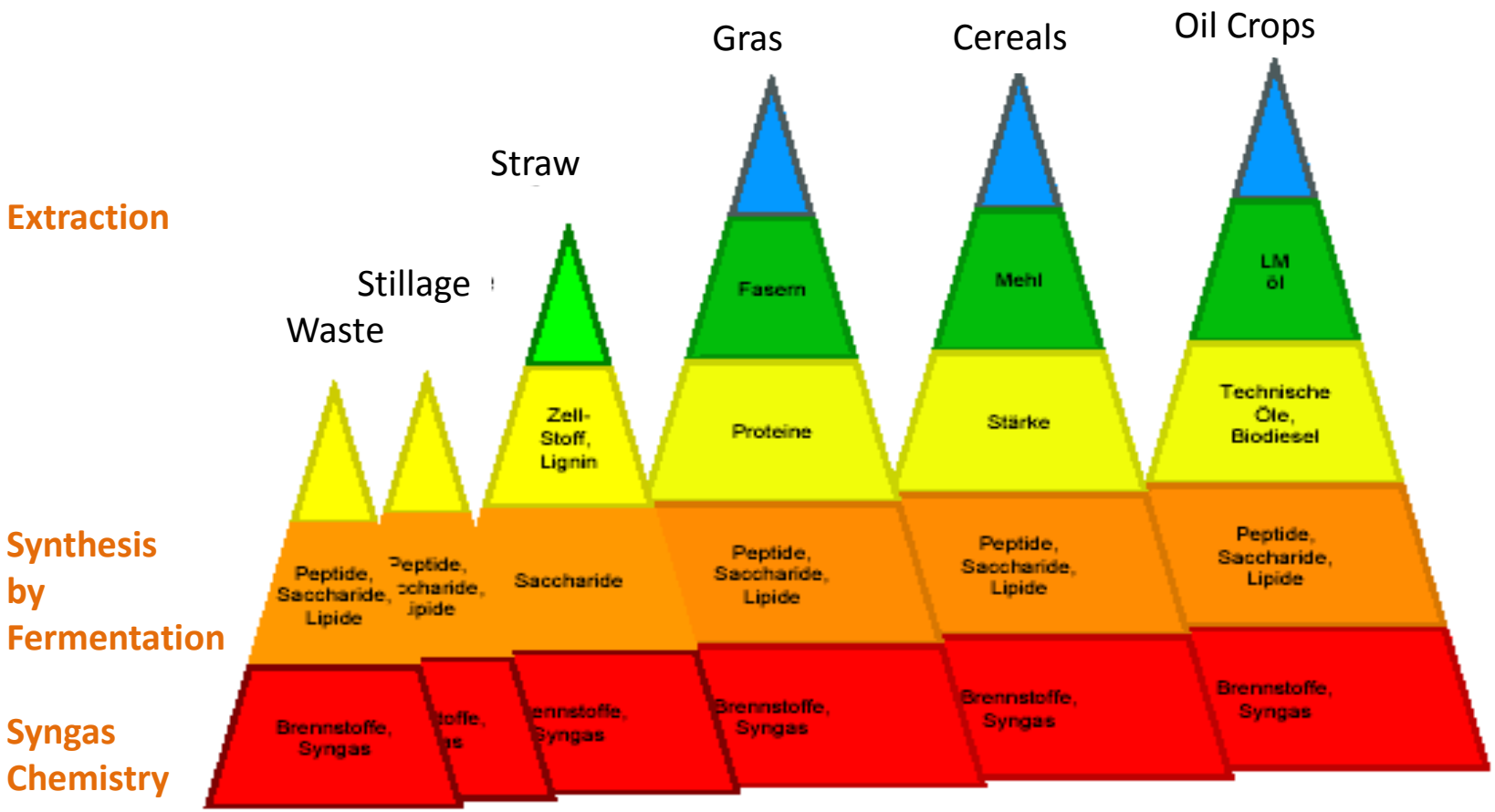
Biorefineries are Utilisation Cascades

Biorefineries will be created as utilisation cascades – the value first the residues for energy



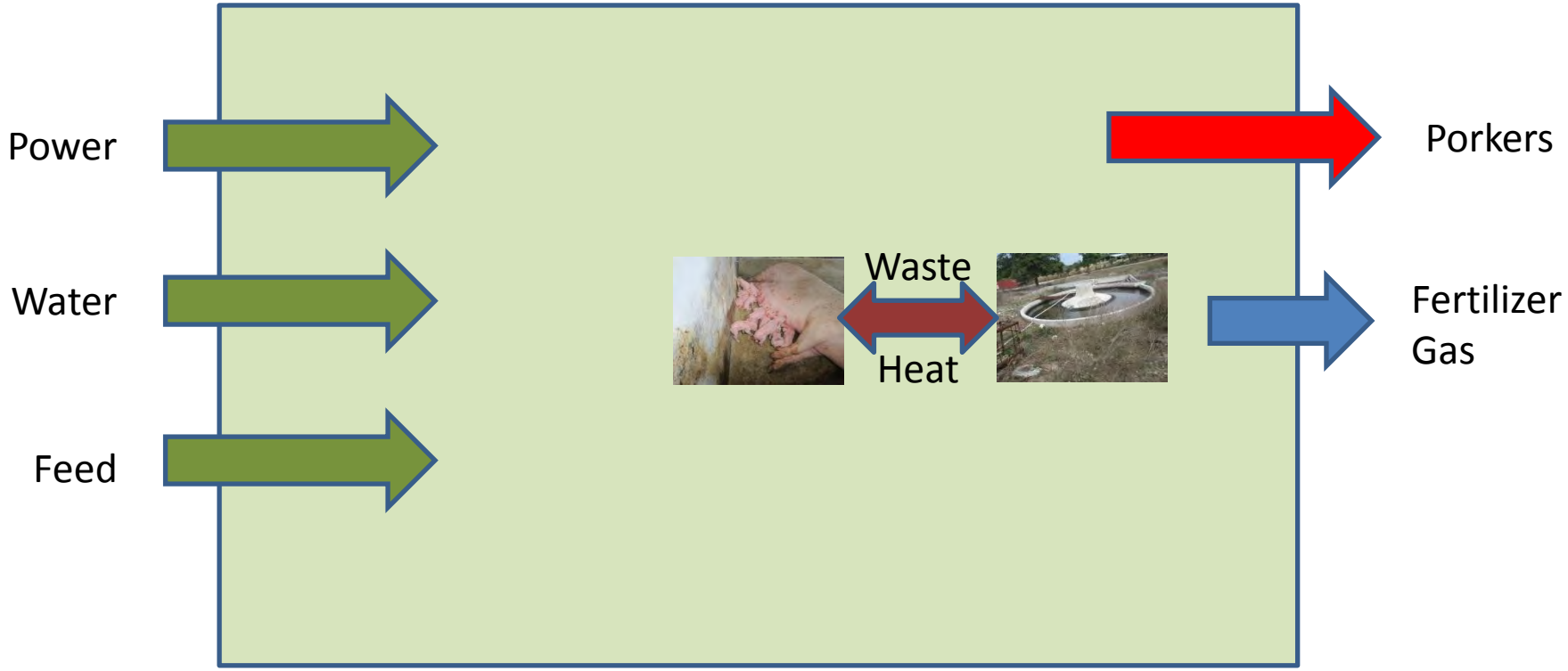
Based on: Gruber: Macromolecular Chemistry of Renewable Resources, 2001

Biorefineries always have value-added products <u>and</u> wastes for energy

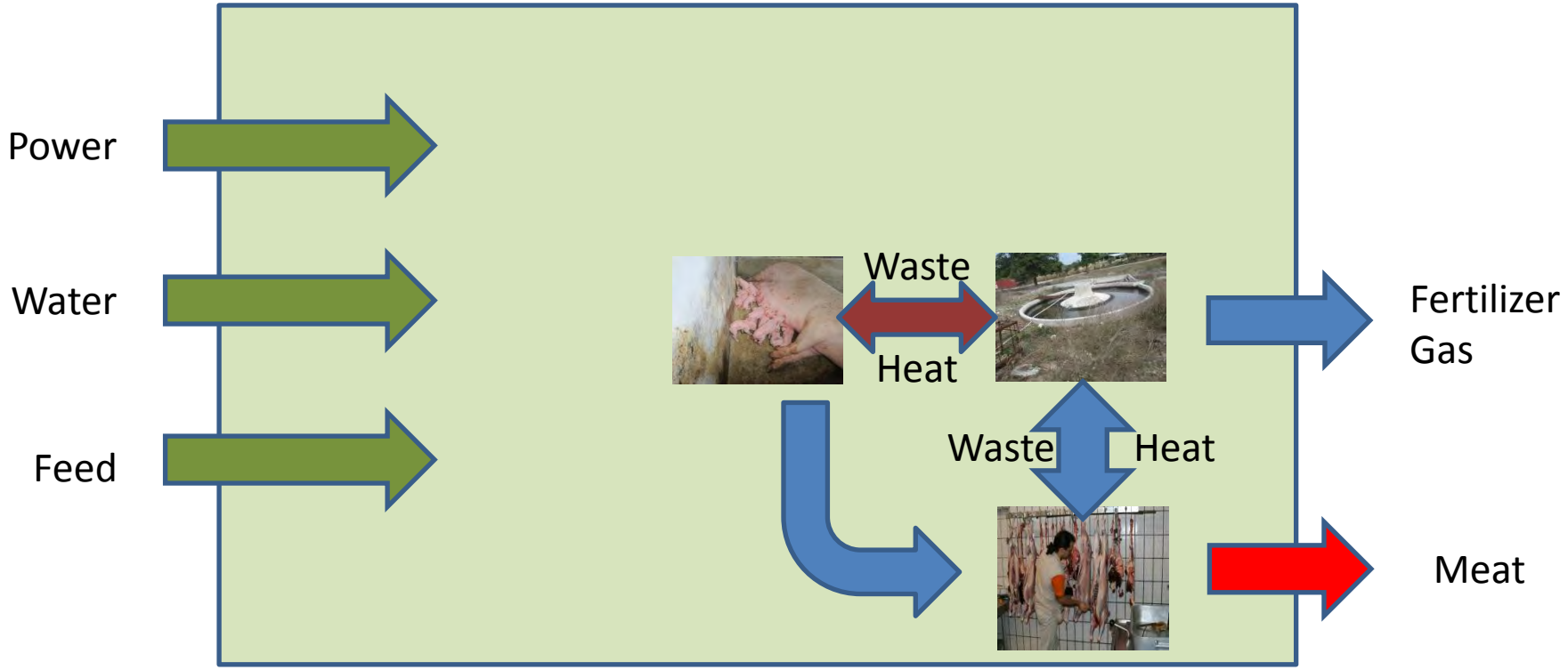


Food Processing is a Biorefinery

Food Processing is a Biorefinery



Food Processing is a Biorefinery



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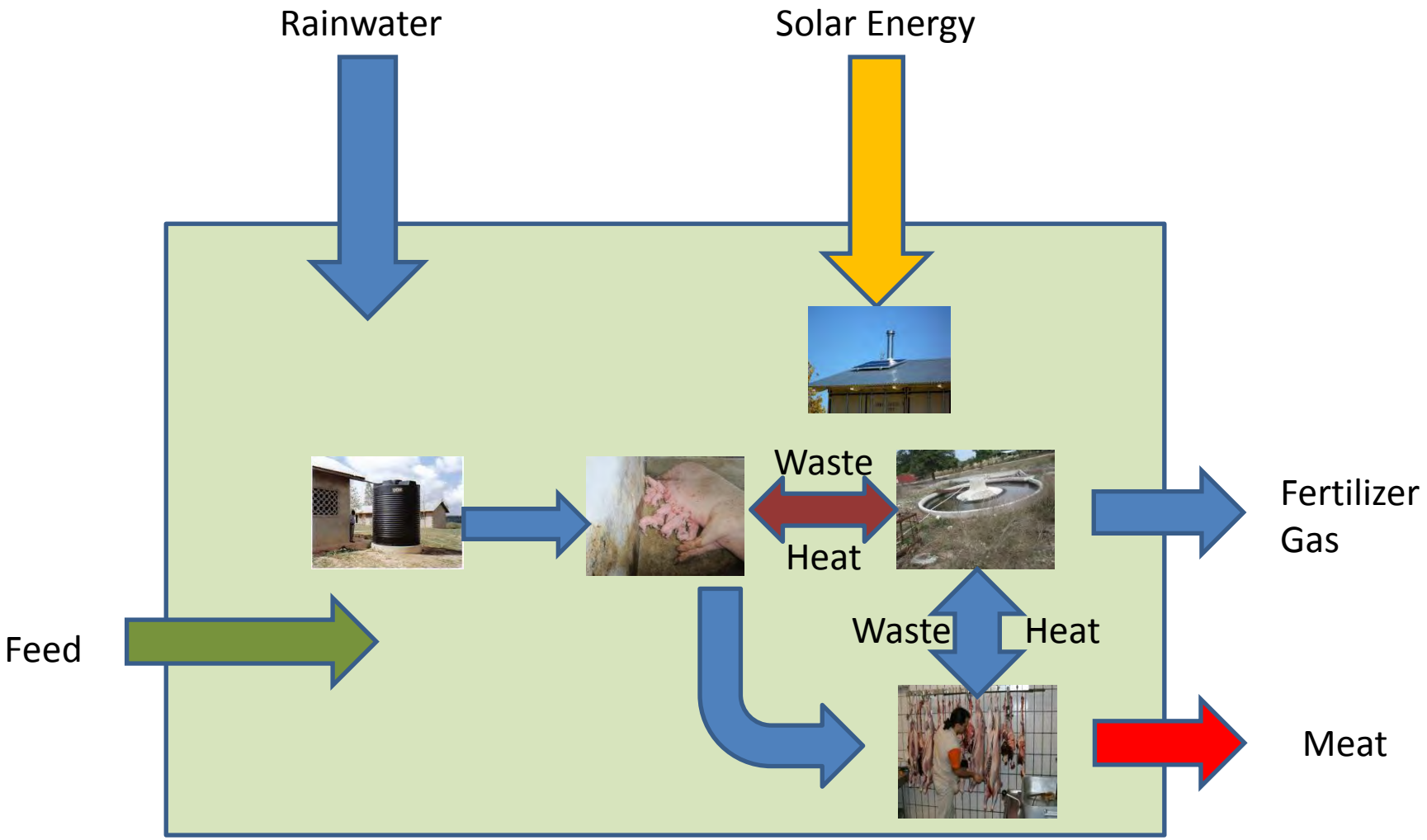

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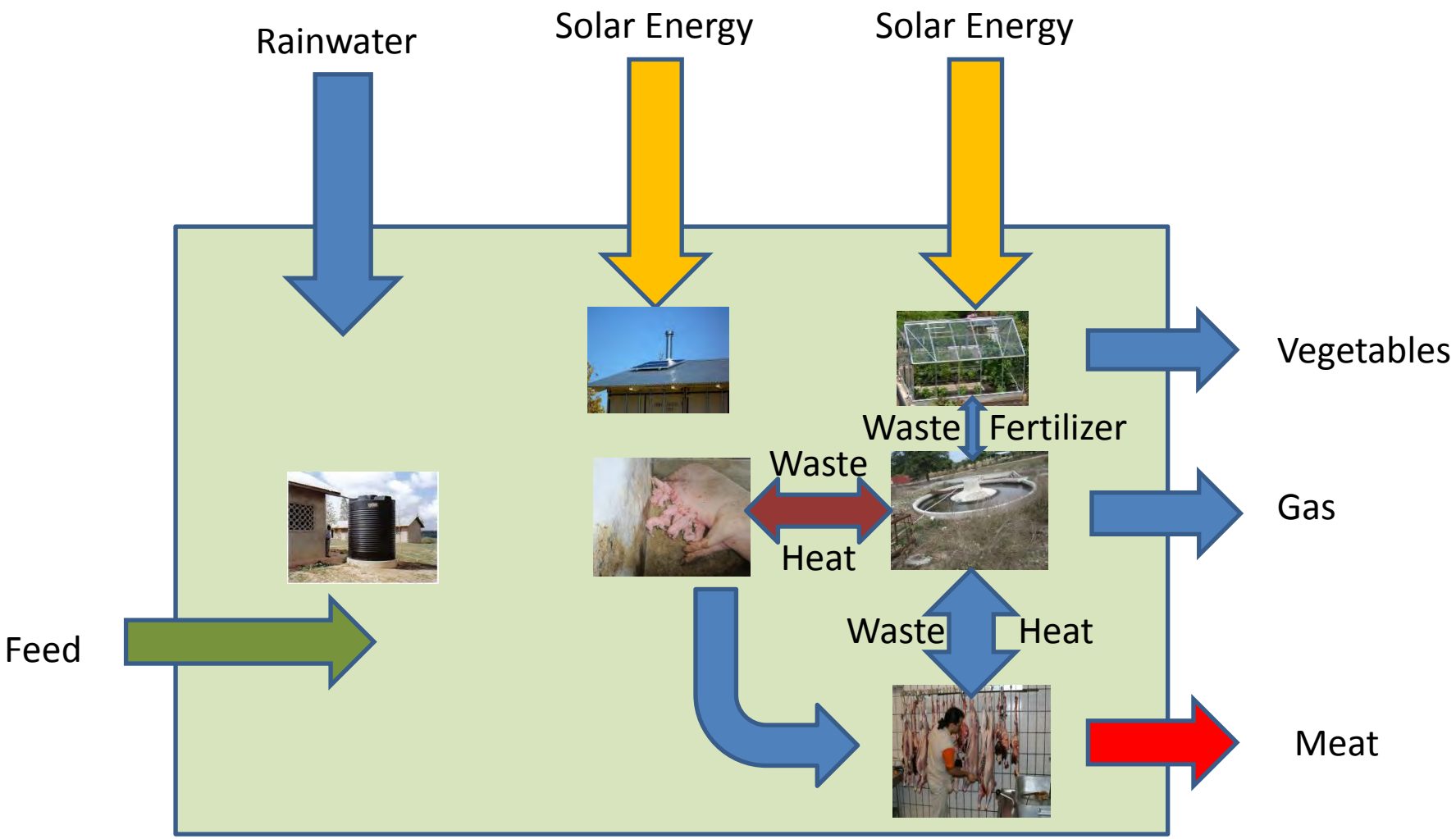
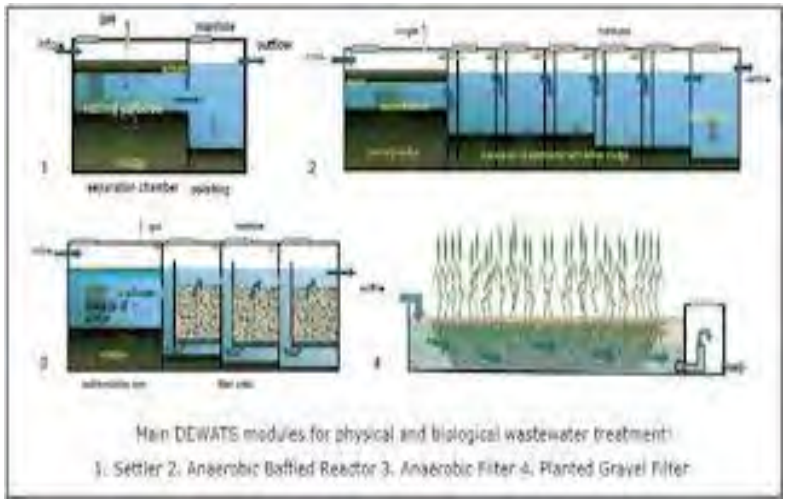


Waste Treatment and Sanitation



Reasons for Biogas Production

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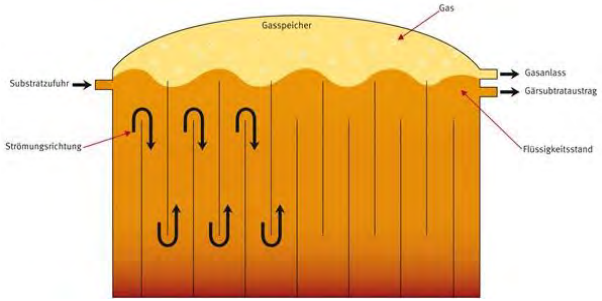
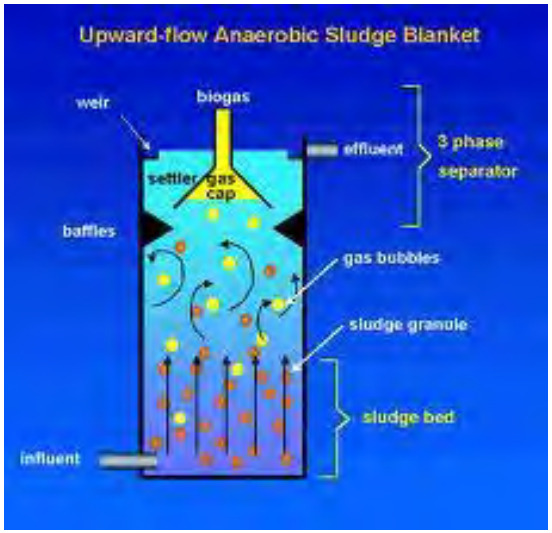
Biogas Waste to Energy Systems

Small Scale



Waste-water-treament



Large Scale

Adding Value to Waste: Fuels and Recycling of Nutrients

Anaerobic fuel production from biomass residues and wastes generates

- gaseous fuel for different purposes

- high value fertilizer as additional product

Biogas Repowering Goals

- Biogas plants have to be substrate invariant (Co-Fermentation)

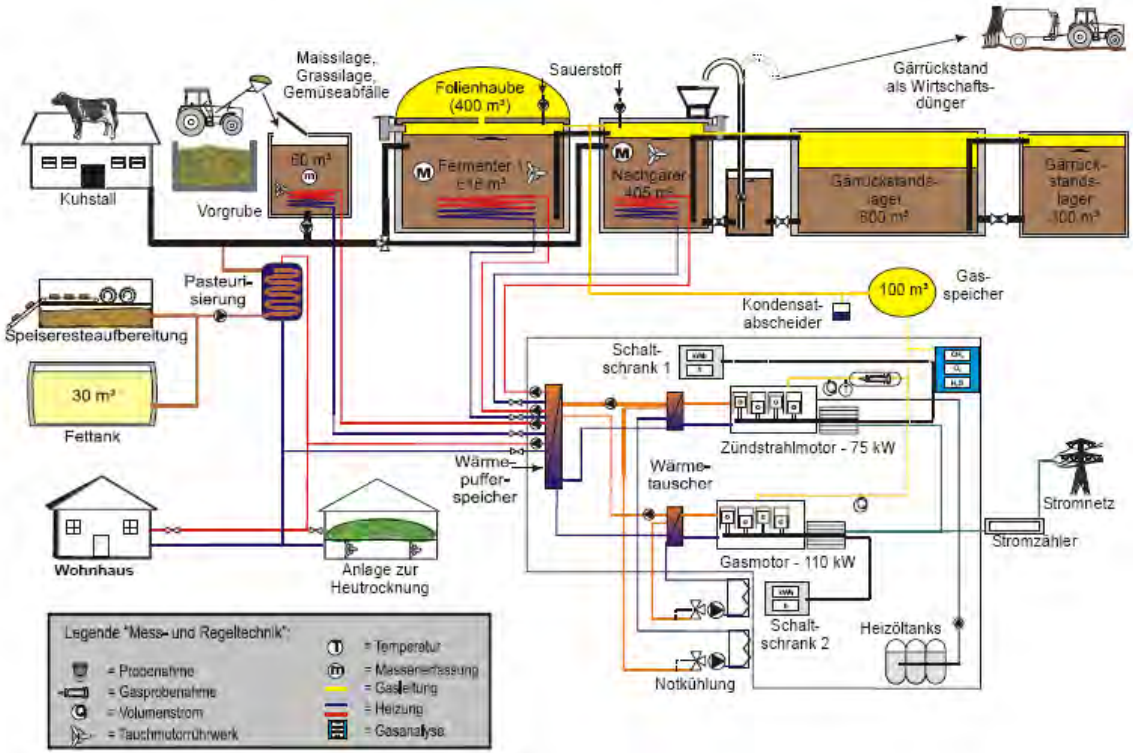
- Biogas technology on the countryside has to be
  - decentralized and
  - directed to the respective situation
  - Simple* and robust

And has to guaranty maximum methane yield per mass unit within shortest retention time

* Progress is the way from the primitive to the complex to the simple (W.v.Braun)

Process Management

A conventional biogas plant is – from the chemical engineering point of view – a complex process plant, i.e. is has to be designed and operated professional



Affordable professional services in

- Engineering
- Maintenance
- Operation

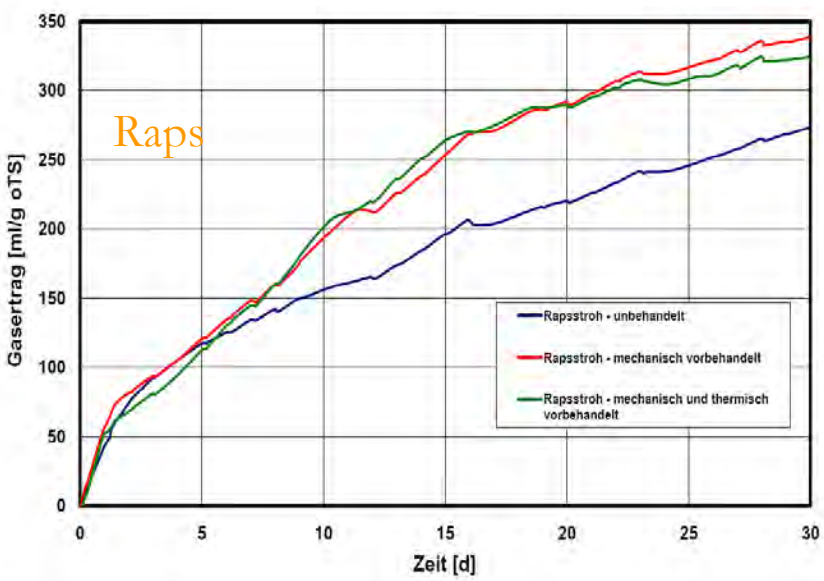
Substrate Pre-Treatment

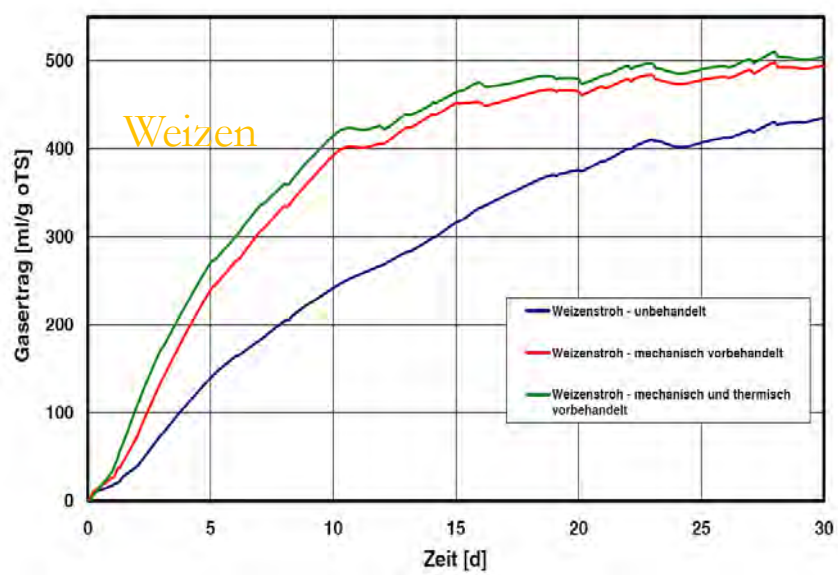
Grinding – Principle squeezing and cutting

Mixed with recycled sludge from fermenter and pumped back into the fermenter

Substrate Pre-Treatment

Rape- and wheat straw with or without mechanical and/or thermal pretreatment





The mechanical pretreatment with hammer mills accelerates the conversion process Substantially and increase gas yield.

Further research with any kind of straw, MSW, wood, jetsam and other is under Development in the LSBEL framework

Control

Quality control of feedstock:

Goals:

- Maximum energy content per mass unit in the product gases
- Homogeneity of the substrats over long time periods

Process control:

Goals:

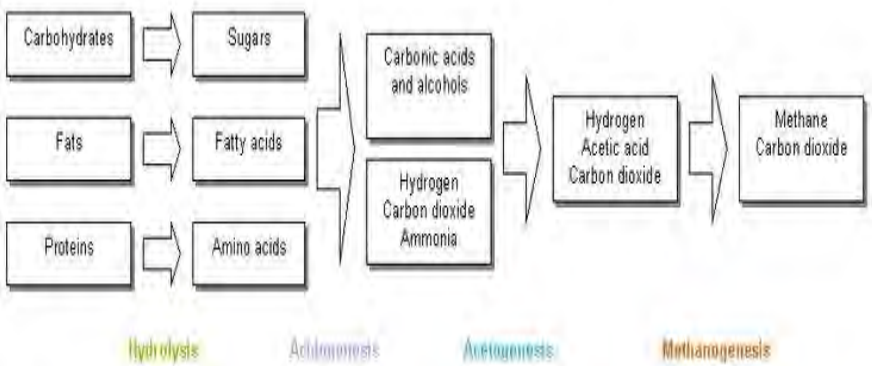
- Maximum energy content per mass unit in the product gases
- Maximum space-time yield
- Stable Processes

Control Procedures

<u>Process control:</u>

Problem:

- **Lack of efficient monitoring (LSBEL)**
- **No process model available**
- **Limited number of actuators**



<u>Future Solutions:</u>

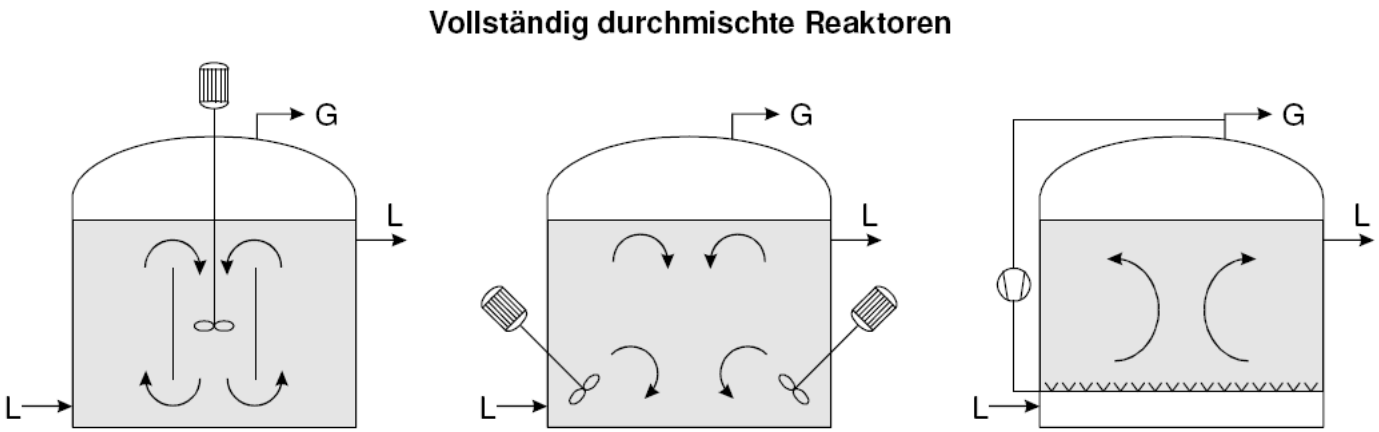
<u>Models</u>

- Fuzzy control
- Chemometric models
- ADM 1

<u>Actuators</u>

- Substrats
- Minerals
- Enzyms
- Starter cultures

Fermenter technology



Weiland, 2006

Conditions in CSTR

- homogeneous distribution of all individual Components in the fermentation brewth
- and in the outlet L. Flow rate of each individual component* is product out of its concentration and the volumetric flow rate

⇒ Volume and volumetric flow have to adapted to biochemical reactiond and bakterial growth rates, i.e long hydraulic retention times

⇒ conditions are equal for all mikroorganisms, i.e. suboptimal

*Components are micro organisms, substrates, intermediates and products

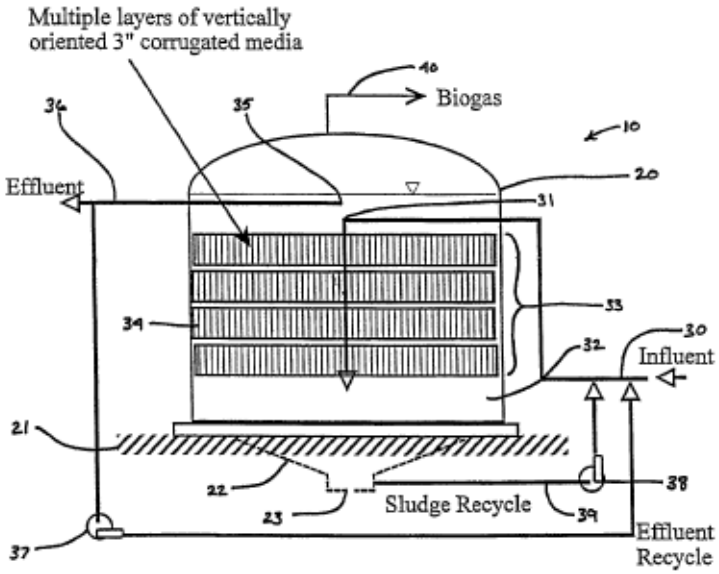
Fermenter technology

Adaption of fermenters to the predilections of the micro-organisms:

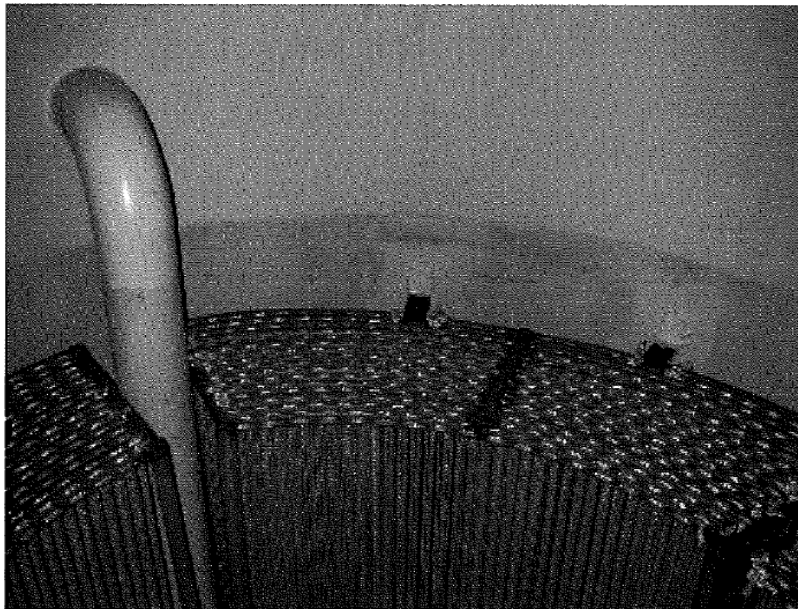
- Fermenter cascades
- Creating the possibility to build biofilms
- Combination of both

Fermenter Technology

- Biofilm building



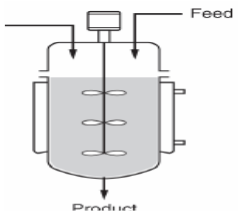
US 2003/0075501 A1, Apr. 24, 2003



ISET, 2007: FFF – Deployment of a fiber packed bed digester

Fermenter Technology

Fermenter cascades– adaption of process condition to particular optimal microbial conversion rate



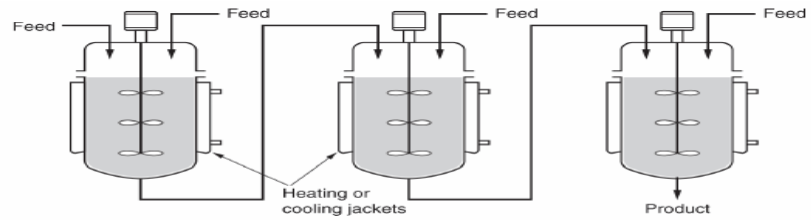


Figure 1-2 Battery of stirred tanks. [Excerpted by special permission from *Chem. Eng.*, *63*(10), 211 (Oct. 1956). Copyright 1956 by McGraw-Hill, Inc., New York, NY 10020.]

OLR	Feed	Biogas Yield	Spalte1	pH
[kg(oDM)/(m3*d)]	[g/d]	[m3/t(oDM)]	[L(G)/(L(F)*D)]	F1
2	27	721	1,7	7,3
4	54	725	2,9	7,3
6	81	701	4,2	6,8
8	108	454	3	6,5
10	135	100	1	6,1

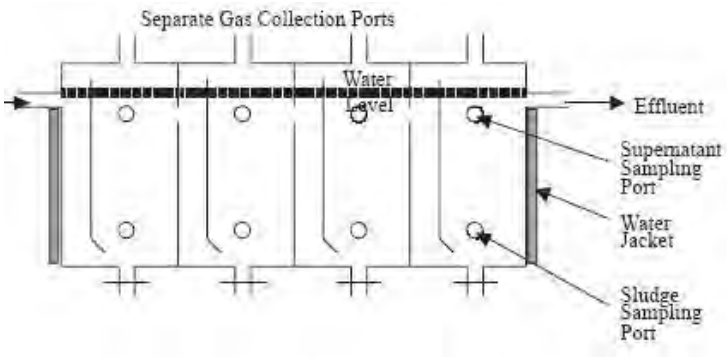
OLR	Feed	Biogas Yield	Spalte1	pH	Spalte2	Spalte3
[kg(oDM)/(m3*d)]	[g/d]	[m3/t(oDM)]	[L(G)/(L(F)*D)]	F1	F2	F3
2	81	740	1,5	7,2	7,3	7,3
4	162	741	2,9	6,6	7,4	7,4
6	244	747	4,4	5,8	6,8	7
8	325	745	5,9	4,7	6,5	7,3
10	406	713	7	4,6	6,3	7,1

OLR: Organic Loading Rate
oDM: Organic Dry Matter

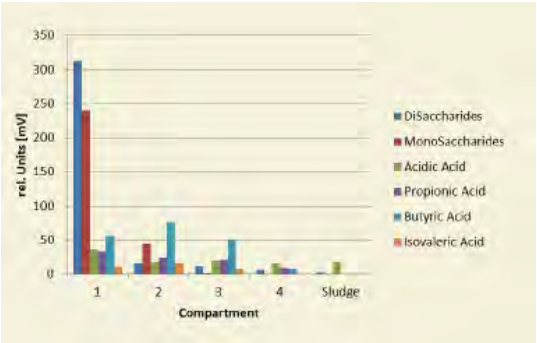
Fermenter Technology - MABR

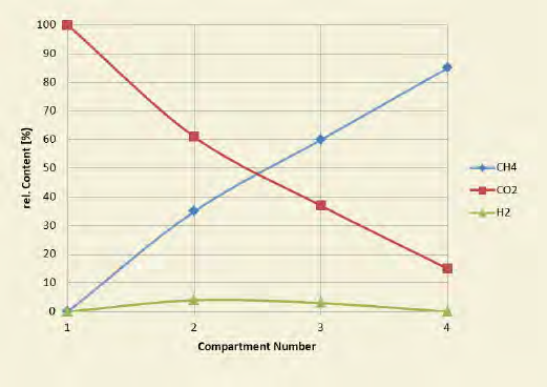
Combination of Cascades and Biofilms

- Multifunctional Anaerobic Baffled Reactor:
  n compartments wiuth settling surface
- Option for inherent biorefinery and internal gas separation (LSBEL)
- Simple and robust container solutions



MABR





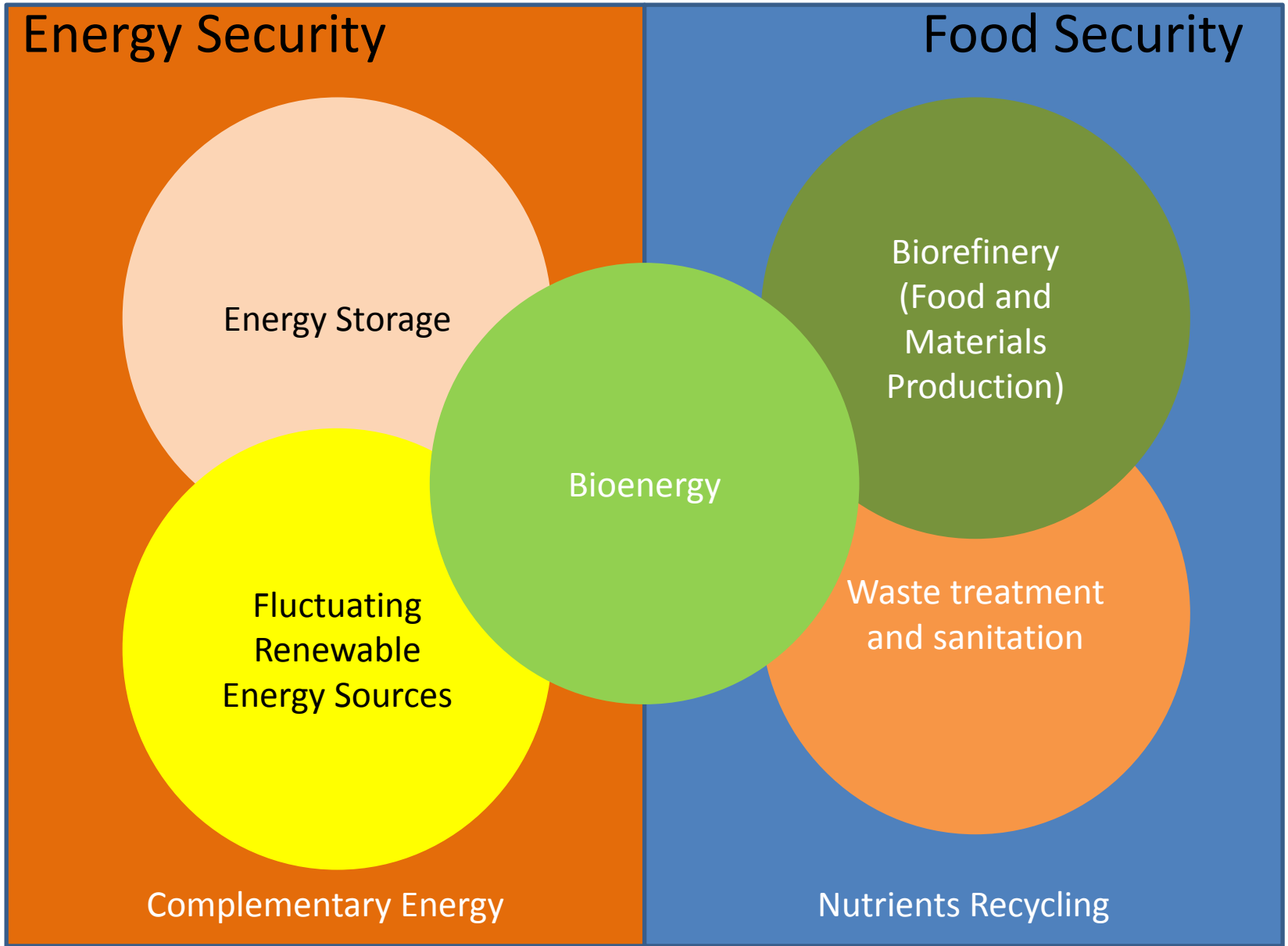
ABR installation at Culmore WwTW, Northern Ireland

Conclusions

1. Biogas technology has a lot of innovative potentials:
   - Simplicity and robustness
   - Maximize efficiency
   - Substrat invariance

2. Promising technologies are already introduced in wastewater treatment, but have to be adapted to the prerequisits in agriculture (dry matter content, .

The Future Role of Bioenergy



The County of Nordfriesland

167.279 Inhabitants;
2052 km^2

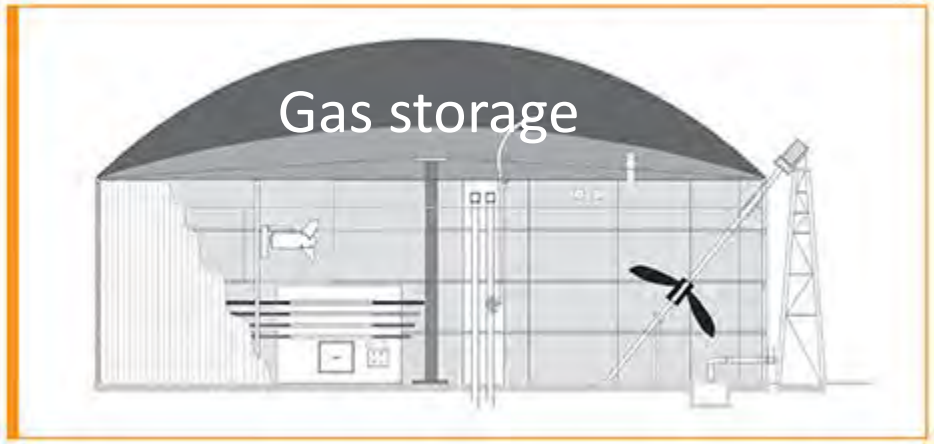
Nordfriesland is the number 3 in Germany in the renewable electricity production to comsumption ratio

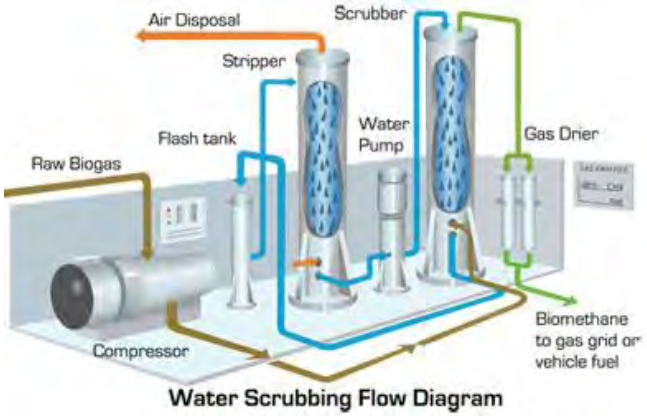
228 %

County of Nordfriesland

Energy Source	plants	Installed Capacity	Electricity Production 2012	Efficiency	Demand Ratio
Renewables			2,823,432 MWh/a		
Solar Power	5,532	247 MWp	232,721 MWh/a	10.8 %	18.8 %
Wind Power	587	887 MWp	2,149,922 MWh/a	27.7 %	173,7 %
Biomass	178	66 MWp	440,787 MWh/a	76,2 %	35,6 %
Demand			1,237,864 MWh/a		

Based on Energymap.info, read 01.02.2013



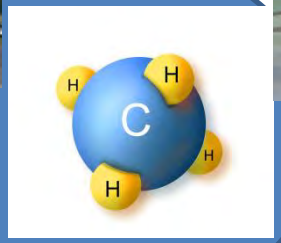


Energy Storage Options

Anaerobic Digestion Supply Chain

Biomass Production

Fuel Production



Electricity Production

Storage Options

Biomass Combustion

Biomass Production

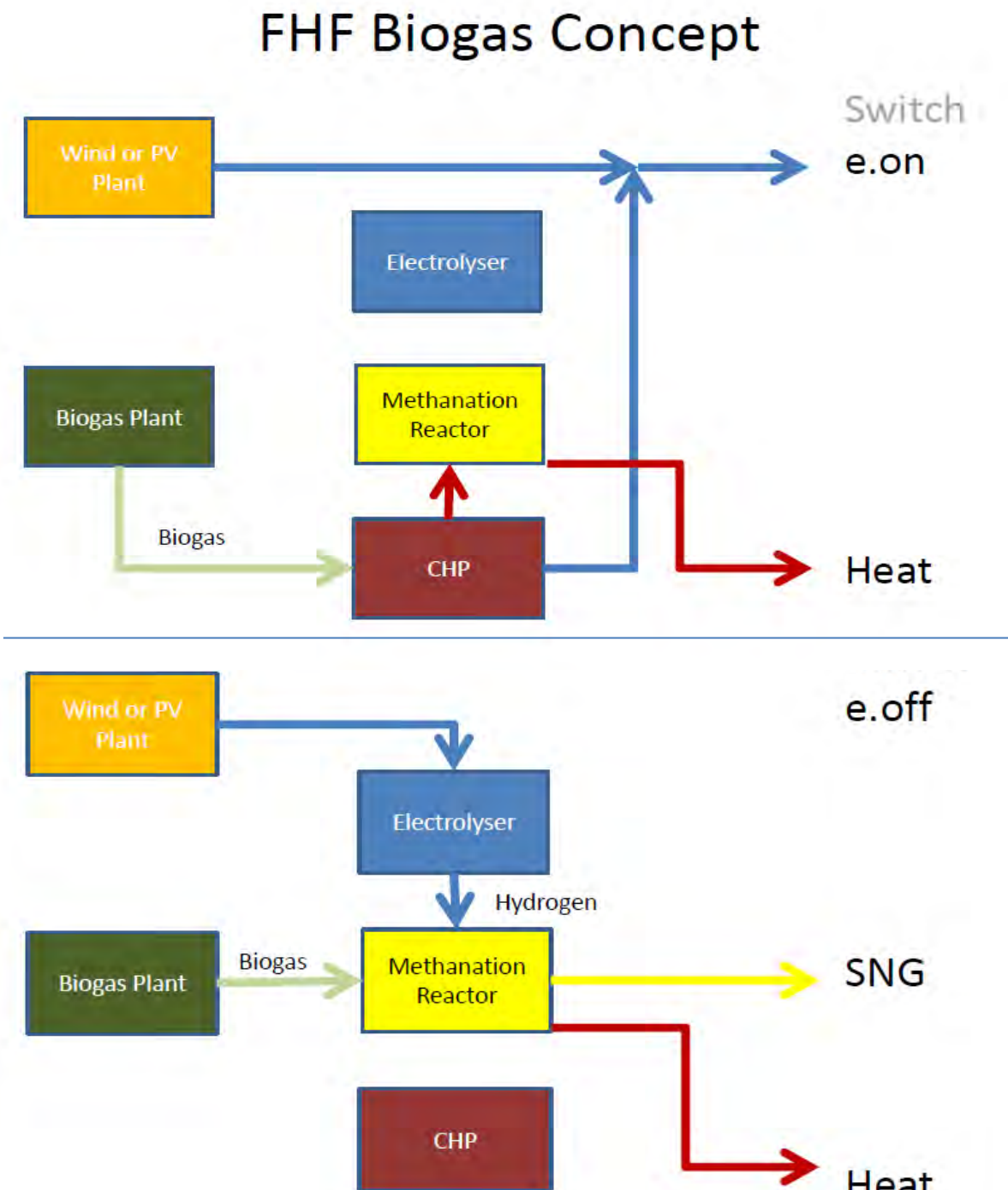
Electricity Production

Complementing the Fluctuating Renewable Energy sources

The five fold amount of electricty from wind or solar energy compared to the electricity produced by the biogas plant may redirected into the gas grid.

The gas grid capacities are much more elastic (4000 fold) than the power grid

(Project within the LSBEL framework)



Conclusions

- Biogas has to be integrated into application contexts
- Biogas offers additional nutrient recycling options
- Biogas offers storage and balance of energy supply to demand relations
- Biogas is a source primarily for decentralized utilisation