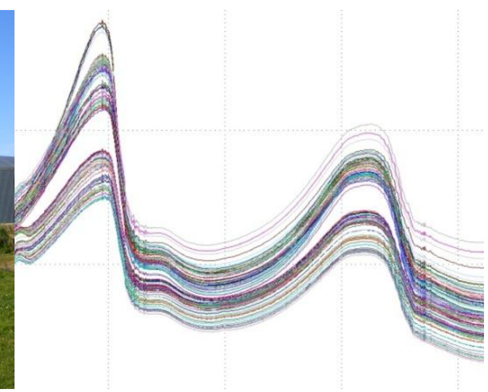
3.rd generation biogas plants and biorefinery platforms

Optimized biogas production by utilization the primary agricultural products: Manure and lignocellulosic crop and crop by-products!

By Jens Bo Holm-Nielsen et al.
Aalborg University, Inst. of Energy Technology

Nordic Biogas Conference
Copenhagen 23-25 April 2012

ACABS Research Group: Applied Chemometrics, Analytical Chemistry, Applied Biotechnology & Bioenergy, and Sampling Research Group (ACABS), Esbjerg Campus, Aalborg University & cooperation with University of Life Science, Biogas Research Center, Oslo, Norway. FHF-Germany and Poldanor, Poland

Sustainable Global Energy

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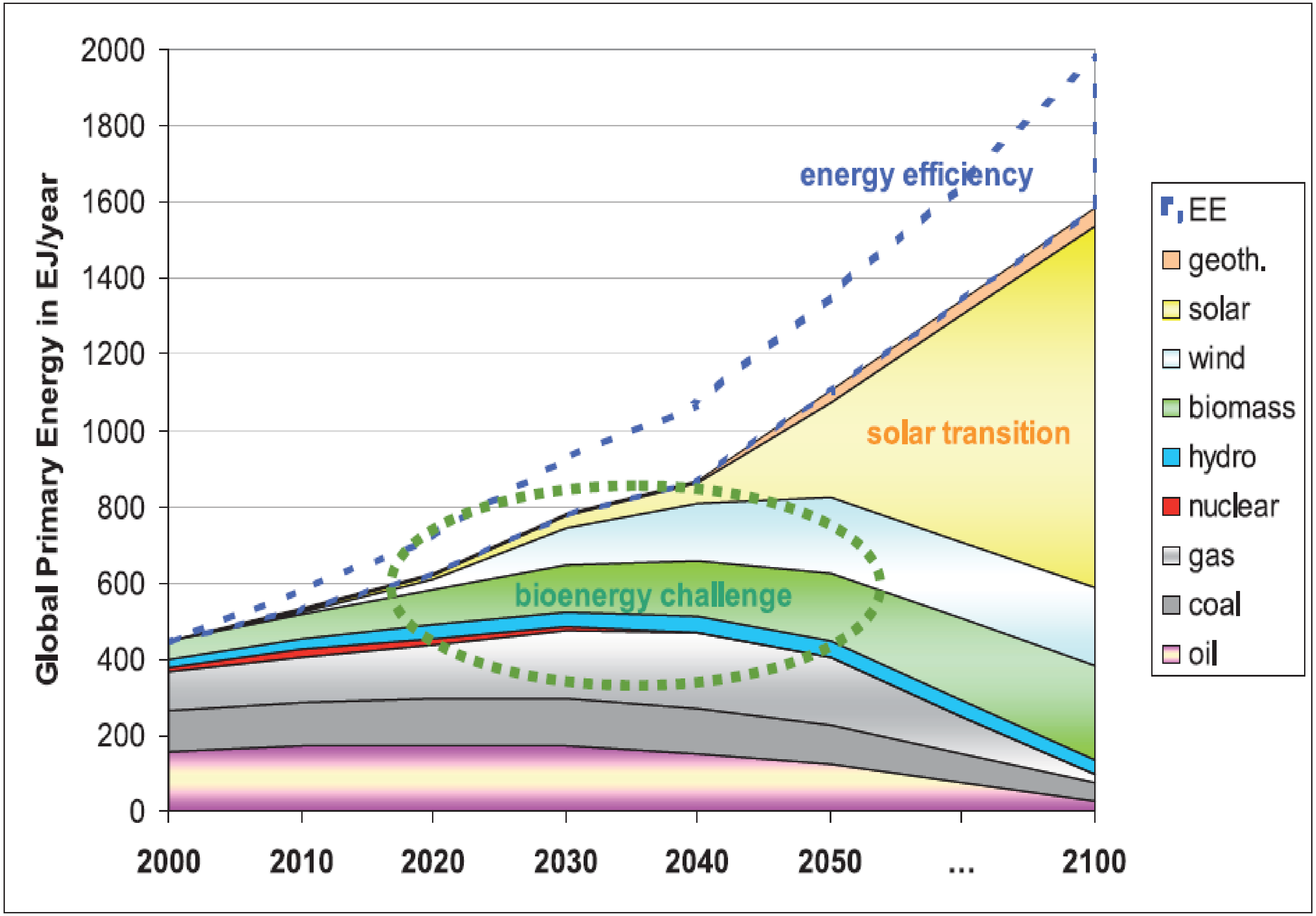
Institut für angewandte Ökologie
Institute for Applied Ecology



Source: IEA (2007), IPCC (2007), UNPD (2004) and WBGU (2003)

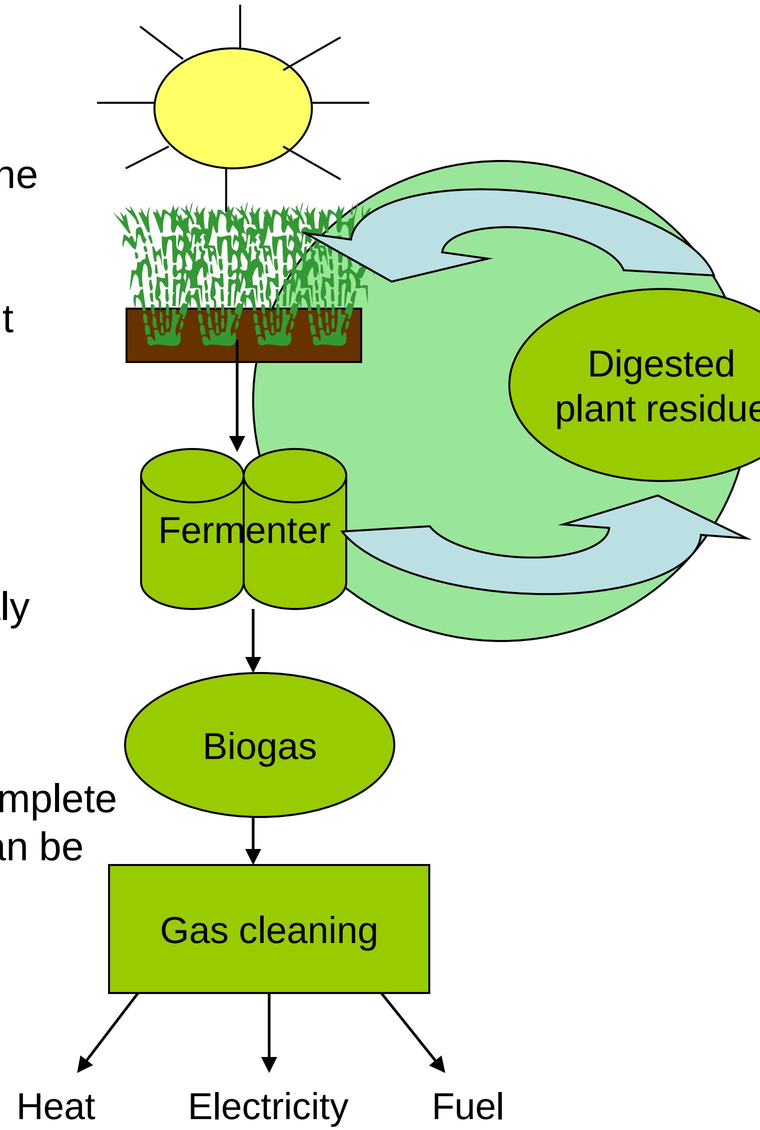
→ Bioenergy will be here to stay, and grow!

Energy unit: PJ	2007	2009	2010	2025
Biomass	101	112	127	200
Windpower	30	30	35	90
Solarpower	~0			75-100
-photovoltaic	~0			
-passive	~0			
Hydropower	~0			
-Wave	~0			
Geothermal	~0			
Fossil fuels	650	666	678	200
Total consumption VE pct.	800-850 15,6%	809 17,6%	836 19,4%	600 66%

Source; JBHN – Centre for Bioenergy, AAU, Esbjerg 2011 , & Energistyrelsen. Governmental stastistics 2010.

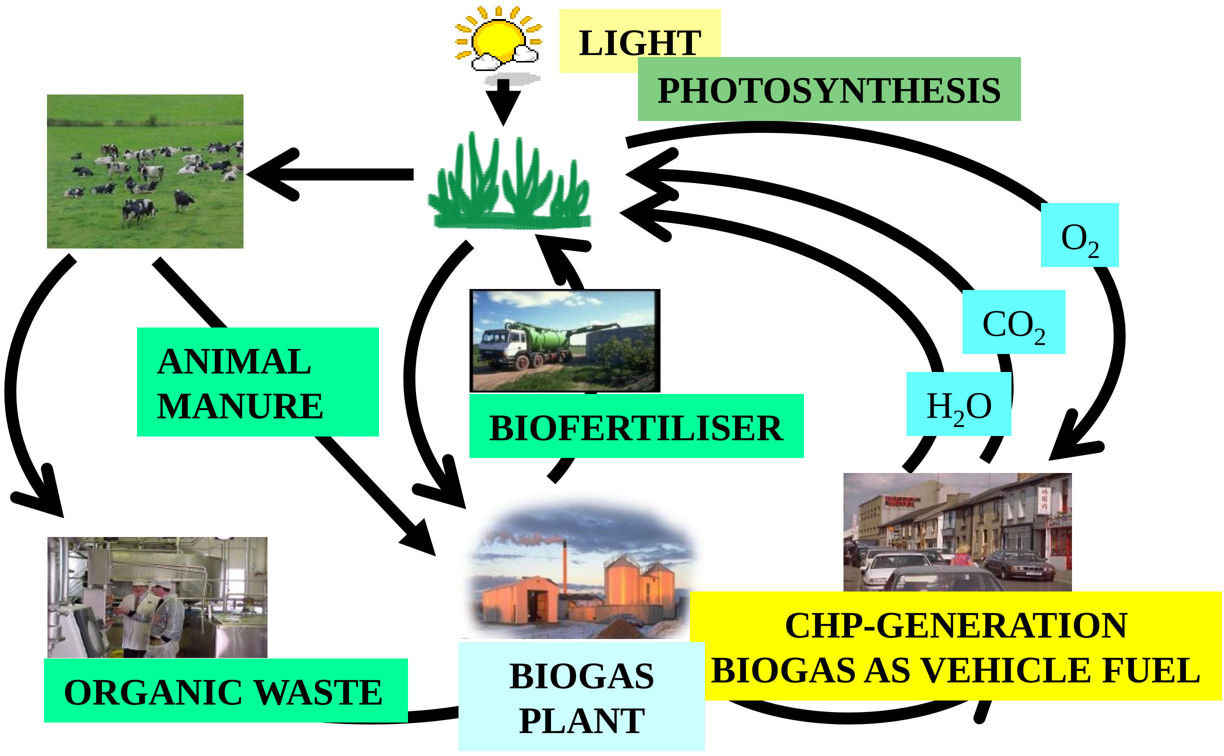
Energy crops → Paradigm shift through land productivity and energy balance

- The Sun as energy source
- Special energy crops that use the entire vegetation period
- Total digestion of the whole plant
- Nutrient cycle possible
  Low Input → High Output
- Large installations work efficiently and are friendly towards the environment
- Upgrading of biogas enables complete utilisation of the crop (the gas can be stored)
- Biorefineries;biothanol/biogas/ biodiesel



Source: KWS

Biogas for a sustainable clean environment and renewable energy production



Source: JBHN/TAS

Estimated amounts of animal manure in EU-27 (based on Faostat, 2003)

Country	**Cattle**	**Pigs**	**Cattle**	**Pigs**	**Cattle manure**	**Pig manure**	**Total manure**
	[1000Heads]	[1000Heads]	1000livestock units	1000livestock units	[10^6 tons]	[10^6 tons]	[10^6 tons]
Austria	2051	3125	1310	261	29	6	35
Belgium	2695	6332	1721	529	38	12	49
Bulgaria	672	931	429	78	9	2	11
Cyprus	57	498	36	42	1	1	2
Czech R.	1397	2877	892	240	20	5	25
Denmark	1544	13466	986	1124	22	25	46
Estonia	250	340	160	28	4	1	4
Finland	950	1365	607	114	13	3	16
France	19383	15020	12379	1254	272	28	300
Germany	**13035**	**26858**	**8324**	**2242**	**183**	**49**	**232**
Greece	600	1000	383	83	8	2	10
Hungary	723	4059	462	339	10	7	18
Ireland	7000	1758	4470	147	98	3	102
Italy	6314	9272	4032	774	89	17	106
Latvia	371	436	237	36	5	1	6
Lithuania	792	1073	506	90	11	2	13
Luxembourg	184	85	118	7	3	0	3
Malta	18	73	11	6	0	0	0
Netherlands	3862	11153	2466	931	54	20	75
Poland	5483	18112	3502	1512	77	33	110
Portugal	1443	2348	922	196	20	4	25
Romania	2812	6589	1796	550	40	12	52
Slovakia	580	1300	370	109	8	2	11
Slovenia	451	534	288	45	6	1	7
Spain	6700	25250	4279	2107	94	46	140
Sweden	1619	1823	1034	152	23	3	26
U.K.	10378	4851	6628	405	146	9	155
EU-27	**91364**	**160530**	**58348**	**13399**	**1284**	**295**	**1578**

Energy potential of pig and cattle manure in EU-27

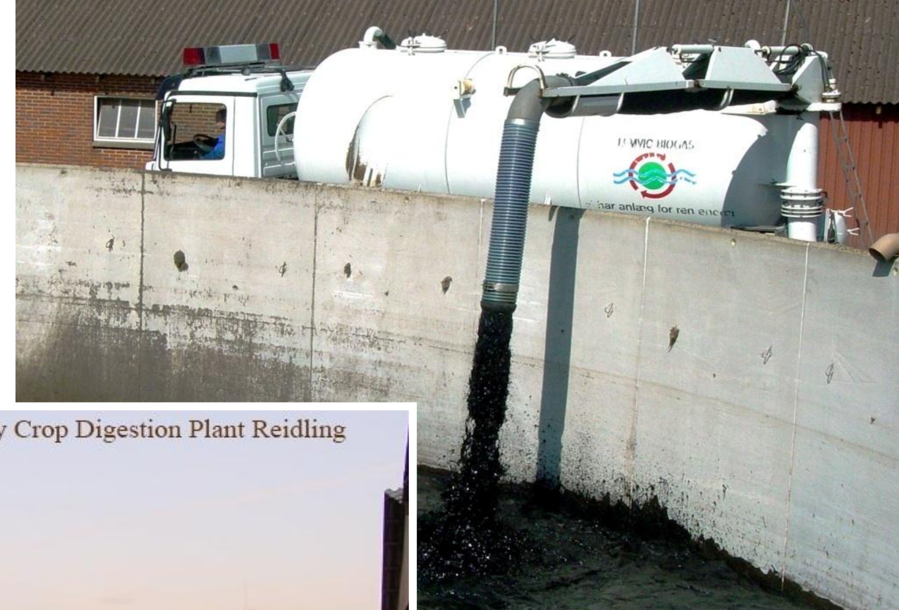
Total manure	Biogas	Methane	Potential	Potential
[10^6 tons]	[10^6 m^3]	[10^6 m^3]	[PJ]	[Mtoe]
1,578	31,568	20,519	827	**18.5**

Methane heat of combustion: 40.3 MJ/m^3; 1 Mtoe = 44.8 PJ
Assumed methane content in biogas: 65%

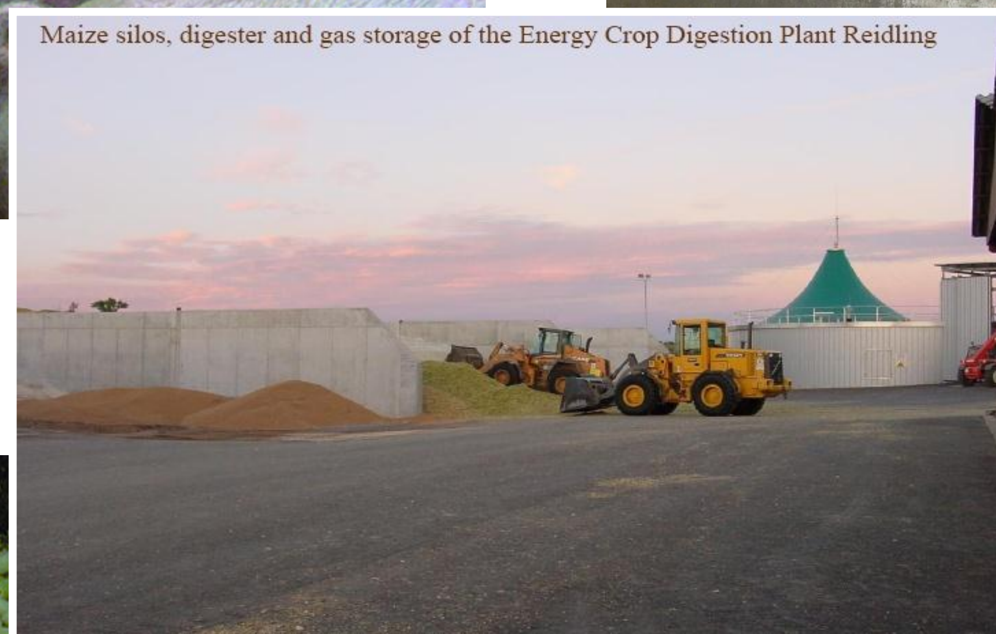
Biogas Production & Forecast:

Actual 2010 production of biogas in EU 27:	10 Mtoe
2012-2015 EU forecast	15 Mtoe
Manure potentials	18.5-20 Mtoe
Organic waste and byproducts	15-20 Mtoe
Crops and crop residuals	20-30 Mtoe
Total long term forcast Biogas	**60 Mtoe**

Biogas can cover 1/3 of EU's total RES 20% demands year 2020



AD Co-digestion - heterogeneous feedstock's

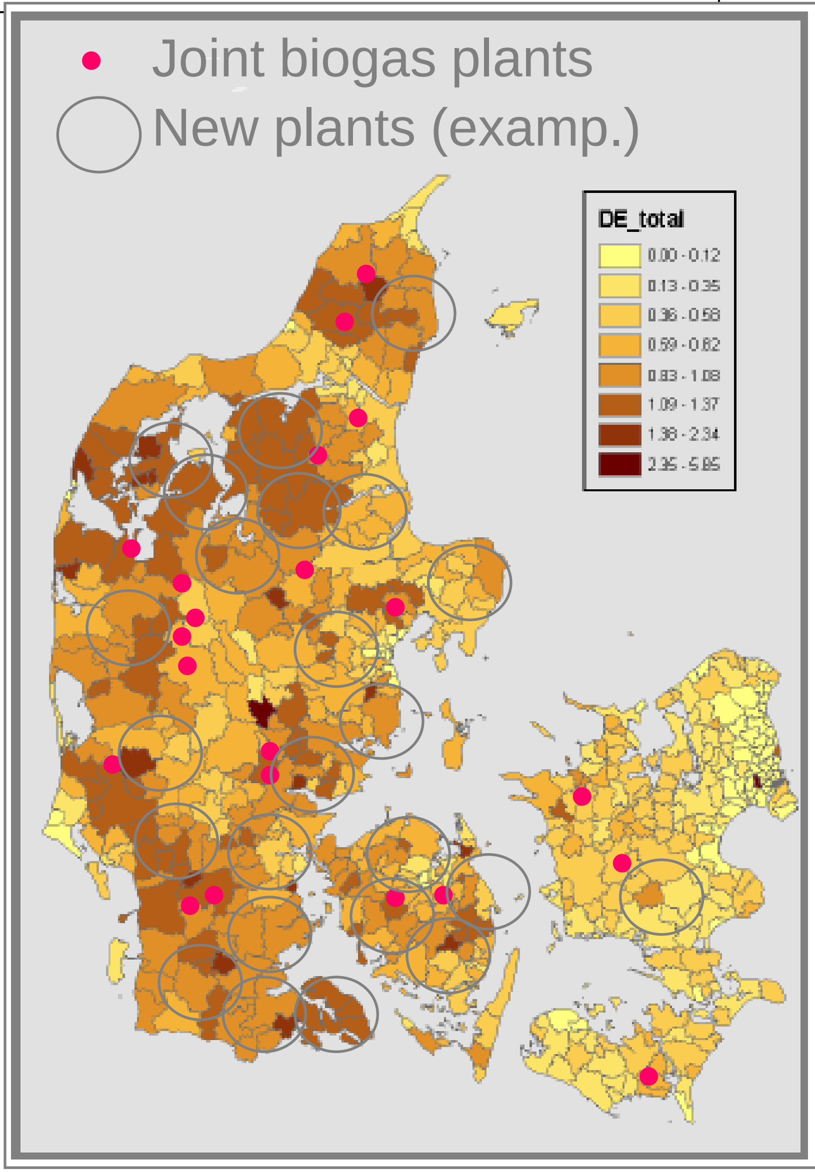


- Manure
- Food waste
- Organic by-products
- Crops

Biogas

- **Redistribution and treatment facilities**
- **Organic fertilizer plants**
  - Bioslurry, biofibres and other biomasses.
  - Redistribution and surplus treatment as organic fertilizer sale products
  - Electricity, heat and transportation fuels
  - Water environment, Climate combat and odour reduction
  - Further treatment of fibres
  - Digested fibre incineration /gasification
- **Increased utilisation of biogas**
  - Local and further distances from the biogas plants – gas
  - CHP utilisation and the transport sector

  *** Biogas are biorefinery platforms step 1.**
  - This is the future challenge 2012-2020
  - Need fast tracks, by all new projects



Biogas and biogas + separation, upgrading facilities

Animal manure

– from farming problems to society resources!

Where to utilize the biogas?

Decentralized CHP

Direct transmission

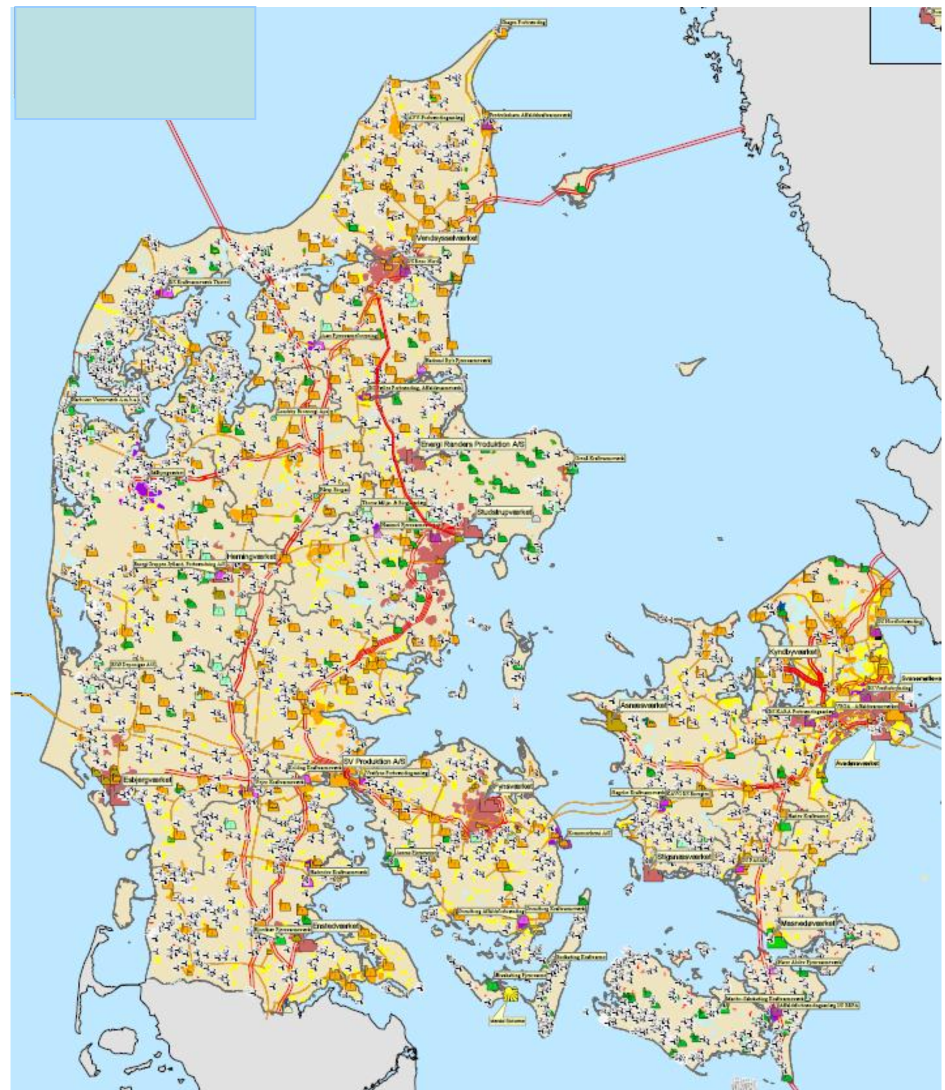
- Cheap and simple
- Local integration

Naturgas grid trans.

- Possibilities of storing
- Better industrial use
- Multi purpose incl. FC's

*** Transport fuels**

- Most efficient biofuel for some apps, low carbon footprint!



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Ribe Biogas Plant; a full scale test facility for several R&D projects. Sampling points for feedstock's and inoculums

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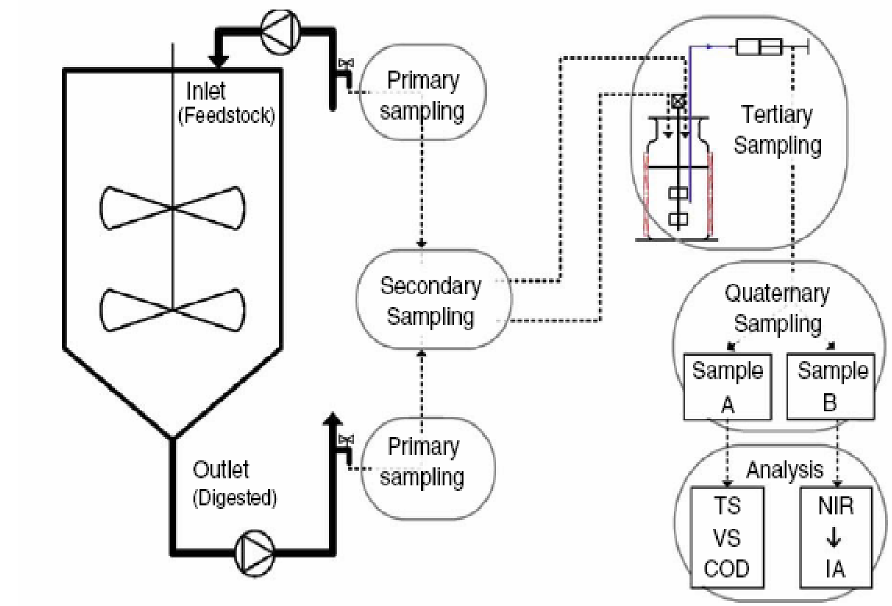
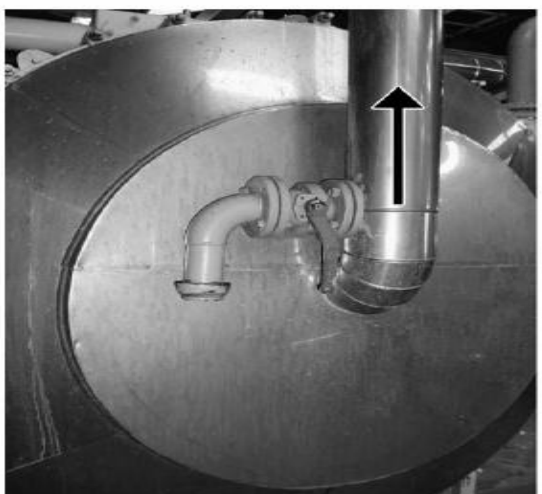
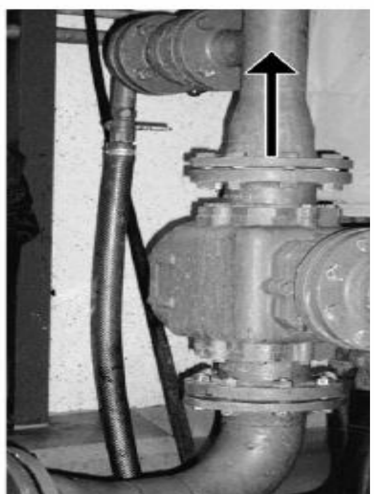
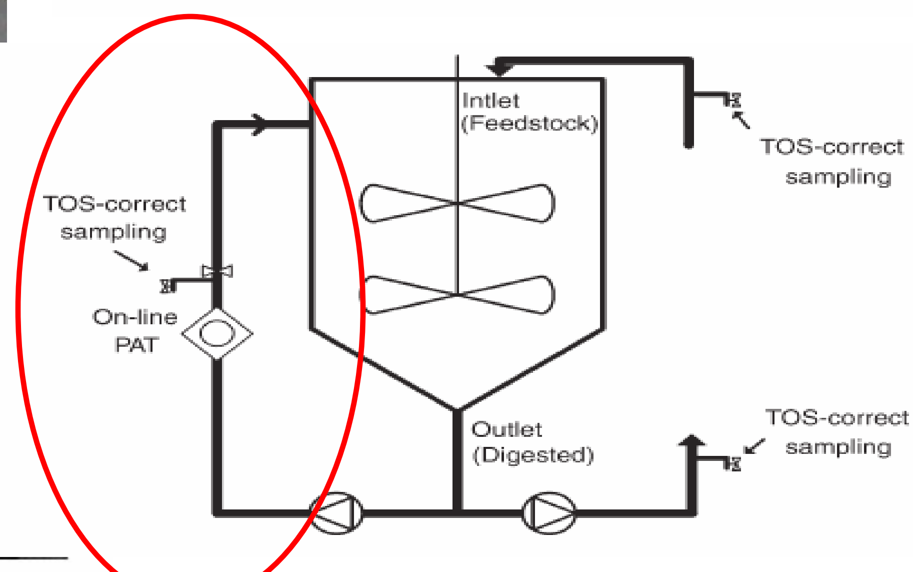








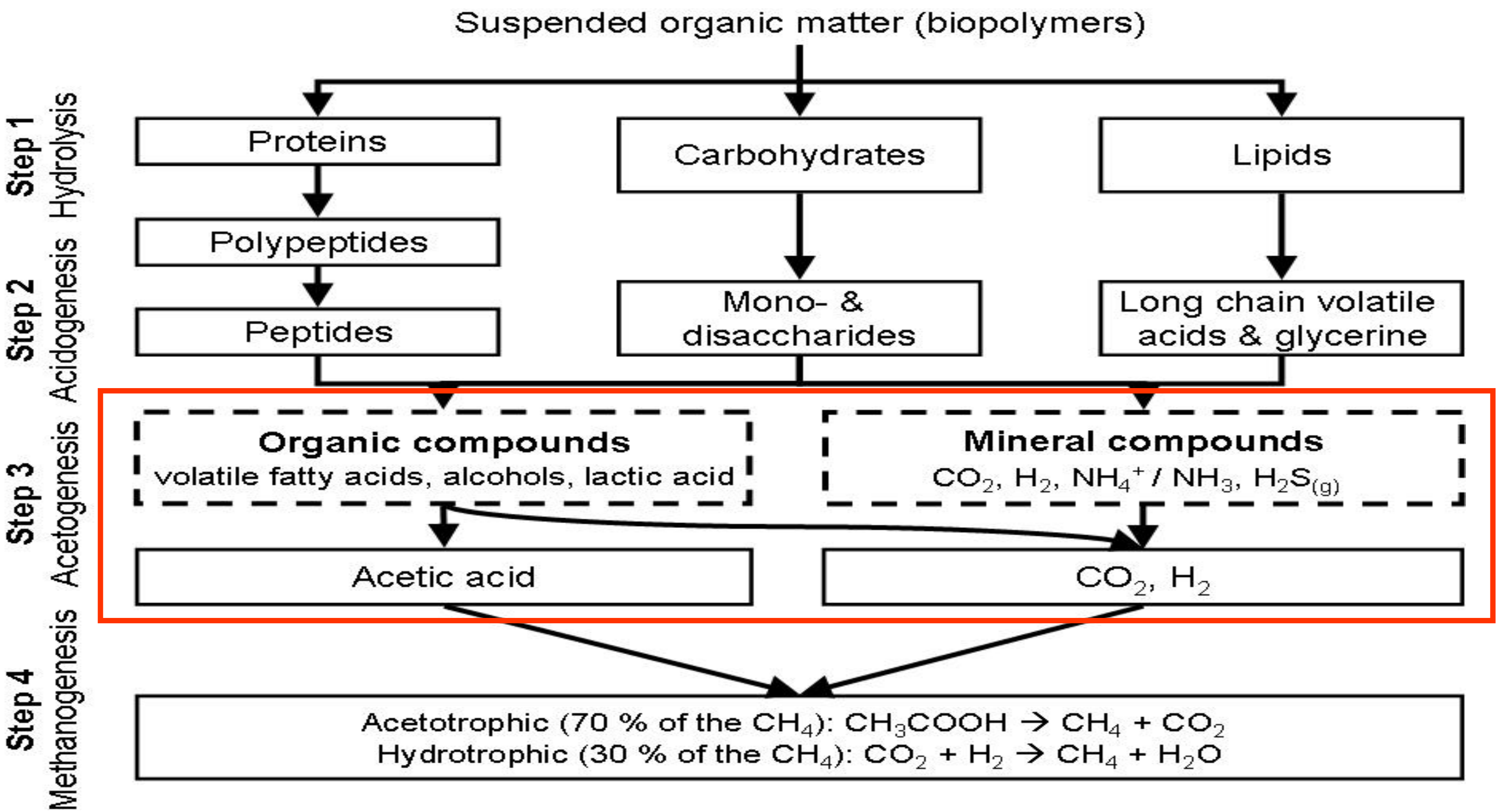
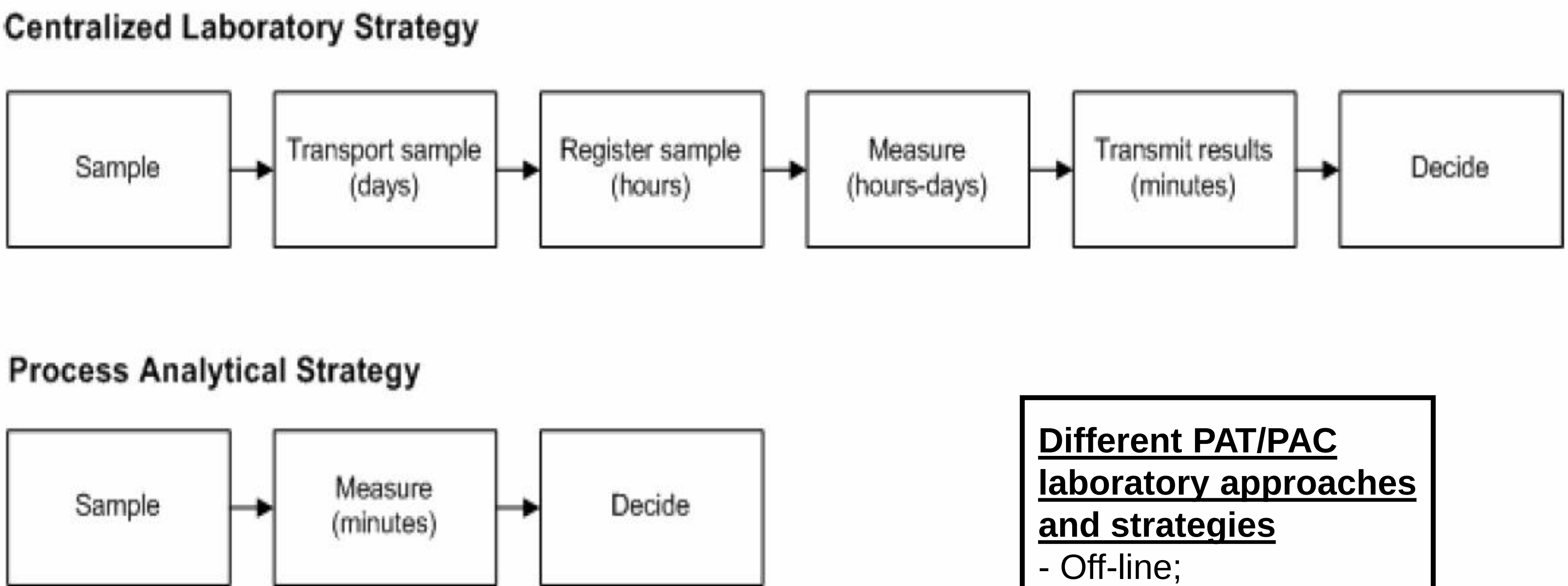


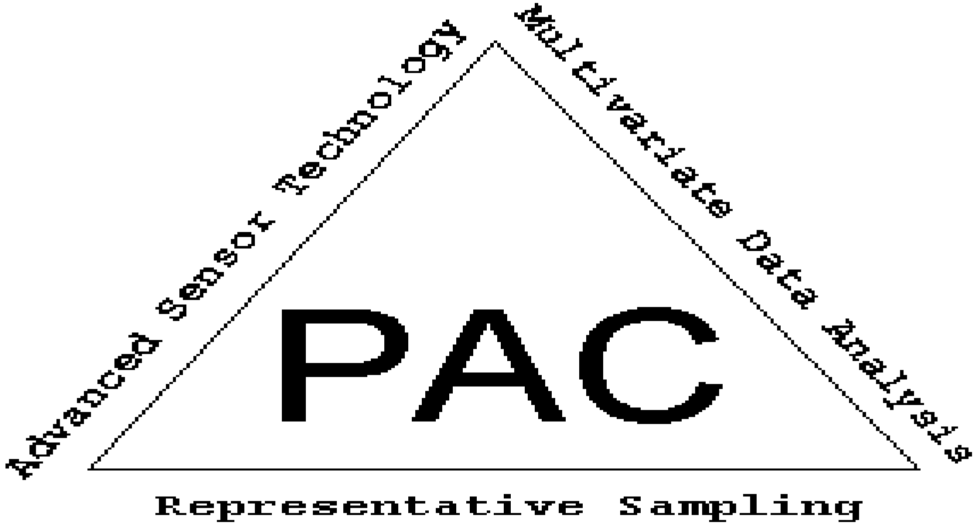
Fig. 4.3: The four principal process steps in the general anaerobic digestion – biogas production process. The dashed boxes indicate important intermediate compounds, where severe inhibitions can occure. (Holm-Nielsen et al 2008).



Comparison of analytical strategies for process monitoring
(Mortensen 2006)

<u>Different PAT/PAC laboratory approaches and strategies</u>
- Off-line;
- At-line;
- On-line;
(McLennan 1995)

Time consuming versus on-line real time measurements!



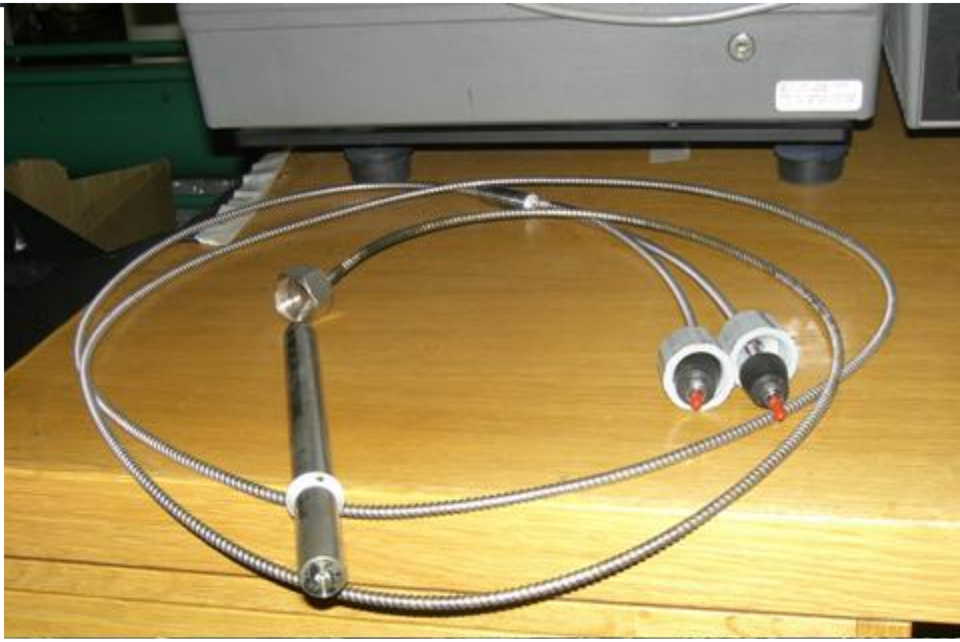
Fundamental disciplines of Process Analytical Chemistry (PAC)
(Mortensen, 2006). PAT integration in the AD sectors (JBHN, 2008)

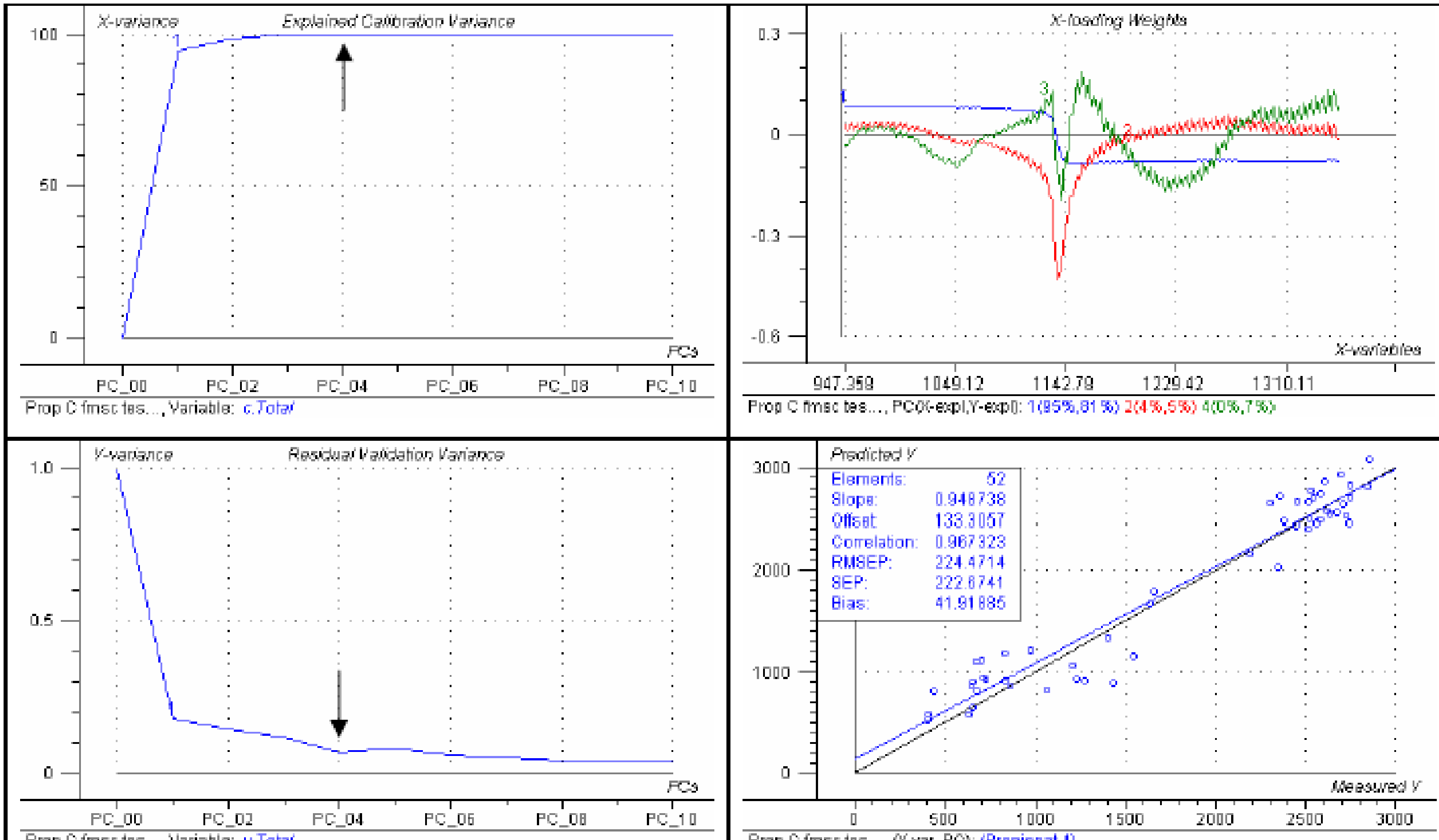
Numerous technologies can be applied in a PAT measuring programs for process understanding and controlling. The technologies can be categorized in four major areas:

1. **Technologies that imply use of Process Analytical Technology or Process Analytical Chemistry**
2. **Technologies for monitoring and control of the process and end products**
3. **Technologies for continuous improvement of gained process knowledge**
4. **Technologies for acquisition and analysis of multivariate data**

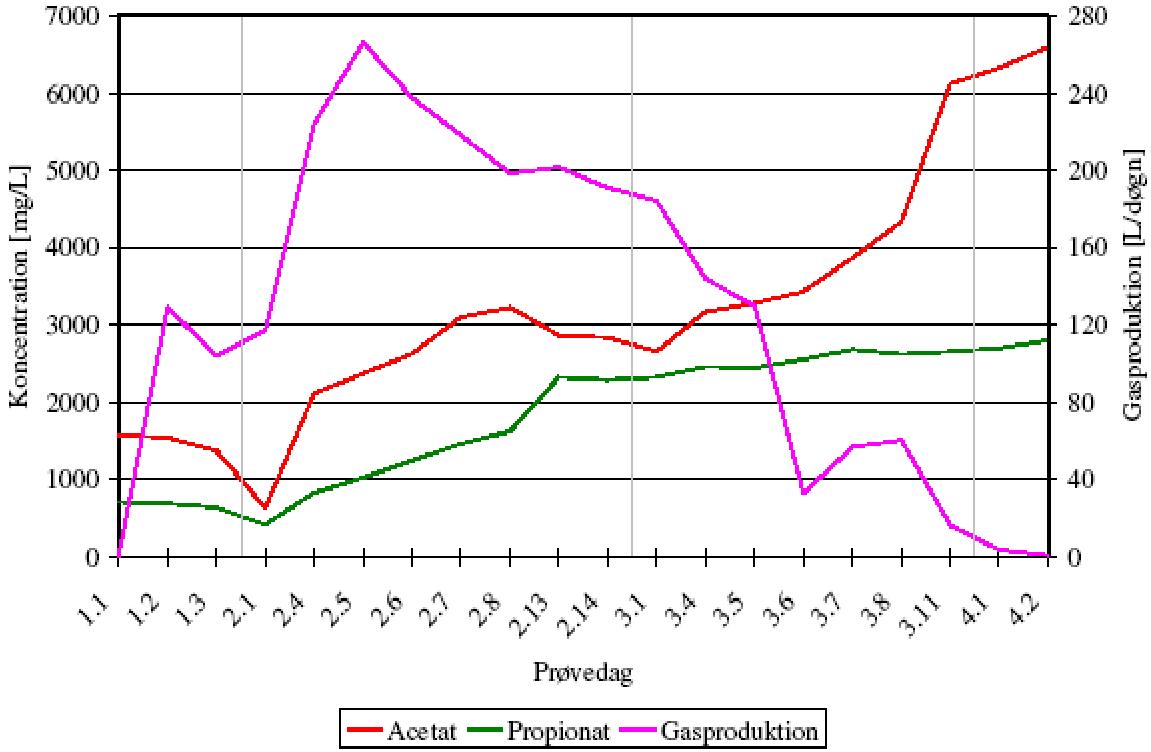
(FDA - PAT Guidance, 2005)

Linkogas full scale trials, 2007 - 2008
- on-line PAT monitoring fermenter 3, 2400 m3

Model for probionic acid; MSC corrected, *test set validation*

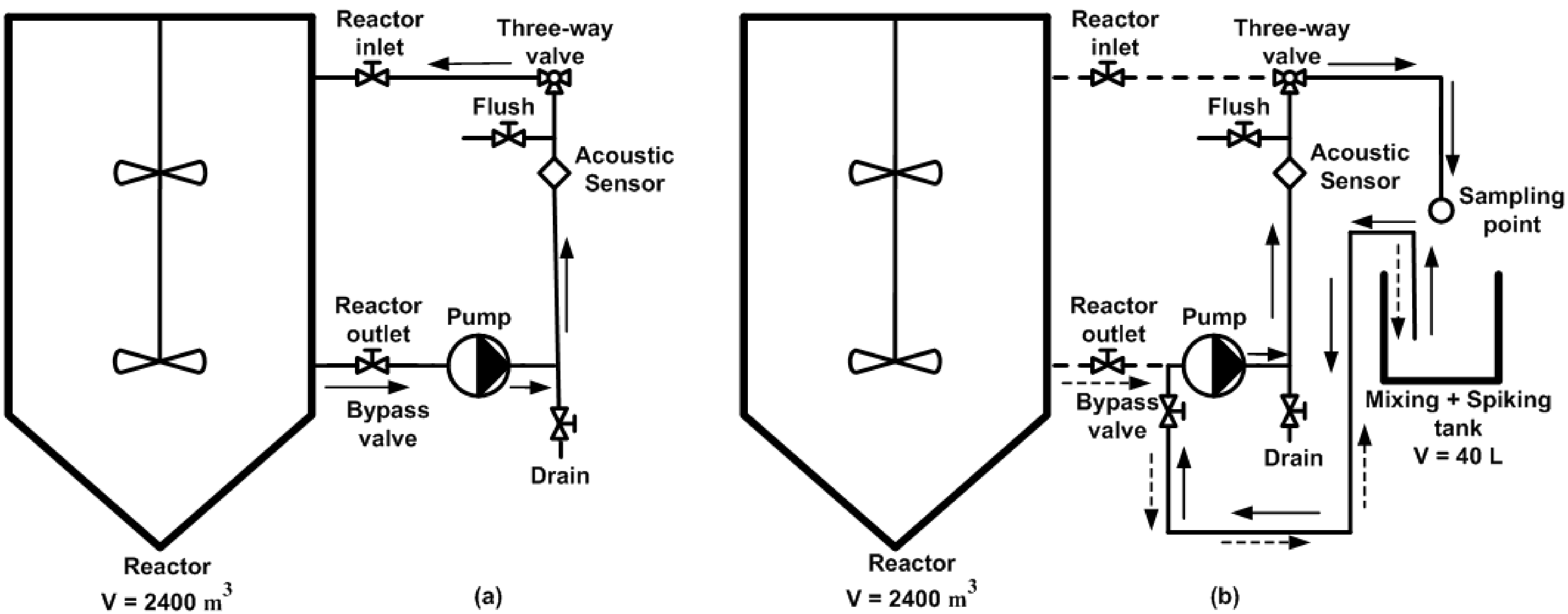


Concentration level of acetate and propanoic acid and corrected biogas production during the trial period.

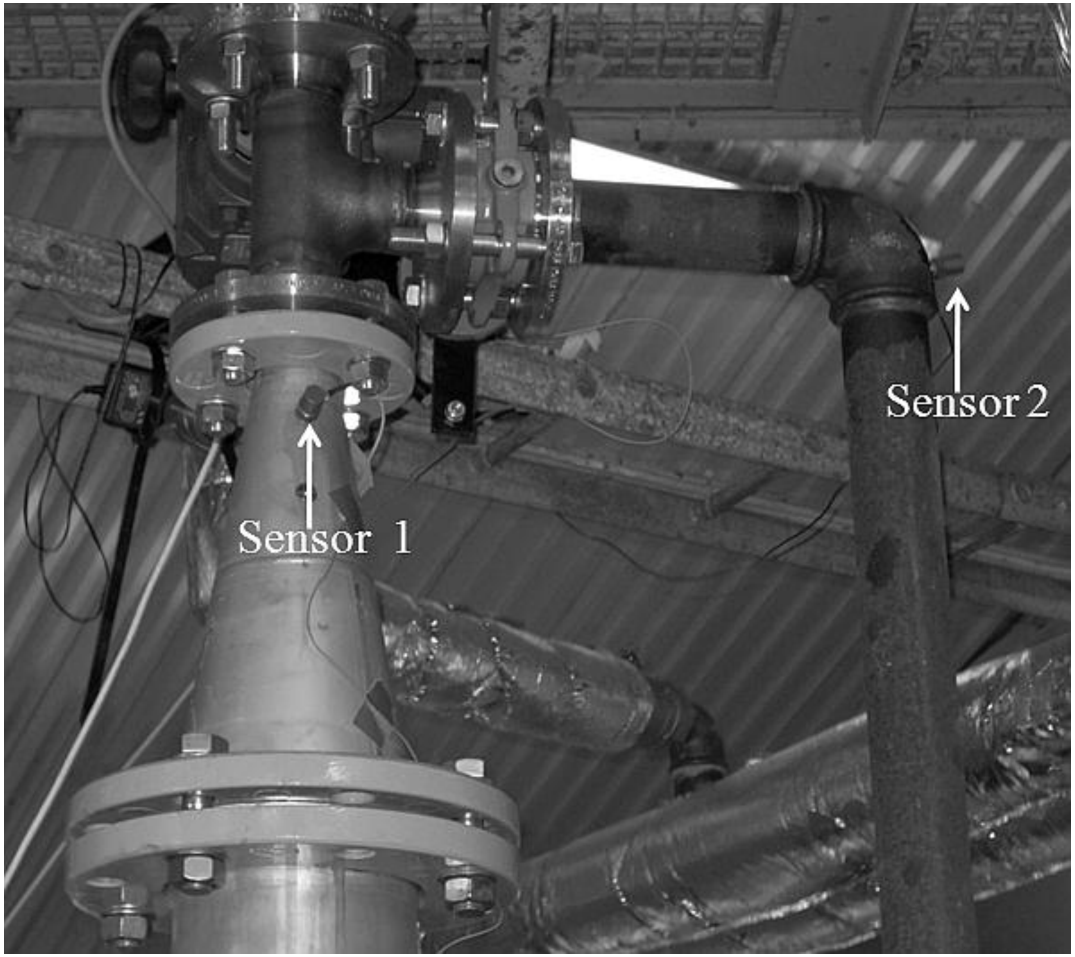
Referenceparameter	Slope	r^2	Outlier	PLS-komp.
Total VFA	0,921	0,919	8	4
Acetat	0,893	0,887	9	4
Propionat	0,949	0,936	8	4
i-butyrat	0,921	0,904	5	2
Butyrat	0,926	0,933	(6) 7	4
Meth.but + i-valerat	0,932	0,950	(6) 5	4
Valerat	0,892	0,920	(18) 6	4
Ammonium-N	0,905	0,882	6	2

Statistics from best calibration models; MSC corrected, *test set validation*

Process instrumentation diagram of the process loop

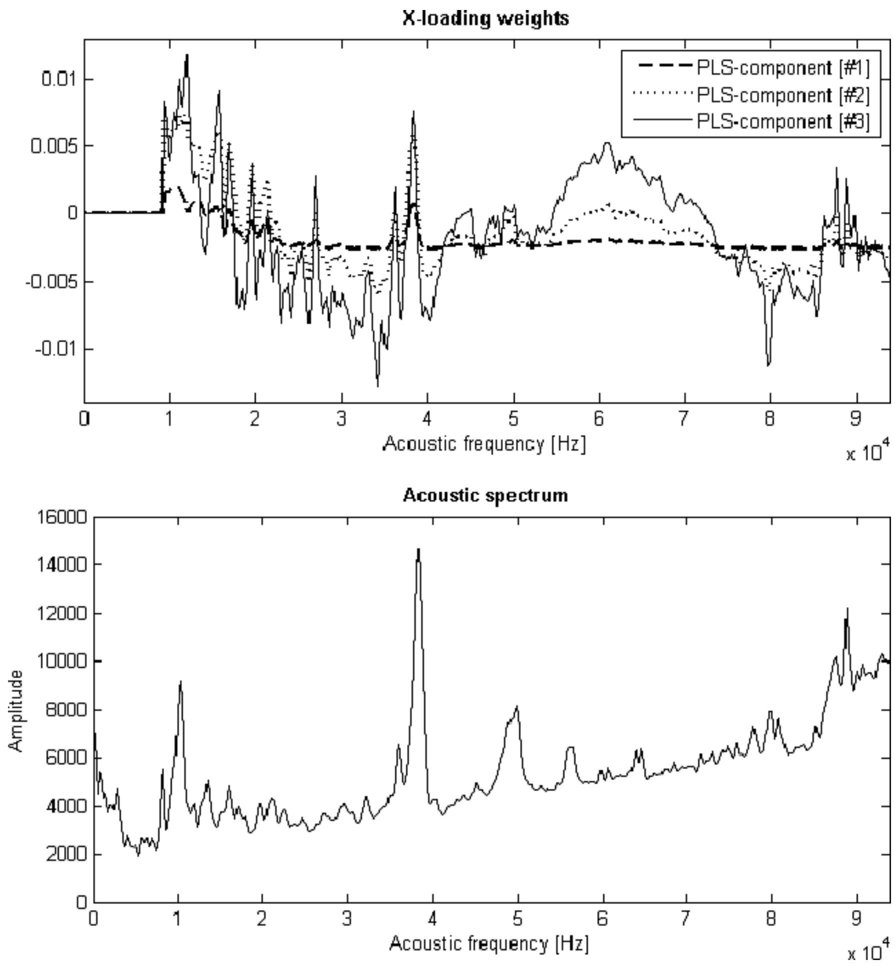


Acoustic sensors deployment at two different bypass string locations

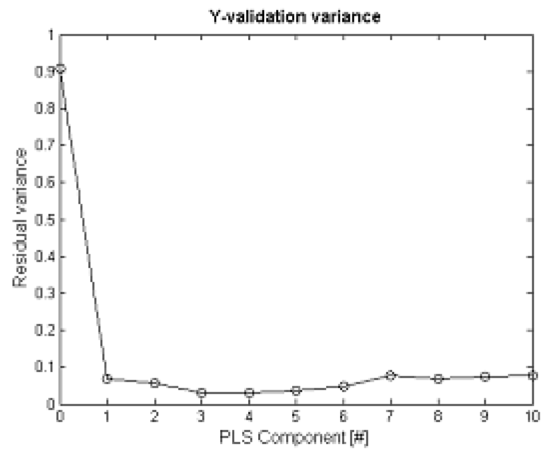


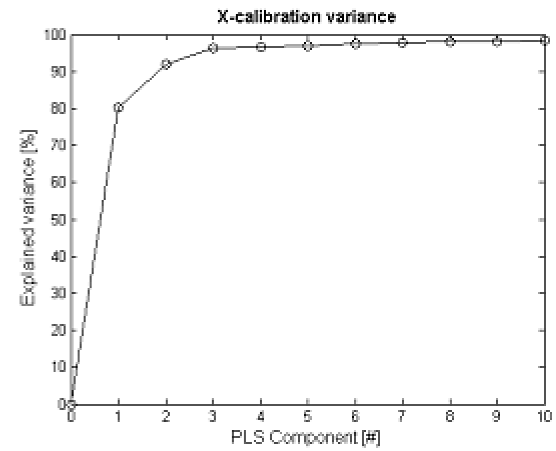
(Felicia N. Ihunegbo et al., in press, 2011)

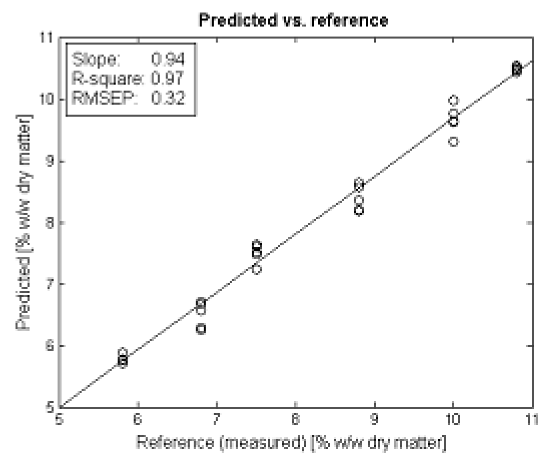
Loading weights and an acoustic spectrum with corresponding frequencies



(Felicia N. Ihunegbo et al., in press, 2011)





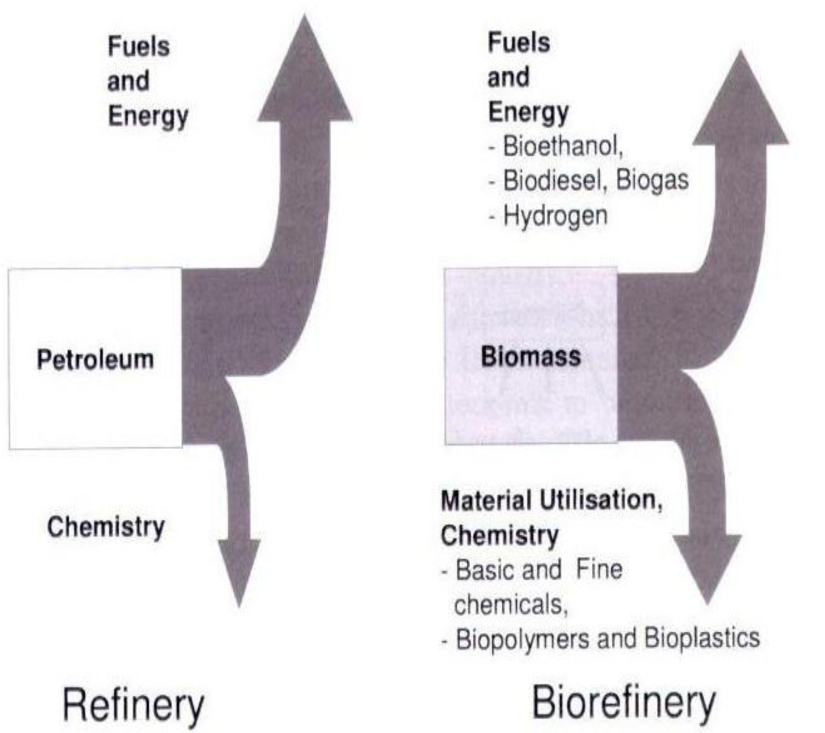


Acoustic chemometric prediction of total solids in bioslurry:
a full-scale feasibility study for on-line biogas process monitoring

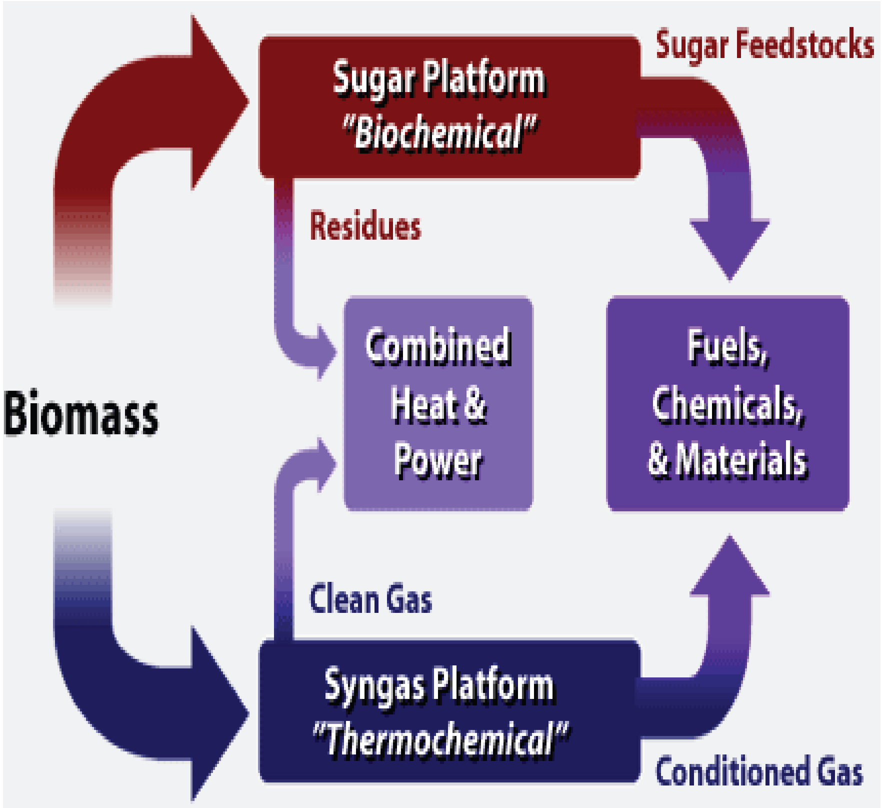
Felicia N. Ihunegbo, Michael Madsen, Kim H. Esbensen, Jens Bo Holm-Nielsen, Maths Halstensen (2011)

Ribe Biogas; 22 years of production, 18.000 m3 biogas/day. New project in the pipelie for 30.000m3/day, 2012. Source J. B. Holm-Nielsen, Energy Technology, AAU, Denmark.

Biorefineries



Comparison of the basic principles of the petroleum refinery and the biorefinery, Source: Kamm et al. 2006



Two-platform biorefinery concept
Source: NREL 2006, Biomass Programm, DOE/US]

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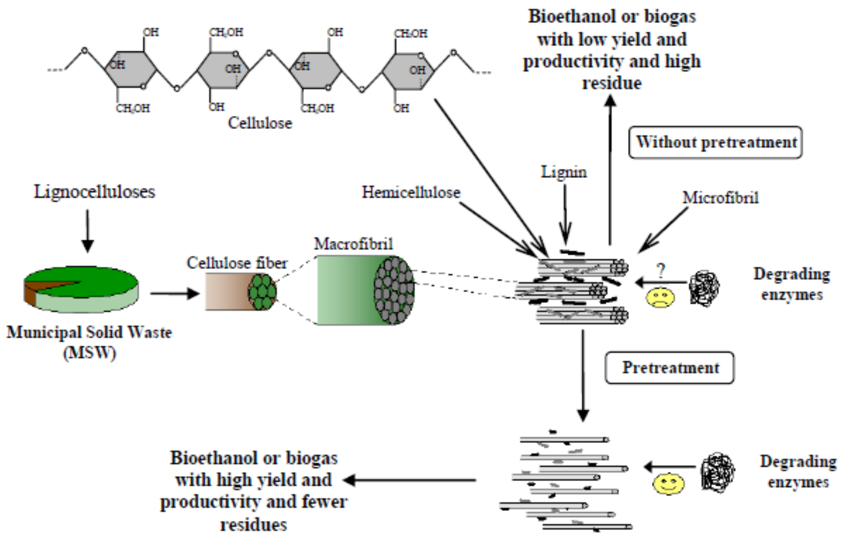
Enhacing biogas production from lignocelluloses and manure using steam explosion pretreatment

Lignocellulosic biomass employed: *Salix viminalis* ”Christina”.

Steam explosion Unit at UMB campus, Ås, Norway.
(CAMBI, Asker, Norway)

Source: Taherzadeh and Karimi, 2008. *Pretreatment of Lignocellulosic Wastes to Improve Ethanol and Biogas Production: A Review. Int. J. Mol. Sci. 9, 1621-1651;* ISSN 1422-0067.



It is a high temperature treatment followed by a rapid pressure drop, causing a mechanical disruption of the lignocellulosic fibers.
Porosity increases and hemicelluloses and celluloses become more available free from lignin for the microorganisms to degrade.
No chemical addition is needed except H2O, no sample pre-treatment and minimum handling, many biomasses can be treated this way in the same unit.

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CAMBI
- recycling energy

Modelling and optimisation of the CAMBI TH process for biomass pretreatment

Sebastian Buch Antonsen
Henrik Tække r Madsen
Anna Frederike Goßmann

8. semester 2010

Figure 30 Product container directly after the flash, releasing a lot of steam

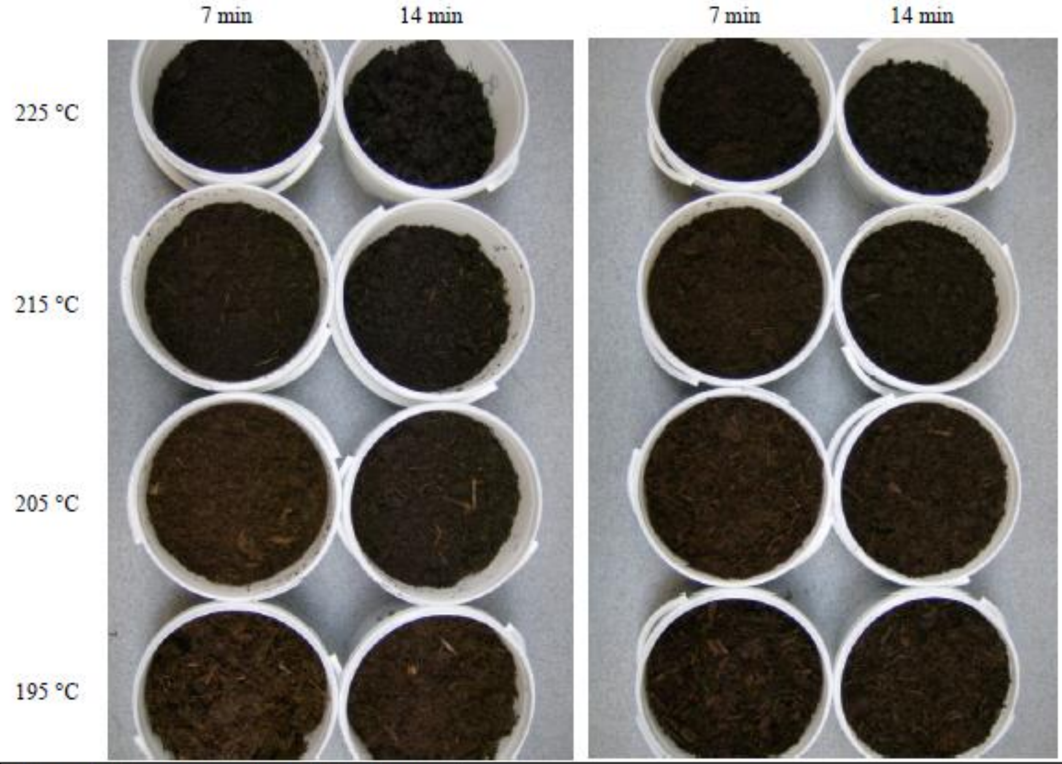


Figure 31 Left: straw series; Right: willow series

Figure 32 Left: willow without flash; Middle: willow at same conditions with one flash; Right: willow at same conditions with double flash

Biogas trials in batch and semi-continuous systems

Best Salix pretreatment?

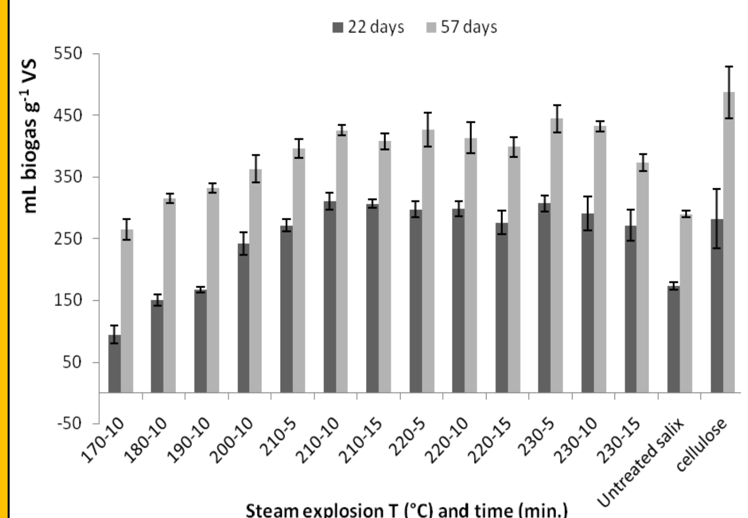
1st batch experiment- Steam Exploded *Salix* at different combinations of Temp. and time.

Best mixture ratio ?

2nd batch experiment- Codigestion of best Steam Exploded *Salix* + cow manure at different C/N ratio mixtures

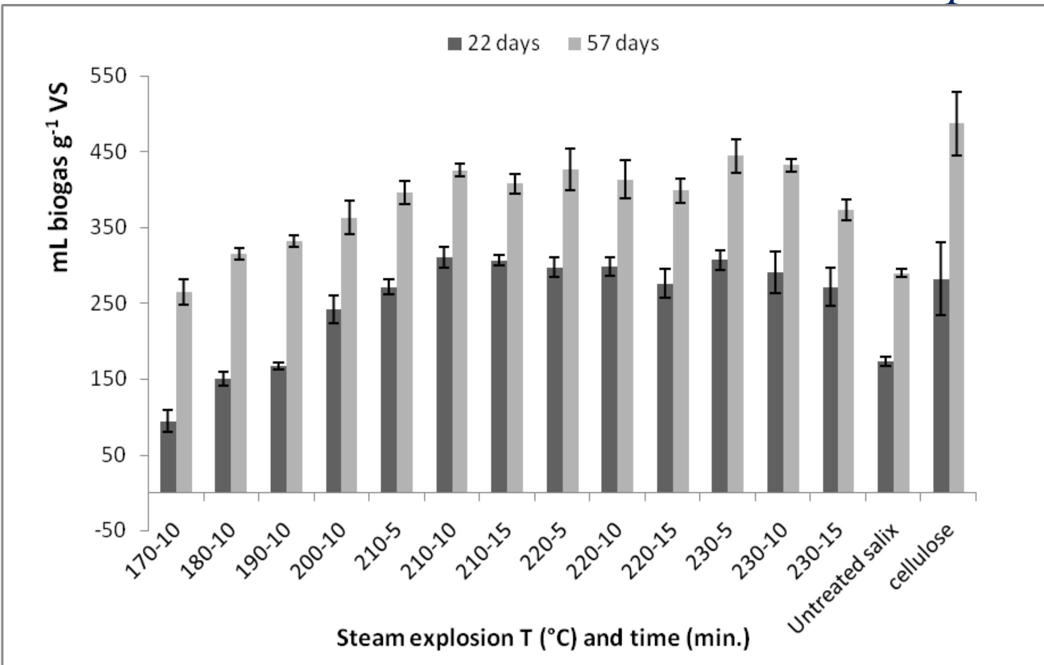
future experiments- Codigestion in CSTR of pretreated *Salix* + cow manure mixtures, monitoring of process balance (stability) and methane yield.

- Steam explosion proved to be an effective pre-treatment for ***Salix*** , methane yield increased up to 50 %.
- Higher and relatively similar methane yield values were obtained for all the treatment temperatures above 210 °C.
- 210 °C - 10 minutes chosen as pre-treatment conditions.
- Co-digestion gave an overall more stable process.
- First 20 days = 82 % of total CH_4 was produced, whilst in no-codigestion 20 days = 69 %.
- Up to 40% lignocellulosic biomass was possible to co-digest giving a good methane yield (230 $mLCH_4$ /gVS)

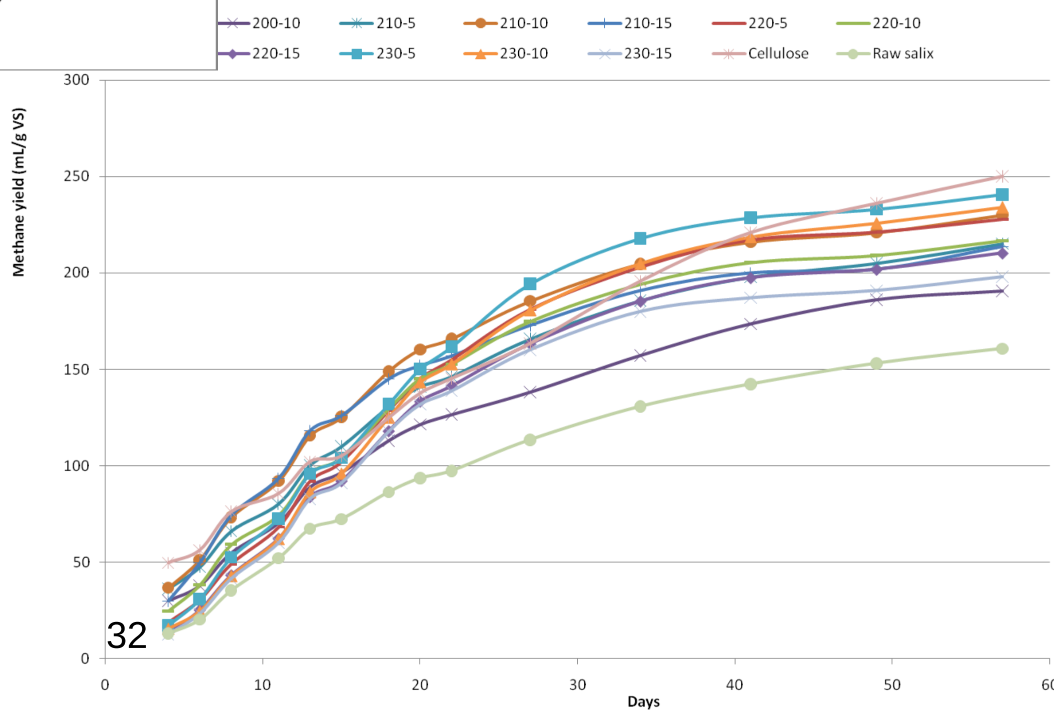


Small scale (batch): Experiment 1.-

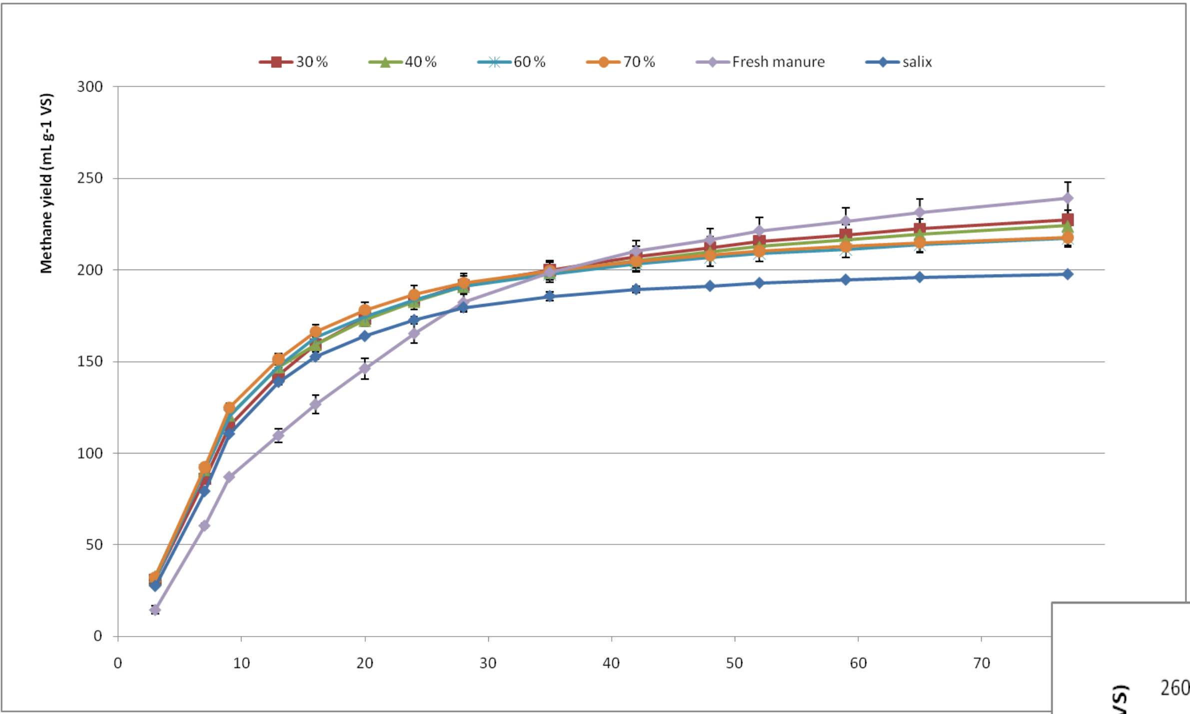
Salix steam exploded at different temperatures and times

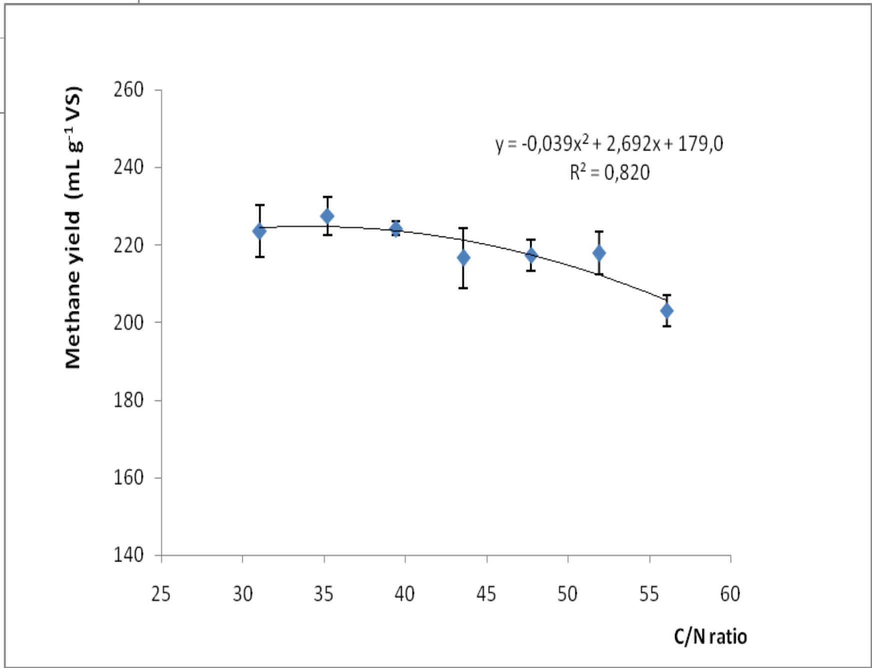


- **Steam explosion proved to be an effective pre-treatment for *Salix* , methane yield increased up to 50 %.**
- **Methane content in the biogas throughout the experiment varied from 45 to 56 %.**
- **Higher and relatively similar methane yield values were obtained for all the treatment temperatures above 210 ºC.**
- **210 ºC - 10 minutes were chosen as the pre-treatment conditions for *Salix* in next experiment.**



Co-digestion of steam exploded Salix and manure at different C/N ratios (% VS of each substrate)





- **Co-digestion gave an overall more stable process.**
- **First 20 days = 82 % of total CH_4 was produced, whilst in no-codigestion 20 days = 69 %.**
- ***23* % less methane produced with already digested manure.**
- **Up to 40% lignocellulosic biomass was possible to co-digest giving a good methane yield (ca.230 mL CH_4 /gVS)**

Environmental and Nature Conservation considerations; Permanent grassland and pastures – at such areas the nature has the highest priority.

- Ruman grasing or small amounts of biomass harvesting from extensive grassland areas can take place if its in a strategy to support the management of species-rich grassland, to maintain a high biodiversity.

The open landscape

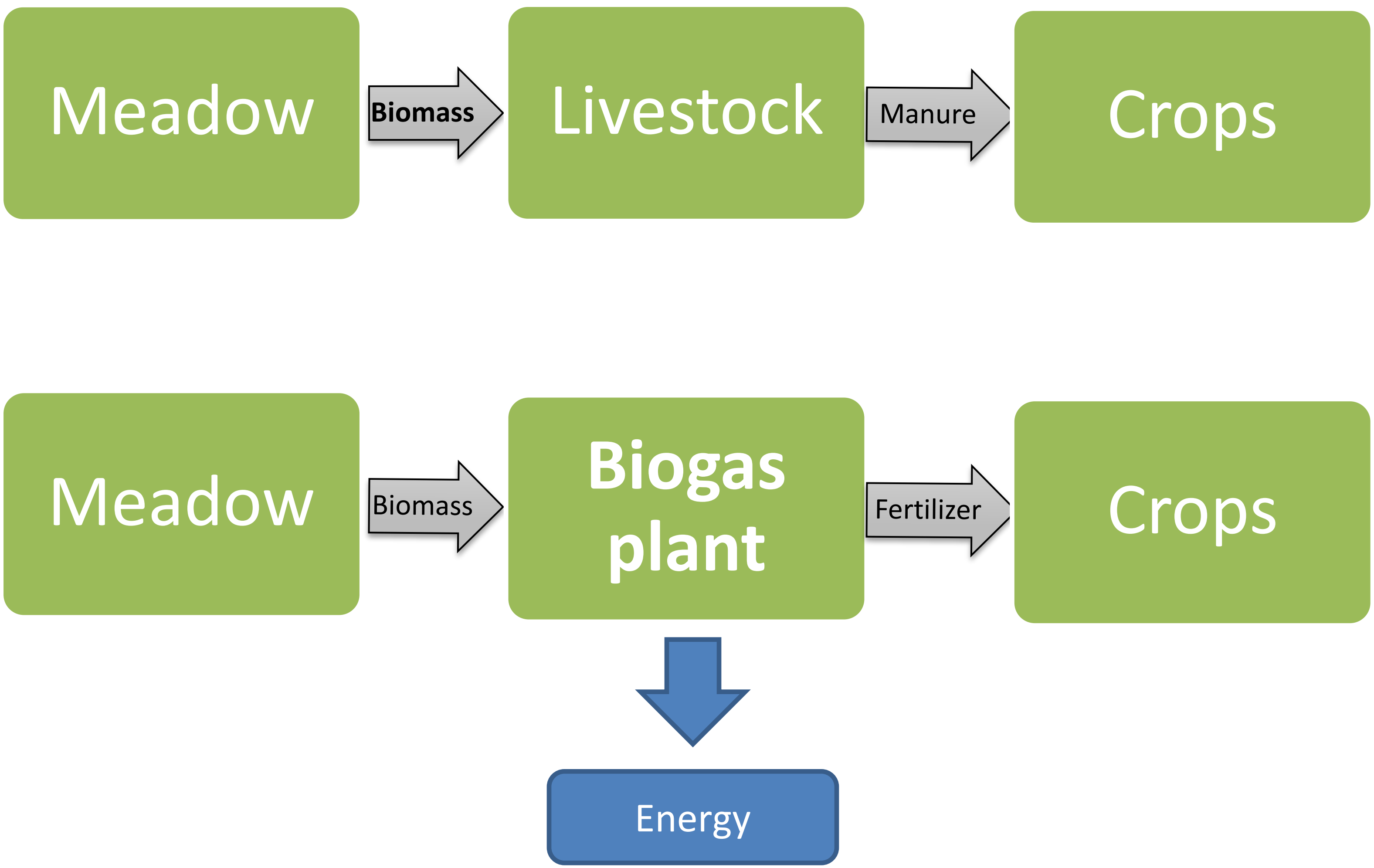
Meadow, heather, marshland, moor, lakes…

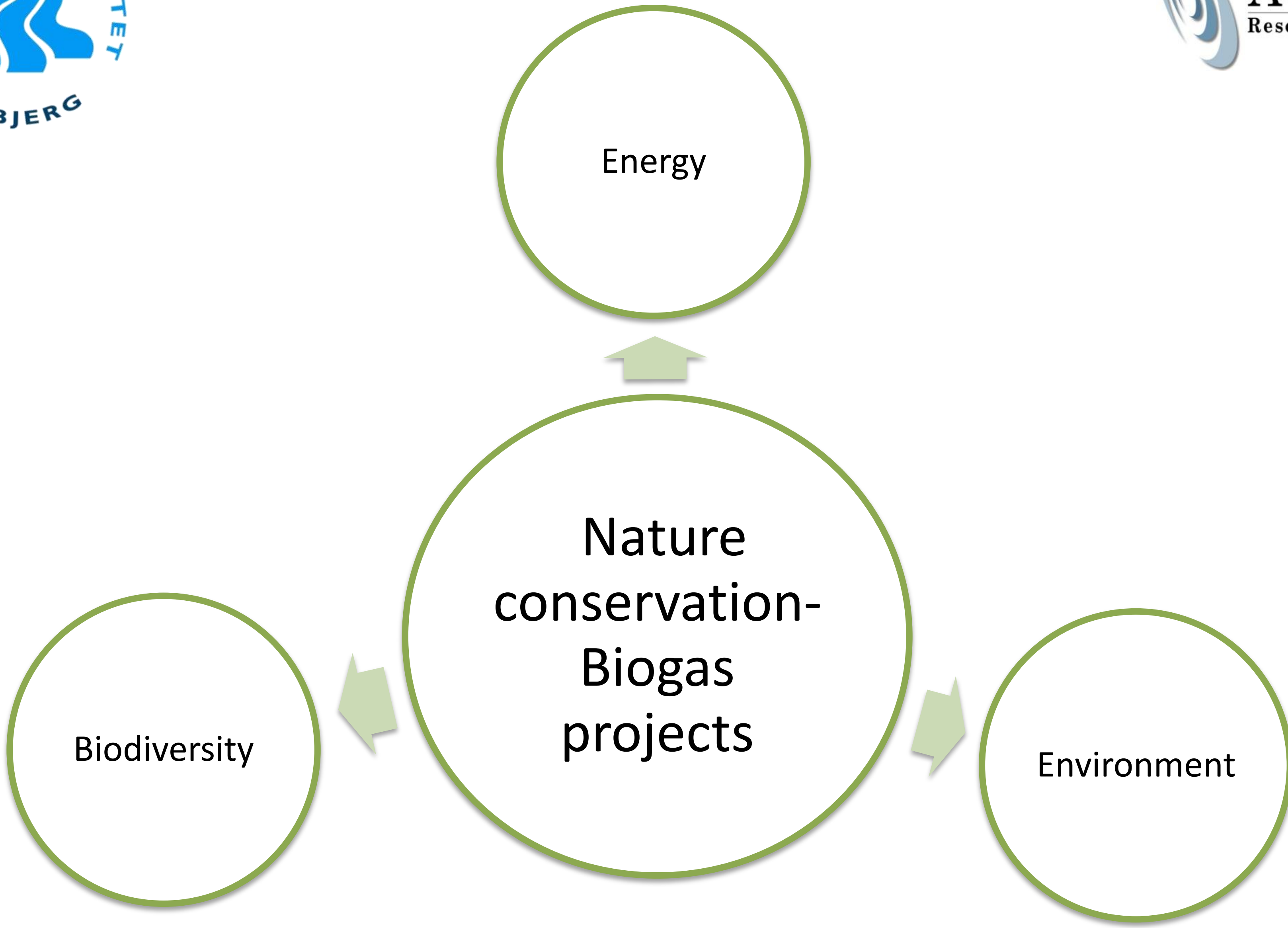
Pressure from society:

- Intensive cultivation
- Urbanization
- Climate changes
- <u>Nutrient pollution</u>
- <u>Lack of nature conservation</u>

”Engen er agerens moder”
(Meadow - the ”mother” of arable land)

Meadow → **Biomass** → Livestock → **Manure** → Crops


Meadow
Biomass
Livestock
Manure
Crops
Meadow
Biomass
Biogas plant
Fertilizer
Crops
Energy


Energy
Nature conservation-Biogas projects
Biodiversity
Environment

Potential

	Ha
60 %	100.200
20 %	33.400

	Denmark
GJ (20-60 %)	794.000 – 3.500.000
Households (20-60 %)	16.800 – 73.100

Benefits

- Production of Renewable Energy
- Alternative to fossil fuel
- Prevents leaching of nutrients
- Recycling of nutrients to croplands
- Potential for organic/ecological fertilizer
- Preserves the open landscape
- Increase in biodiversity
- Recreational value will increase

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Large Scale Bioenergy Lab

Project focus 2012 -2015. New biomass, innovations technologies, lot's of green jobs in the cross border region.

Identification, Analysis, Mapping and Management of Sustainable Biomass Resources in the Region of Southern Denm
Germany:

INTERREG4A
SYDDANMARK-SCHLESWIG-K.E.R.N.

European Regional Development Fund
European Union · Investing in your future

- Biomass from nature conservation
  - Protected nature: meadow, marshland
- Biomass from permanent grassland
- Agricultural residues
  - Manure
- Biomass from other areas
  - Airports
  - Roadside grass
- Biomass from recreational areas
  - Golf course
  - Parks
  - Football fields
- Others..
  - Algae, seaweed
  - Household waste
  - Industrial waste

Thank you for your attention!

Q & A 's

<u>R, D & D cooperation partners;</u>

- **AAU, Denmark**: Bioenergy Research Group; - *Ane Katharina Paarup Meyer, Ehiaze Augustine Ehimen, Michael Madsen, Kim H. Esbensen, Felicia Nkem Ihunegbo (HIT), Saqib Sohail Toor, Lasse A. Rosendahl*
- **UMB, Norway**: Biogas and Bioenergy Center; - *Kristian Fjørtoft, Maria Magdalena Estevez, Magdalena Bruch, Zehra Sapci, John Morken.*
- **FHF, Germany**; Biogas R&D group - *Lars Jürgensen, Thorsten Philips, Jens Born*
- **Poldanor, Poland**; Biorefinery test-platform – *Benny Laursen, Pawel Krawat, Bjarne Møller, Grzegorz Brodziak.*

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