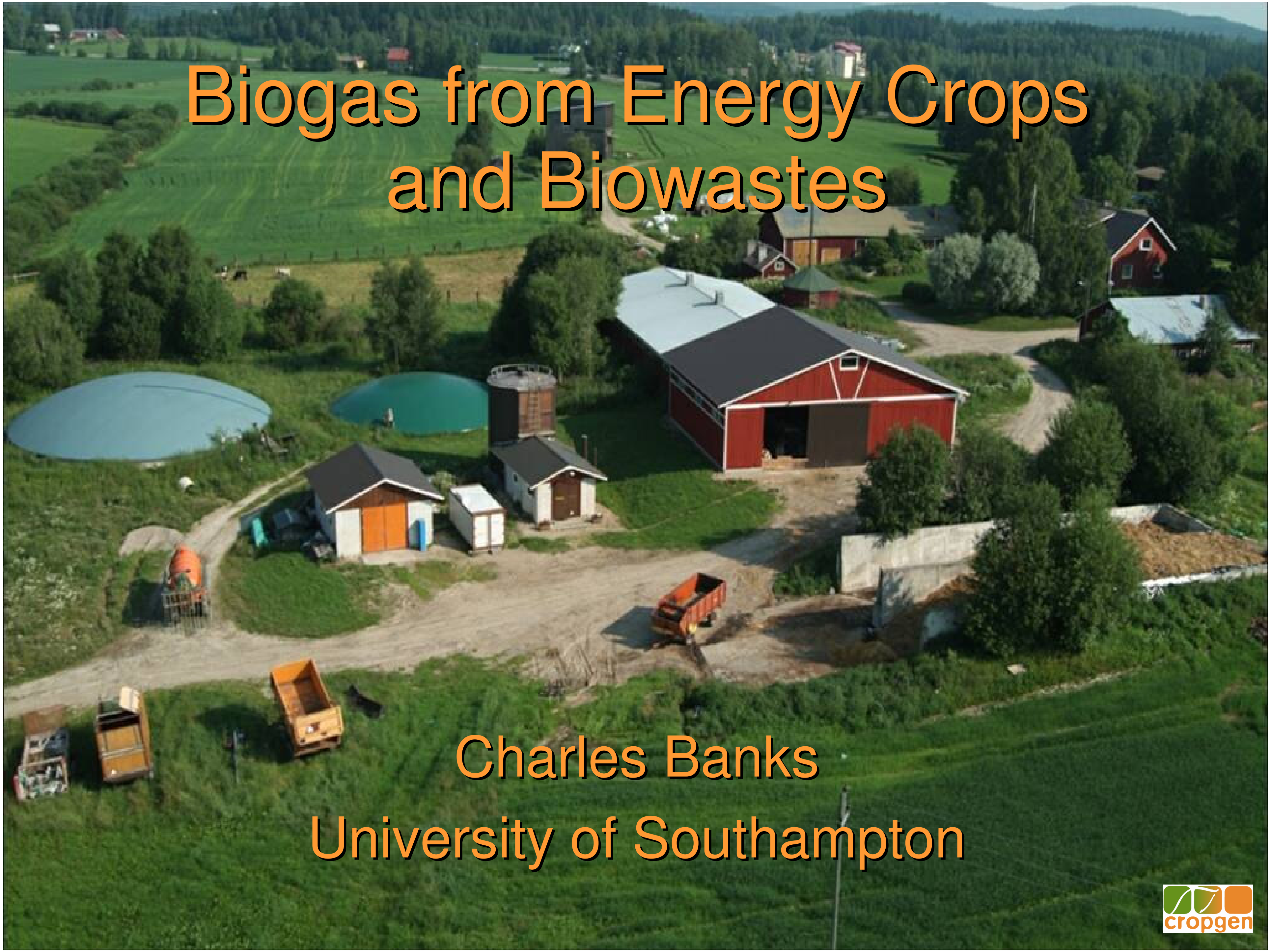
Biogas from Energy Crops and Biowastes



Charles Banks

University of Southampton

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Acknowledgements - Current project

Acronym: CROPGEN

Title: **Renewable energy from crops and agrowastes**

Contract: SES6-CT-2004-502824

Sixth Framework Programme

Duration: **1 March 2004 – 28 February 2007**

Total cost: **2.5 M€ EC funding: 2.1 M€**

website: **www.cropgen.soton.ac.uk**

University of Southampton

JYVÄSKYLÄN YLIOPISTO
University of Jyväskylä

CSIC

WAGENINGEN UNIVERSITY

Greenfinch

BOKU

IFA TULLN

ORGANIC POWER LTD

Metener Oy
Biokaasuteknologiaa

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Old technology - new application

- The technology of biochemical methane generation is well established
- Traditionally it has been used for waste stabilization
- Current focus is on energy production
- To be cost-effective in this role may require
  - engineering and technical improvements to increase conversion efficiencies
  - Selection and production of biomass feedstocks from a variety of sources
    - including novel and multi-use crops and agro-wastes from integrated farming systems, commercial and industrial wastes and by-products.

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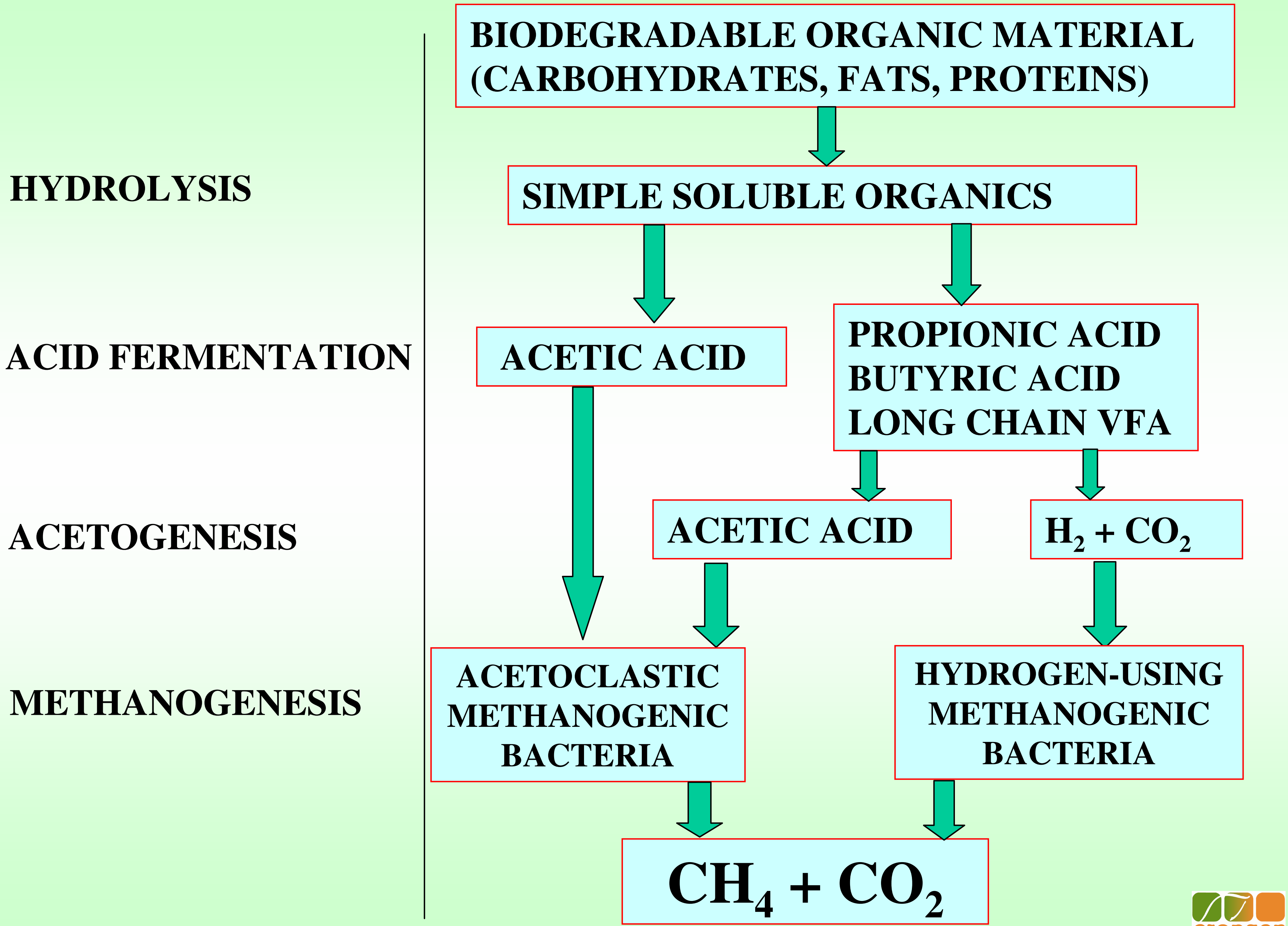
HYDROLYSIS
ACID FERMENTATION
ACETOGENESIS
METHANOGENESIS
BIODEGRADABLE ORGANIC MATERIAL (CARBOHYDRATES, FATS, PROTEINS)
SIMPLE SOLUBLE ORGANICS
ACETIC ACID
PROPIONIC ACID
BUTYRIC ACID
LONG CHAIN VFA
ACETIC ACID
$H_2 + CO_2$
ACETOCLASTIC METHANOGENIC BACTERIA
HYDROGEN-USING METHANOGENIC BACTERIA
$CH_4 + CO_2$
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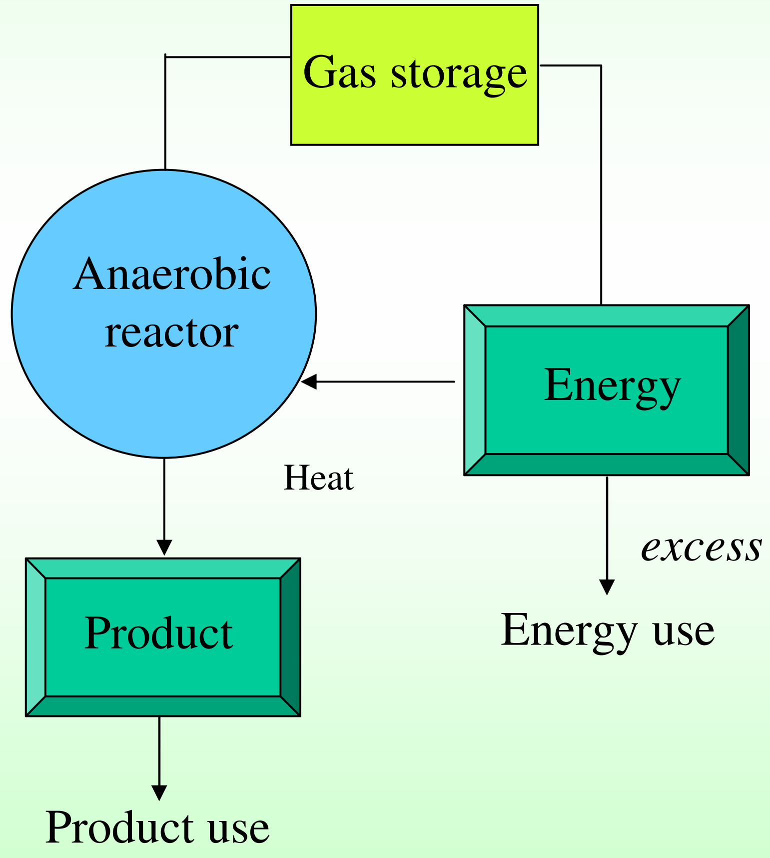
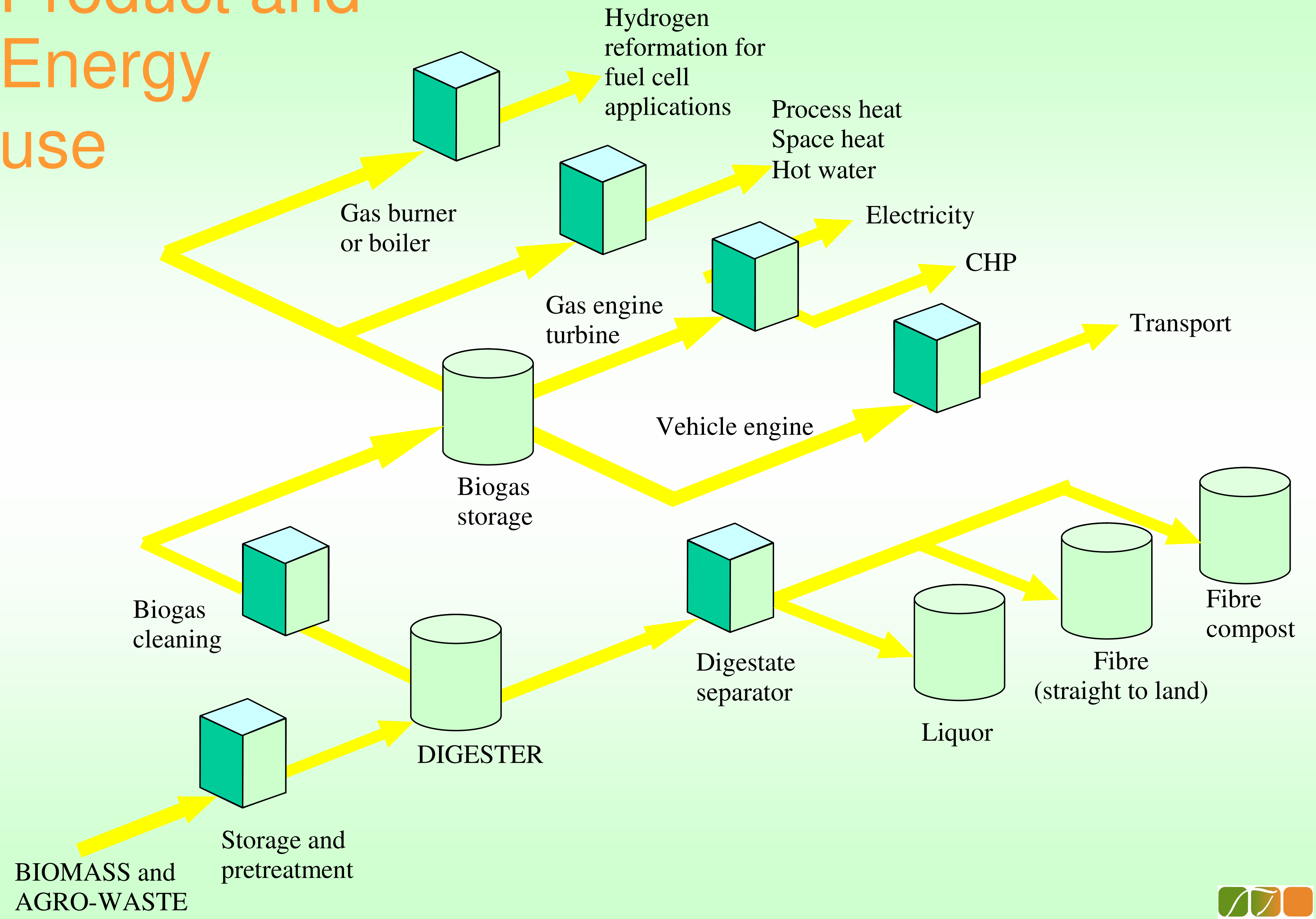
Anaerobic digestion in its simplest form

- Closed reactor
- System of gas collection
- Production of biogas
- Production of digestate



Product and Energy use



Process types

Wet

Dry

One stage

Multi-stage

Mesophilic

Thermophilic

Process differences

Wet Process

- less than 15 % feedstock solids concentration
- one or several stages
- usually operate at 35^{o}C
- requires water addition or recycle
- larger reactor
- proven technology for sewage sludge digestion
- more applicable to co-digestion with other waste

Dry Process

- more than 15% feedstock solids concentration
- usually one stage
- can operate at 35^{o}C or 55^{o}C
- minimal water addition
- smaller reactor
- becoming most popular choice for MSW
- more data and reference plants needed

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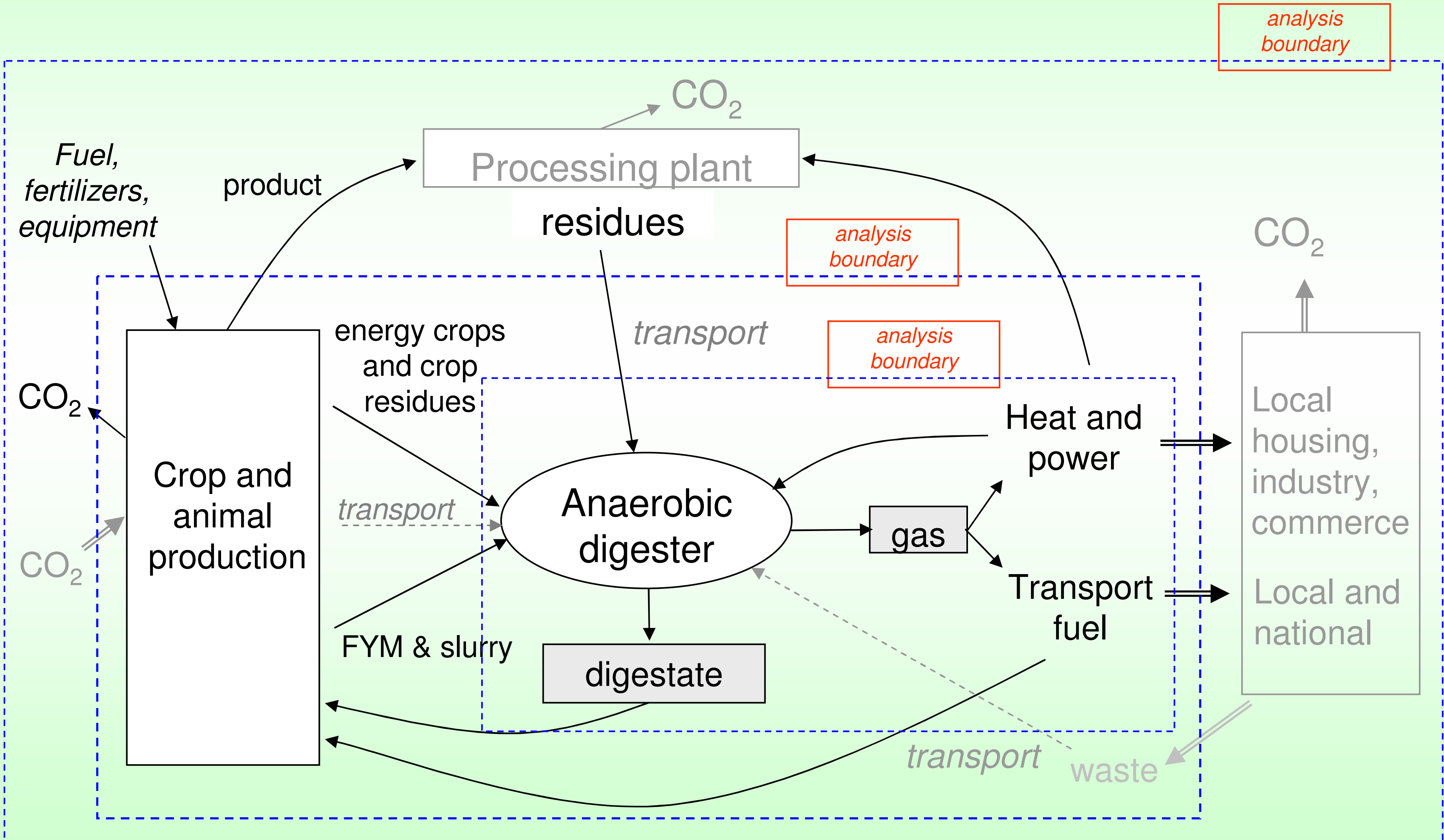
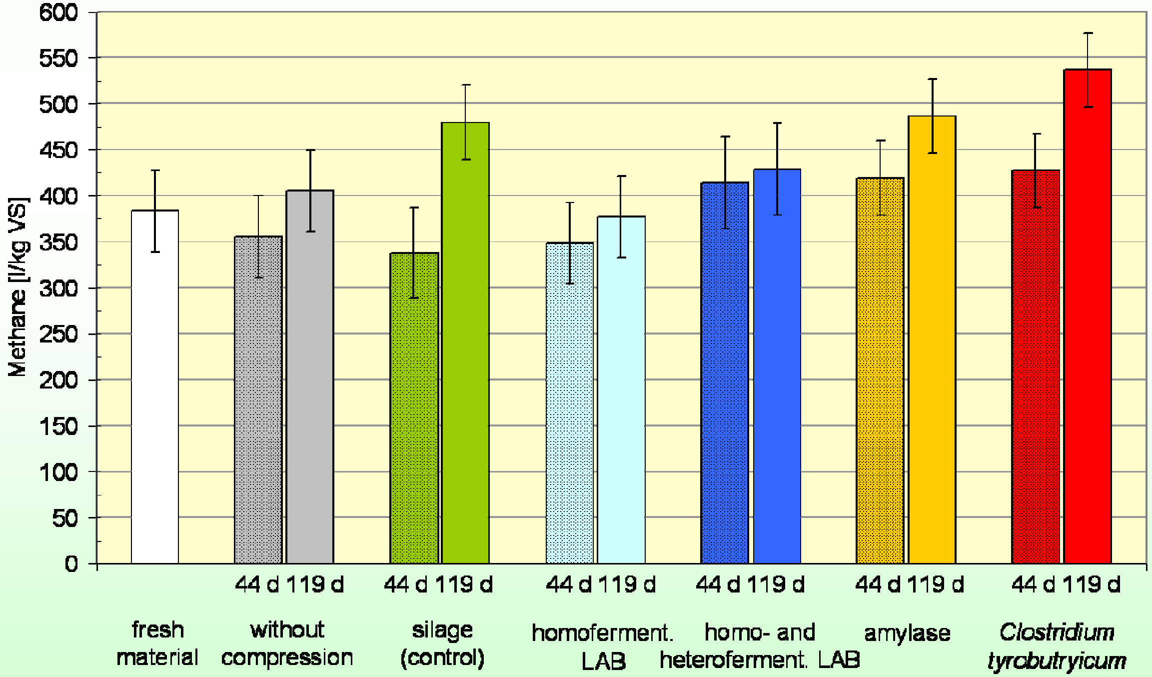
Instantly recognisable!

Biogas as a renewable energy source



Results: storage and pretreatment

- **Some potential to increase methane production by alkaline and water-based pre-treatments, and certain spoilage organisms.**
- **More important, poor treatment or storage conditions reduce biogas yields.**



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Digestion trials

- **Single phase digestion trials on a wide range of substrates at laboratory and large scale providing valuable design data**

Pilot plant trials for crops and agro-wastes

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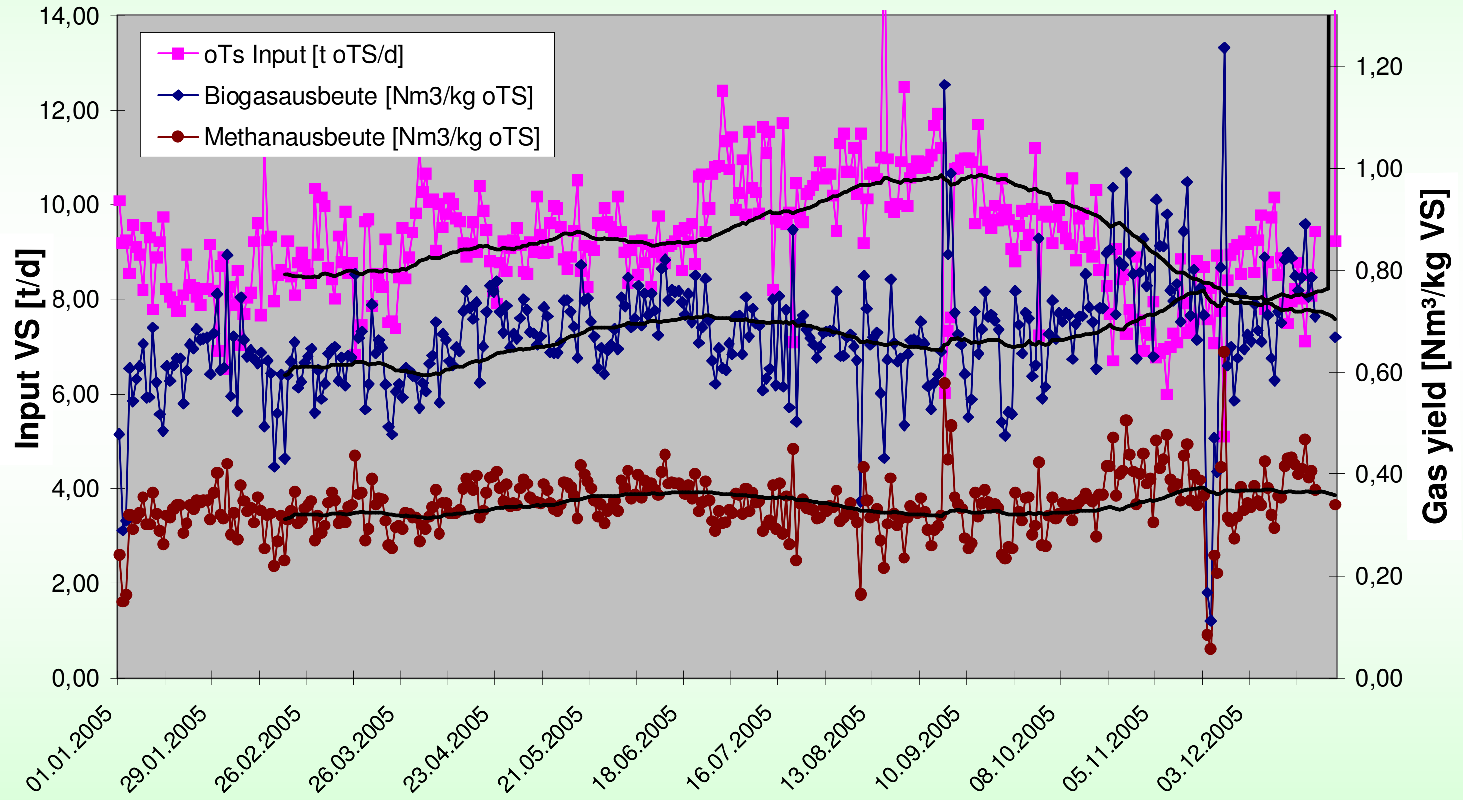
Results: single phase digestion trials

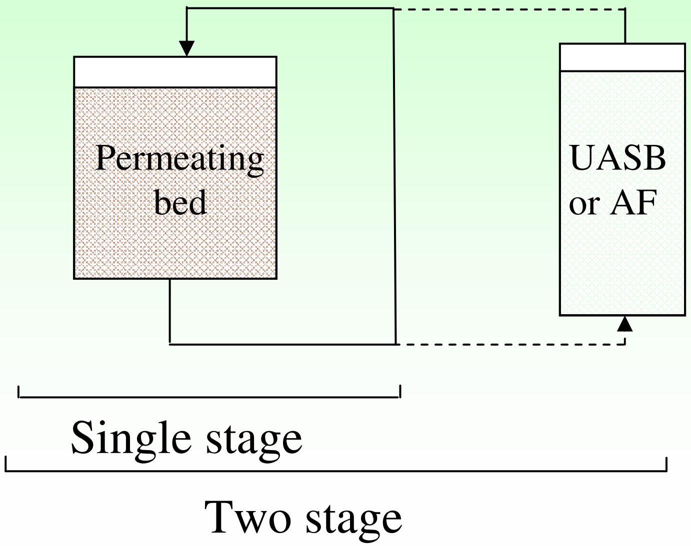
- **Single phase digestion trials on a wide range of substrates at laboratory and large scale providing valuable design data**



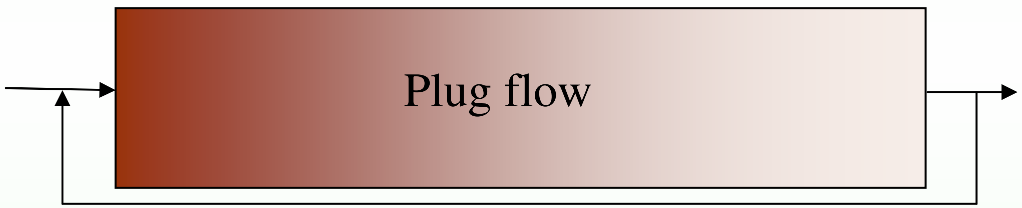
Volumetric and specific gas yields per kgVS. Trend lines based on 50-day average.

Phase separation innovations

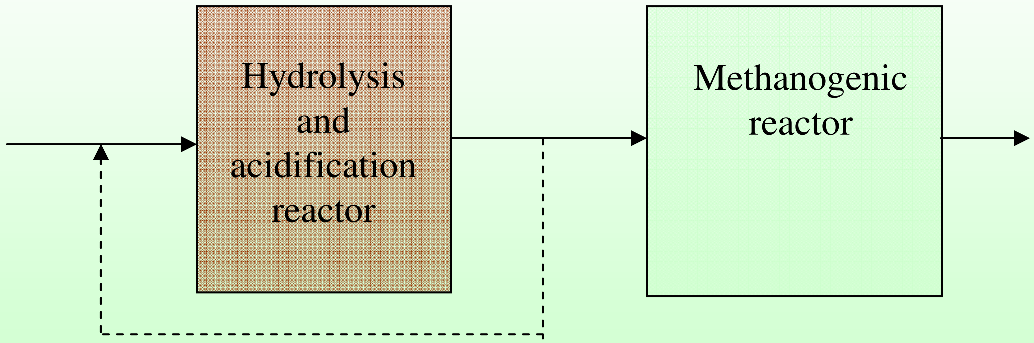
Permeating beds



Plug flow reactors

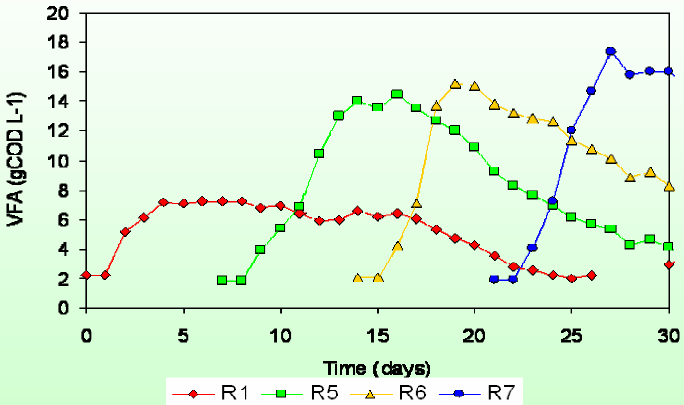


Two phase systems (coupled and uncoupled)



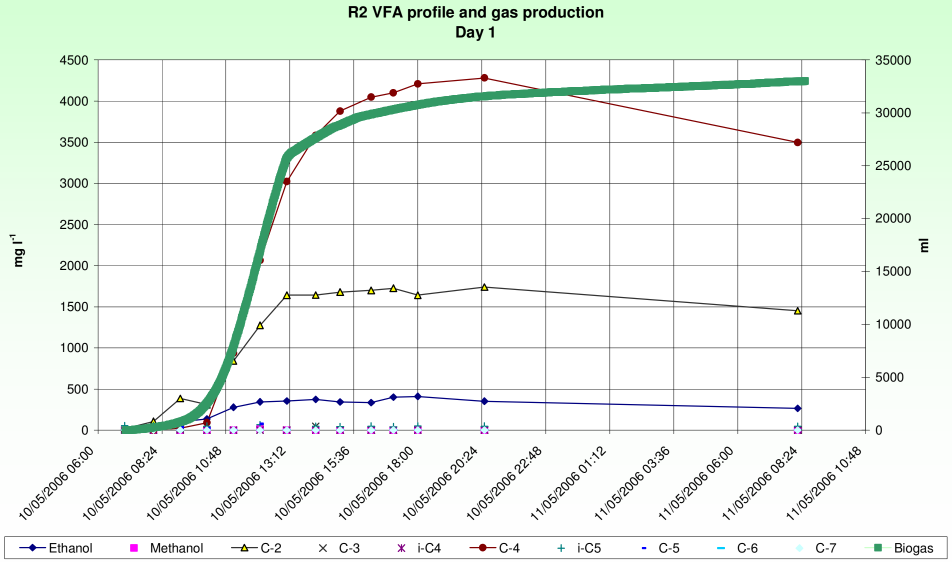
Uncoupling of solids and liquid retention time

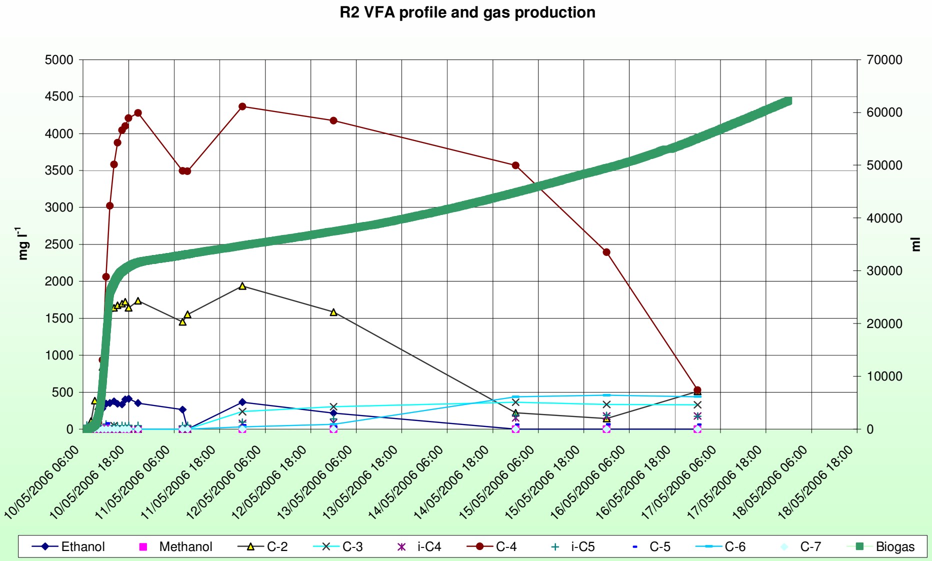
Permeating bed reactors



- Single bed systems using grass and maize have given poor results even with pH control
- Permeating bed with second stage high rate methanogenic reactors gives greater potential for stable operation and biogas production
- May be some potential for certain crop types but preliminary results indicate that overall process efficiency is likely to be poorer than for single phase mixed reactors
- Potentially an interesting mix of fermentation products

Plug flow systems





- Result from a high initial loading in the reactor
- Plug flow may limit the overall loading that can be achieved
- Give an interesting gas and acid production profile (H_2)
- May have potential for certain waste types and the concept could be further exploited for refined fuel production and biorefinery intermediates
- Still to explore very high solids systems with high recycle rates

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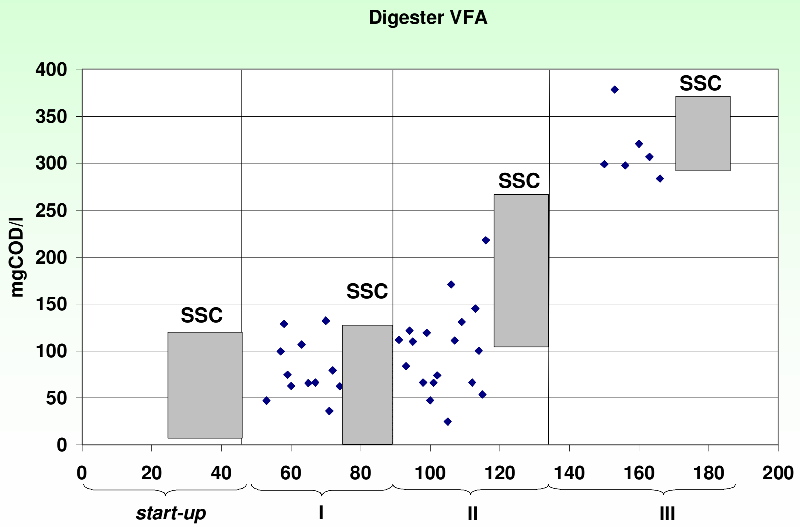
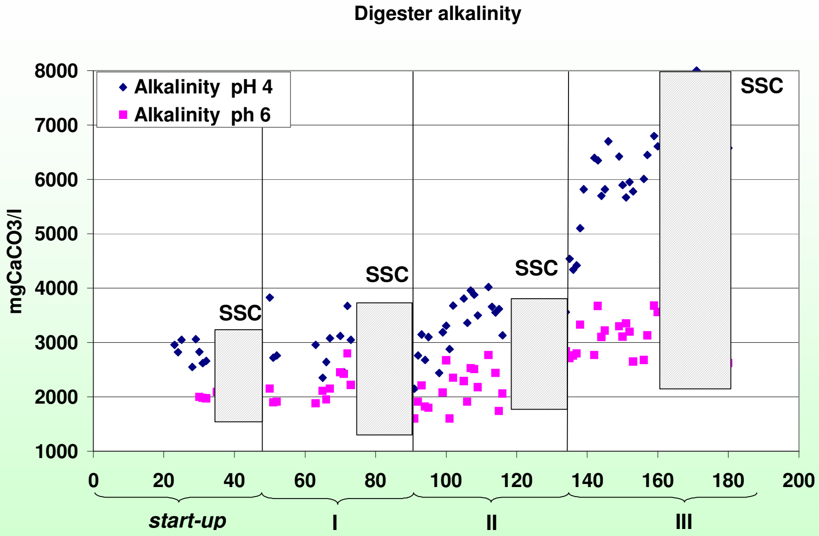
Two phase systems

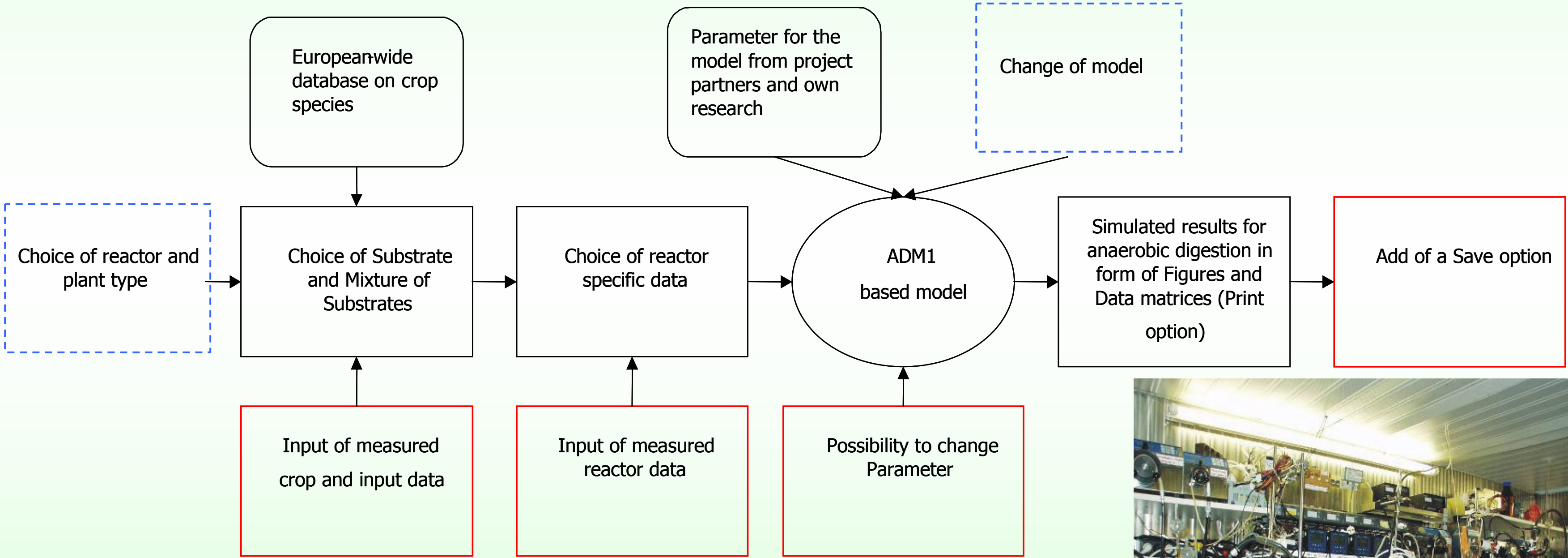




- Overall performance for the treatment of market wastes at thermophilic temperatures and the loading used shows no advantage in process stability or performance compared to single phase controls
- Uncoupling of solids and liquids retention time in a first phase mixed reactor using maize as a substrate failed to improve rates of hydrolysis and solids destruction

Process modelling

- **The anaerobic digestion model 1 (ADM1) has been adopted as a basis for the establishment of:**
  - **Virtual Laboratory**
  - **DSS**



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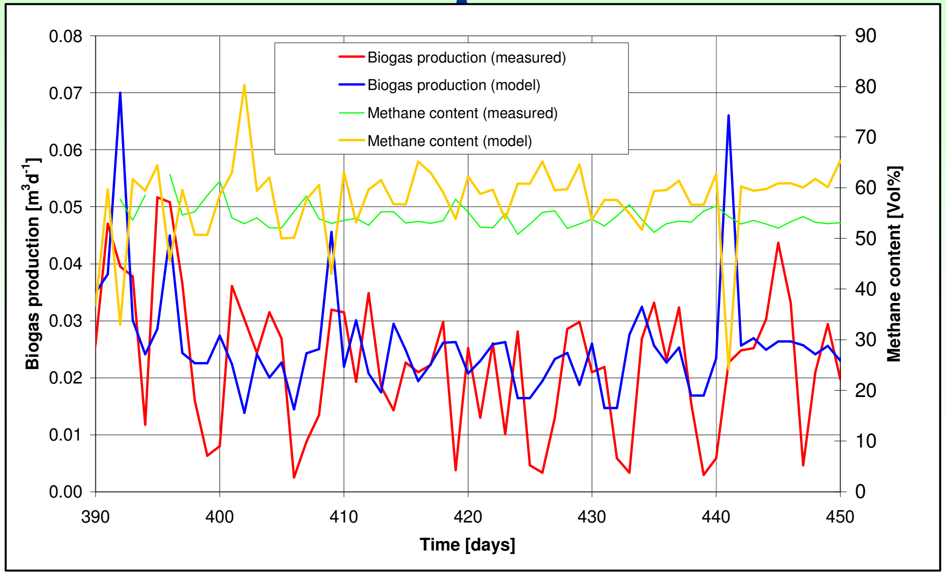
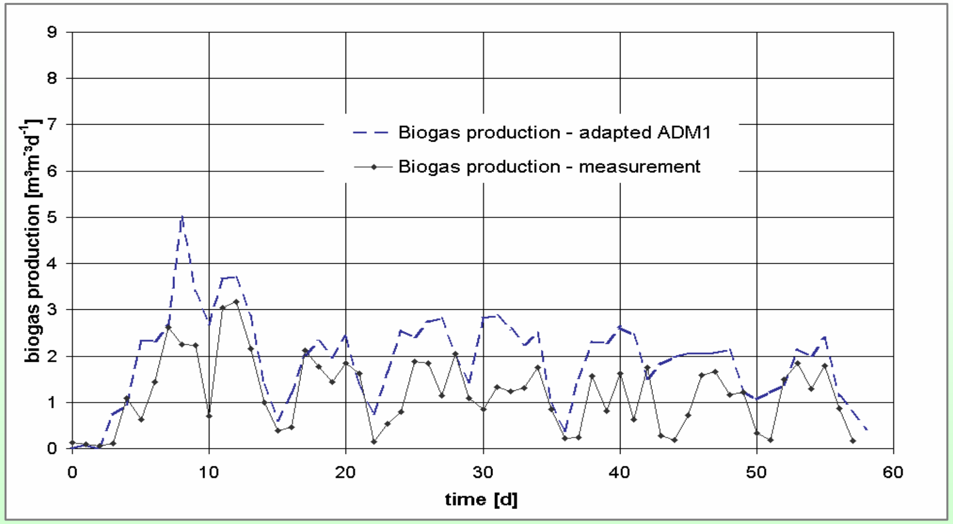
Results: process modelling

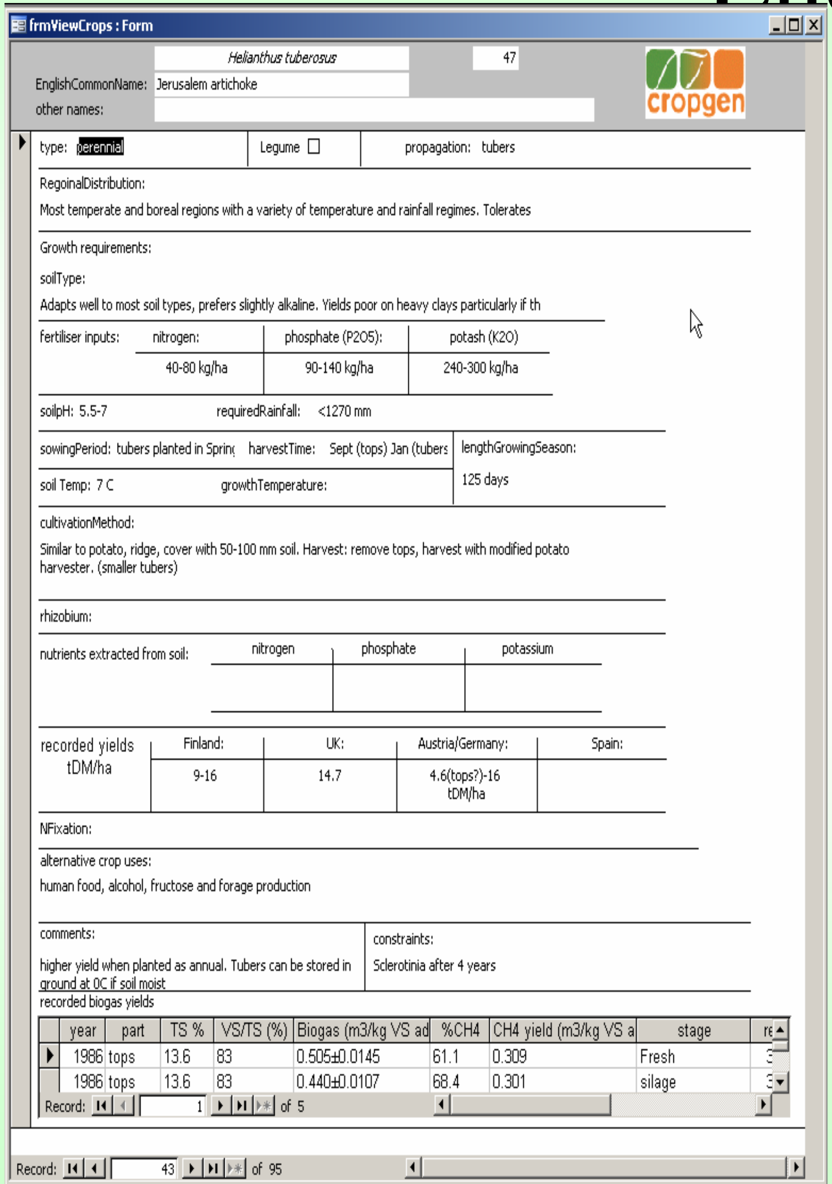


Preliminary results with original ADM1. The model follows the course of the experiment, but the correlation is too low for practical application



Adjusted model after first manual calibration ($k_{hyd} = 1\ d^{-1}$)

Energy models

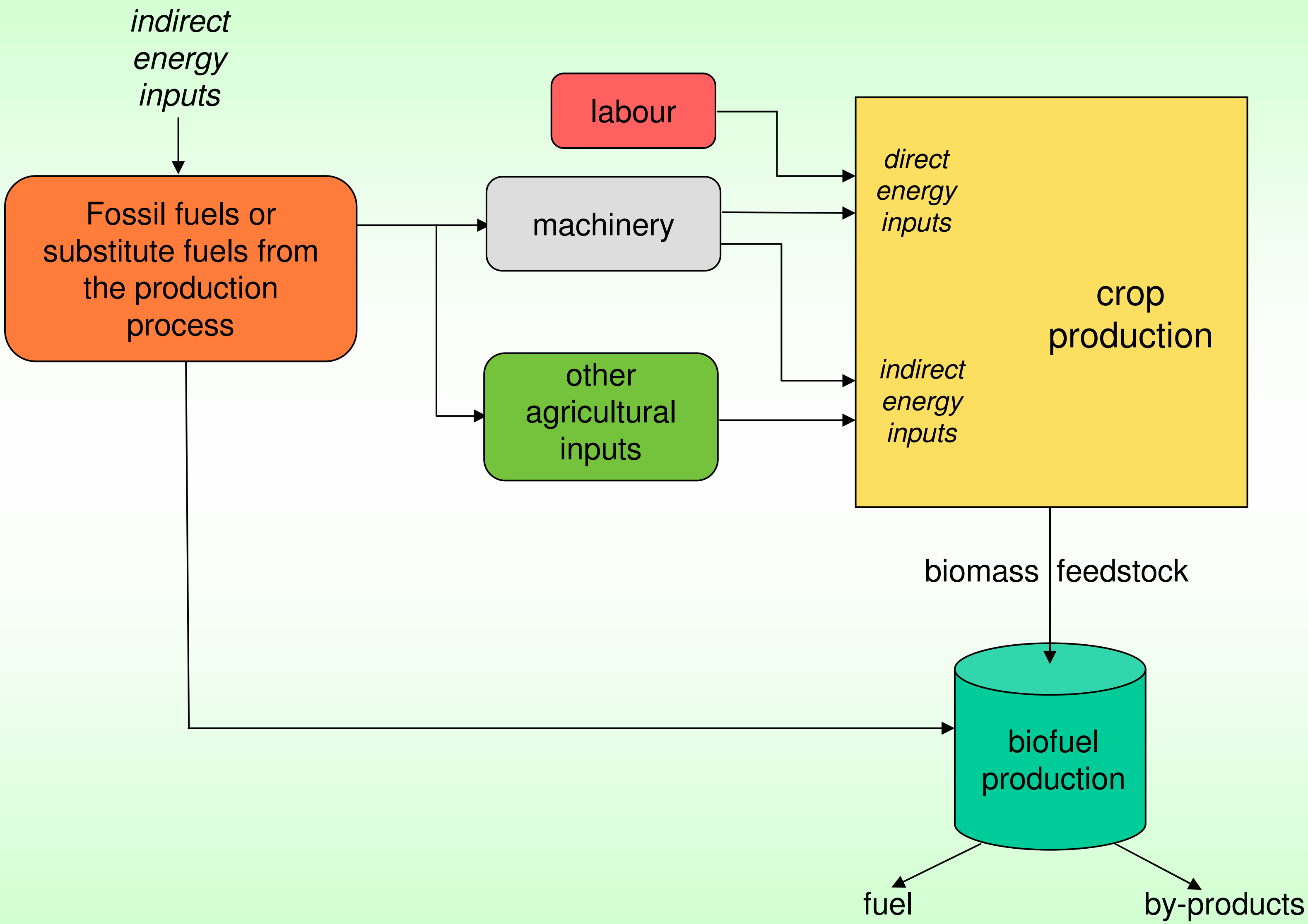


- Data base of energy inputs into the cultivation of different crop types established
- Factors affecting the energy use in the process have been identified
- Equations developed to account for energy usage in the digestion process
- Energy usage model developed based on typical anaerobic digestion plant configurations and substrates

Energy balance

- Inputs / outputs
- Direct energy
- Indirect energy
- Energy balance
- Energy ratio

Energy inputs



Direct and indirect energy

- Direct energy
  - consumption of energy directly in the production process - includes:
    - fossil fuels
    - labour

- Indirect energy
  - energy which has been used in producing something then used in the production process - includes:
    - fertiliser
    - pesticides / herbicides
    - machinery

Direct & indirect energy inputs

operation/input	energy input type: direct	energy input type: indirect
cultivation	fuel	equipment
fertiliser	application fuel	production, application equipment
harvest	fuel	equipment
fuel		production and transport
processing	heat, power	construction
product distribution	fuel	transport equipment

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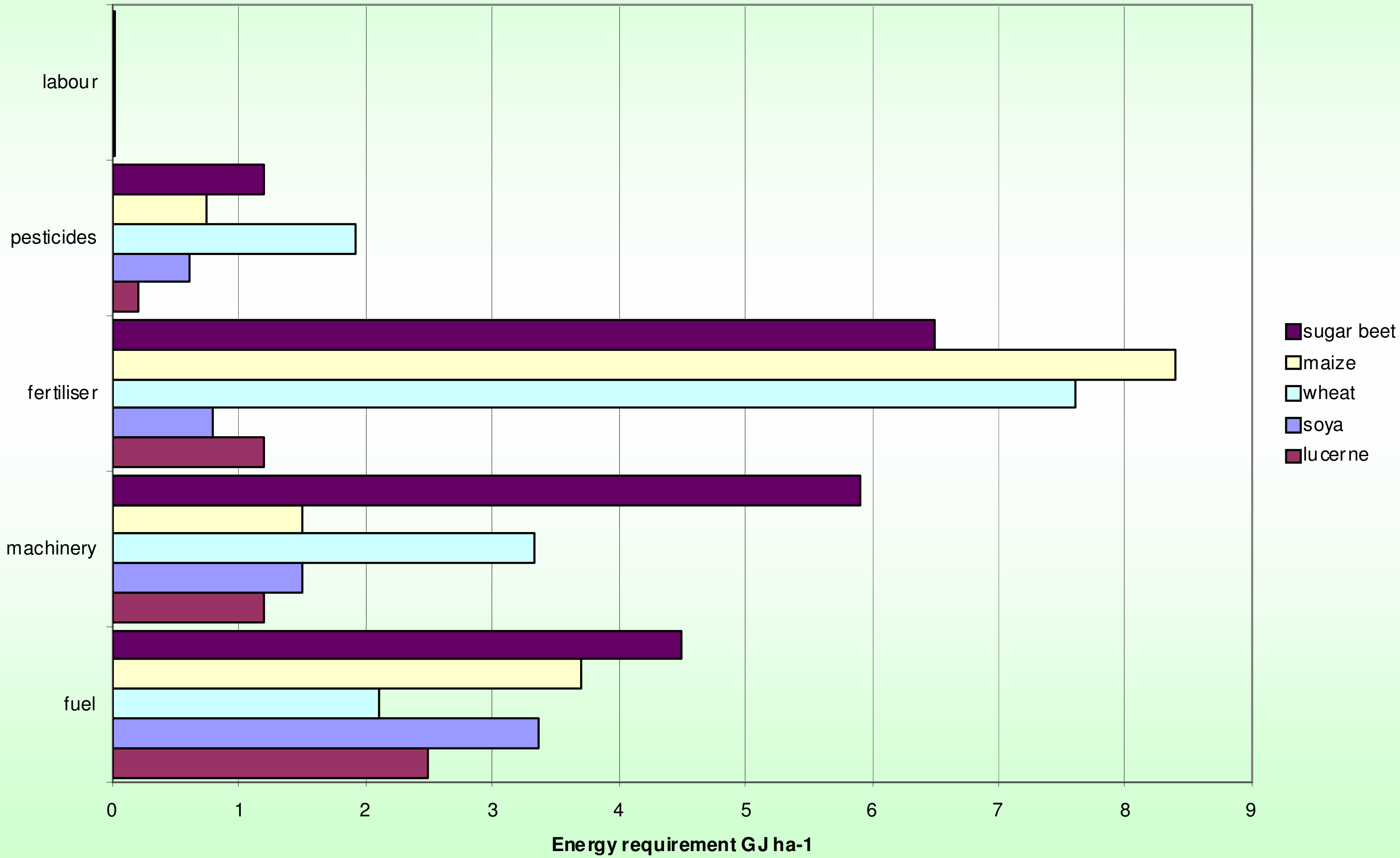
Energy inputs in maize crop production

operation	No of operations	equipment	time (h/ha)	energy of equipment MJ/ha		tractor (kW)	fuel used (l/ha)	CO_2 indirect (kg/ha)	
subsoil	1	subsoiler	1.333	120		90	14.6	5.4	
plough	1	plough+press	1.333	120		90	17.5	5.4	
drill/harrow	1	combined drill and harrow	0.62	158		90	3.9	7.1	
fertiliser	1	fertiliser spreader	0.36	45		55	1.2	2.0	
spray	2	sprayer	0.54	68		55	2.4	3.1	
harvest	1	forage harvester	2	420			17.5	33.6	
cart	1	trailer	2	120		55	7.8	5.4	
ensile	1	tractor and bucket	1.48	8		55	5.8	0.4	
tractor		90 kW	3.286	564				45.1	
tractor		55 kW	4.38	297				23.8	
fuel used (litres)				2785	MJ/ha		70.7	213.6	
total indirect				1920	MJ/ha			131.2	
			hours						
labour			9.7	18.8	MJ/ha				
seed		kg/ha	16	215	MJ/ha			2.4	
chemicals			(kg/ha)						
N			150	6045	MJ/ha			285.6	
P_2O_5			200	680	MJ/ha			140	
K_2O			175	1277.5	MJ/ha			79.3	
packaging & transport				1362	MJ/ha				
sprays			12.8	2432	MJ/ha			63.0	
total energy input to crop production and storage				**16.7**	**GJ/ha**			**915.2**	**kg/ha**

Crop production inputs



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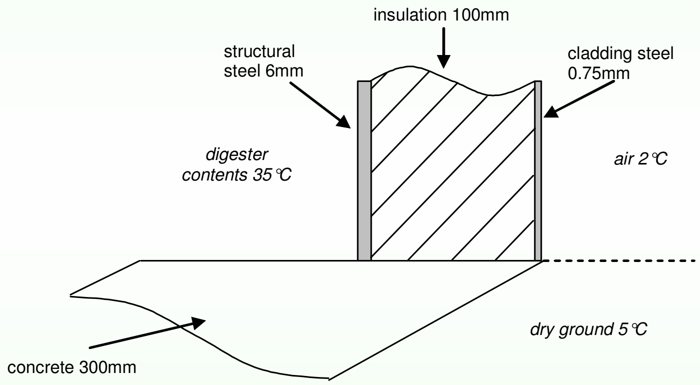
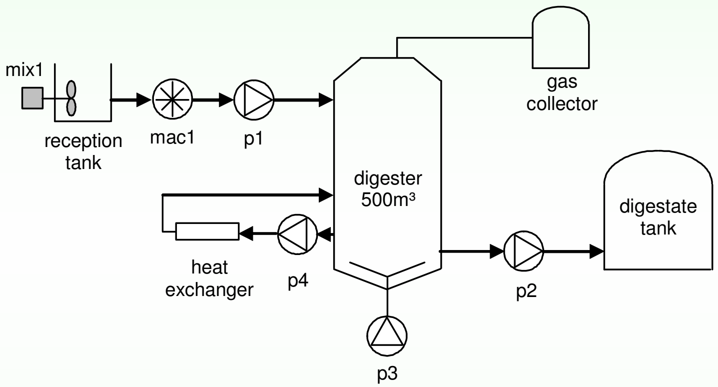
Digester energy flows

Main energy inputs are heat and electricity

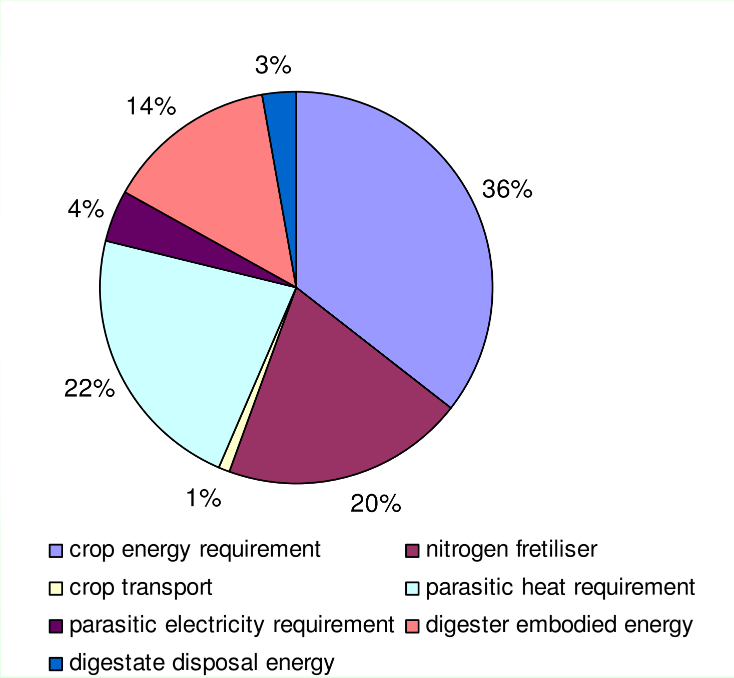




mix1	reception tank mixer	3.0 kJ s^{-1}	0.64 hrs d^{-1}
mac1	feedstock macerator	2.2 kJ s^{-1}	1.75 hrs d^{-1}
p1	digester feed pump	3.0 kJ s^{-1}	1.75 hrs d^{-1}
p2	digester discharge pump	3.0 kJ s^{-1}	1.75 hrs d^{-1}
p3	digester mixing pump	2.2 kJ s^{-1}	7.25 hrs d^{-1}
p4	digestate heating pump	0.5 kJ s^{-1}	8.0 hrs d^{-1}

An energy balance

	value	unit
digester capacity	2000	m^3
daily load	34.8	t/day
crop area	318	ha
crop energy requirement	5310.6	GJ/year
crop transport	93	GJ/year
parasitic heat requirement	2133	GJ/year
parasitic electricity requirement	420	GJ/year
digester embodied energy	1350	GJ/year
digestate disposal energy	259.5	GJ/year
total energy requirement	**9566**	**GJ/year**
	30	GJ/ha
biogas produced	**2,331,092**	**m^3**
methane	1,398,655	m^3
energy value	**49,932**	**GJ/year**
	157	GJ/ha



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Digestate

- the digestate is what remains after the biogas has been removed
- it contains most of the nutrients of the original feedstock
- the nutrients are in a form which are more available for crop uptake
- it has a consistency similar to slurry (approx 10% solids)
- it can be separated into solid and liquid fractions

Effect of digestate use on the energy balance

	value	unit
mineral fertiliser		
crop energy requirement	16.7	GJ/ha
energy for nitrogen	6.04	GJ/ha
total energy requirement	**30.1**	**GJ/ha**
digestate fertiliser		
crop energy requirement	9.3	GJ/ha
total energy requirement	**22.7**	**GJ/ha**
methane energy value	**157**	**GJ/ha**
net energy yield		
mineral	126.9	GJ/ha
digestate	134.3	GJ/ha

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Example energy comparisons

fuel	biodiesel	bioethanol		methane				methane
crop	OSR seed	sugar beet	wheat grain	sugar beet	wheat grain	maize	whole crop triticale	whole crop triticale
fertiliser (N kg/ha)	195	147	150	147	150	150	160	80
crop yield (fresh yield t/ha)	3	56	8	56	8	40	38	38
crop yield (t DM/ha)	3	11.5	6.9	11.5	6.9	12.6	15	15
energy for crop production (GJ/ha)	12.7	11.9	12.8	11.9	15.5	16.7	16	11.6
energy for processing (GJ/ha)	9.2	41.4	13.2	10.8	8	8	8.3	8.3
energy of fuel produced (GJ/ha)	40.4	117	61.1	124.8	89	157.1	166	166
energy ratio (output/input)	**1.84**	**2.20**	**2.35**	**5.50**	**3.79**	**6.36**	**6.83**	**8.34**
net energy produced (GJ/ha)	**18.5**	**63.7**	**35.1**	**102.1**	**65.5**	**132.4**	**141.7**	**146.1**

Elsayed, M. A., Matthews, R. and Mortimer, N. D. (2003) *Carbon and Energy Balances for a Range of Biofuels Options*, School of Environment and development, Sheffield Hallam University, B/B6/00784/REP

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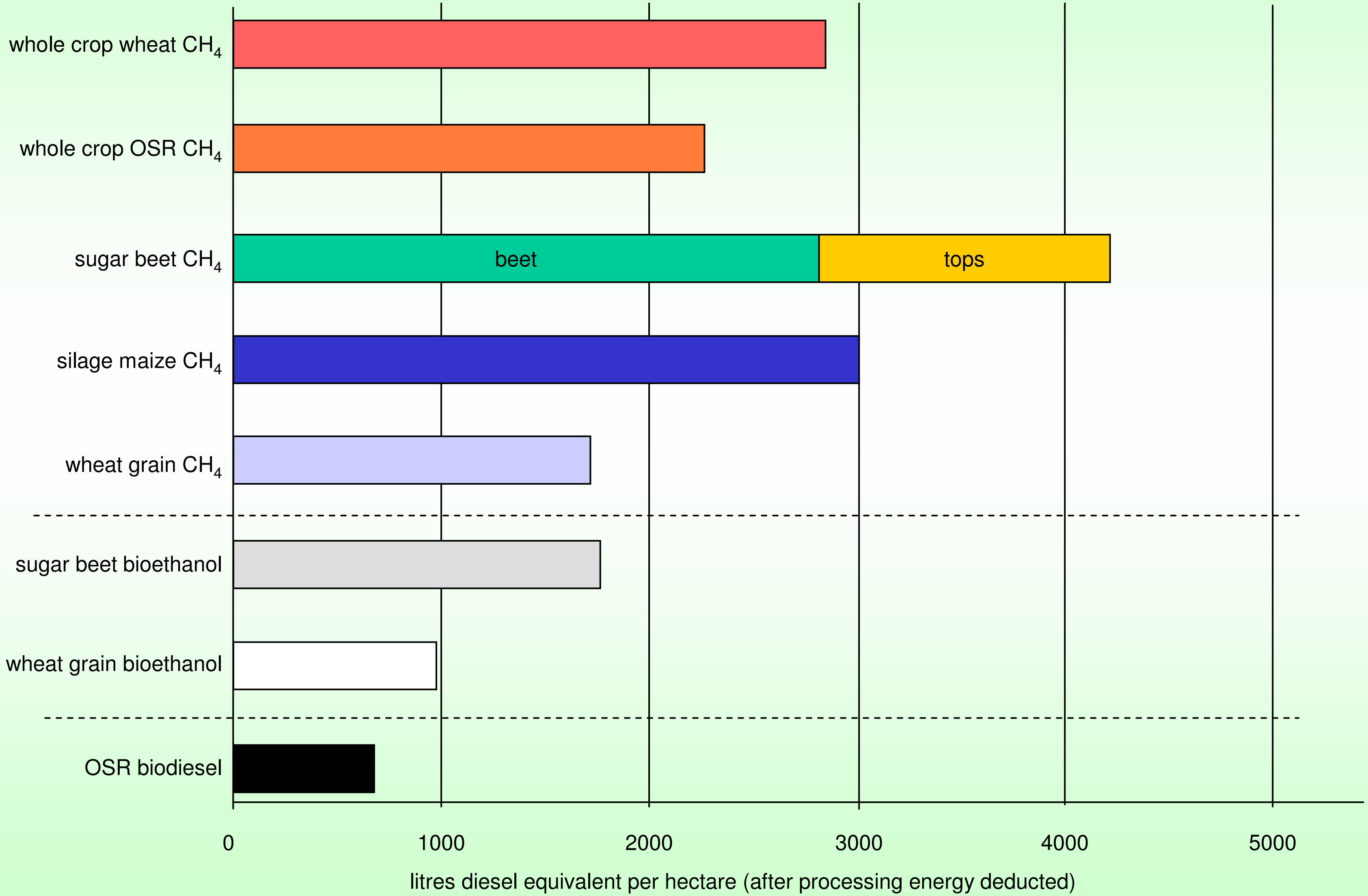
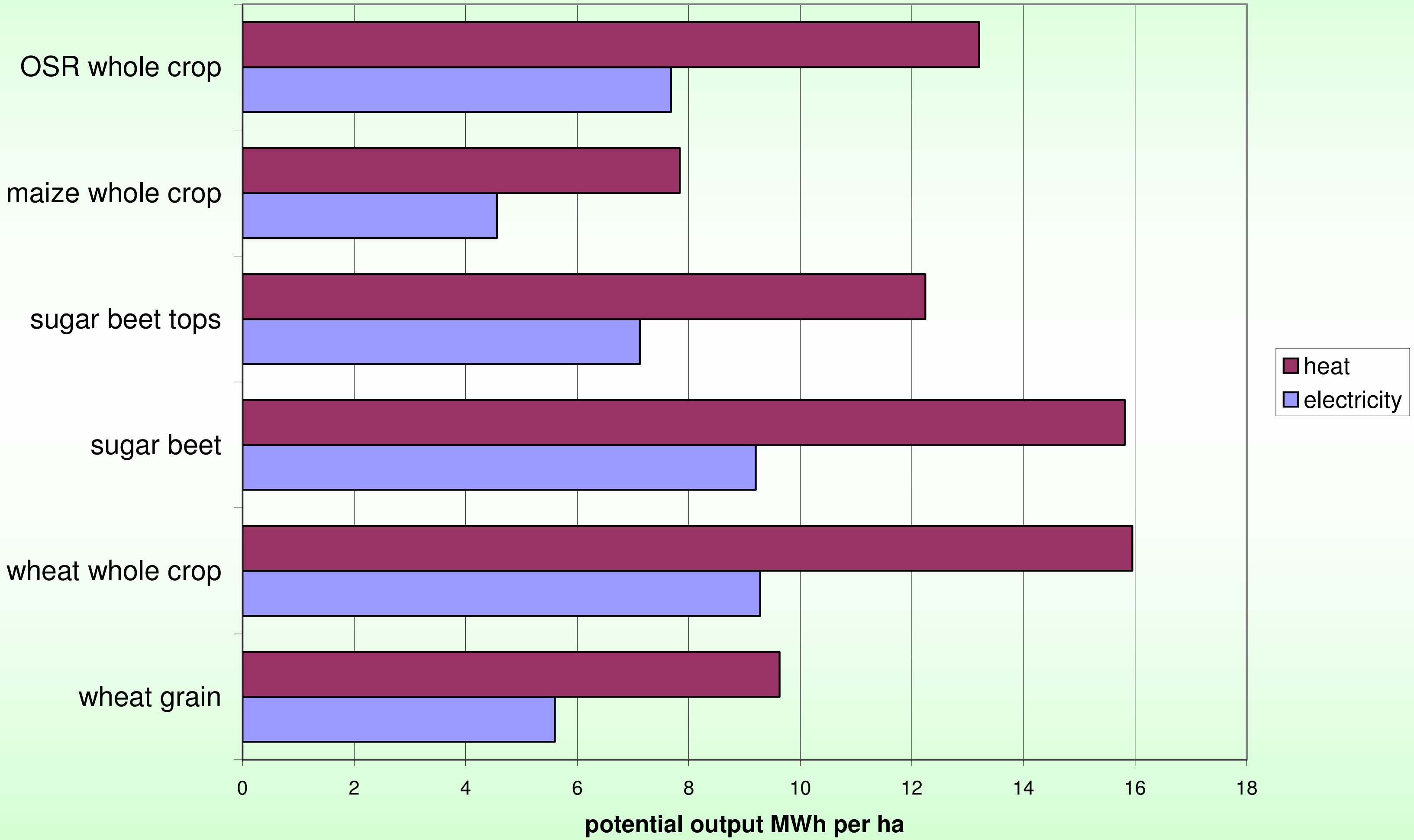
Potential vehicle fuel produced per ha



Potential CHP per hectare



Feedstocks for biofuel production

- for biodiesel
  - oilseed rape
  - sunflower
  - linseed
  - soya
  - peanut

- for bioethanol
  - wheat
  - sugar beet
  - maize
  - sugar cane

  - *lignocellulosic material*

- for biogas
  - barley
  - cabbage
  - carrot
  - cauliflower
  - clover
  - elephant grass
  - flax
  - fodder beet
  - giant knotweed
  - hemp
  - horse bean
  - jerusalem artichoke
  - kale
  - lucerne
  - lupin
  - maize
  - marrow kale
  - meadow foxtail
  - miscanthus
  - mustard
  - nettle
  - oats
  - pea
  - potato
  - rape
  - reed canary grass
  - rhubarb
  - ryegrass
  - sorghum
  - sugar beet
  - triticale
  - turnip
  - verge cuttings
  - fetch
  - wheat

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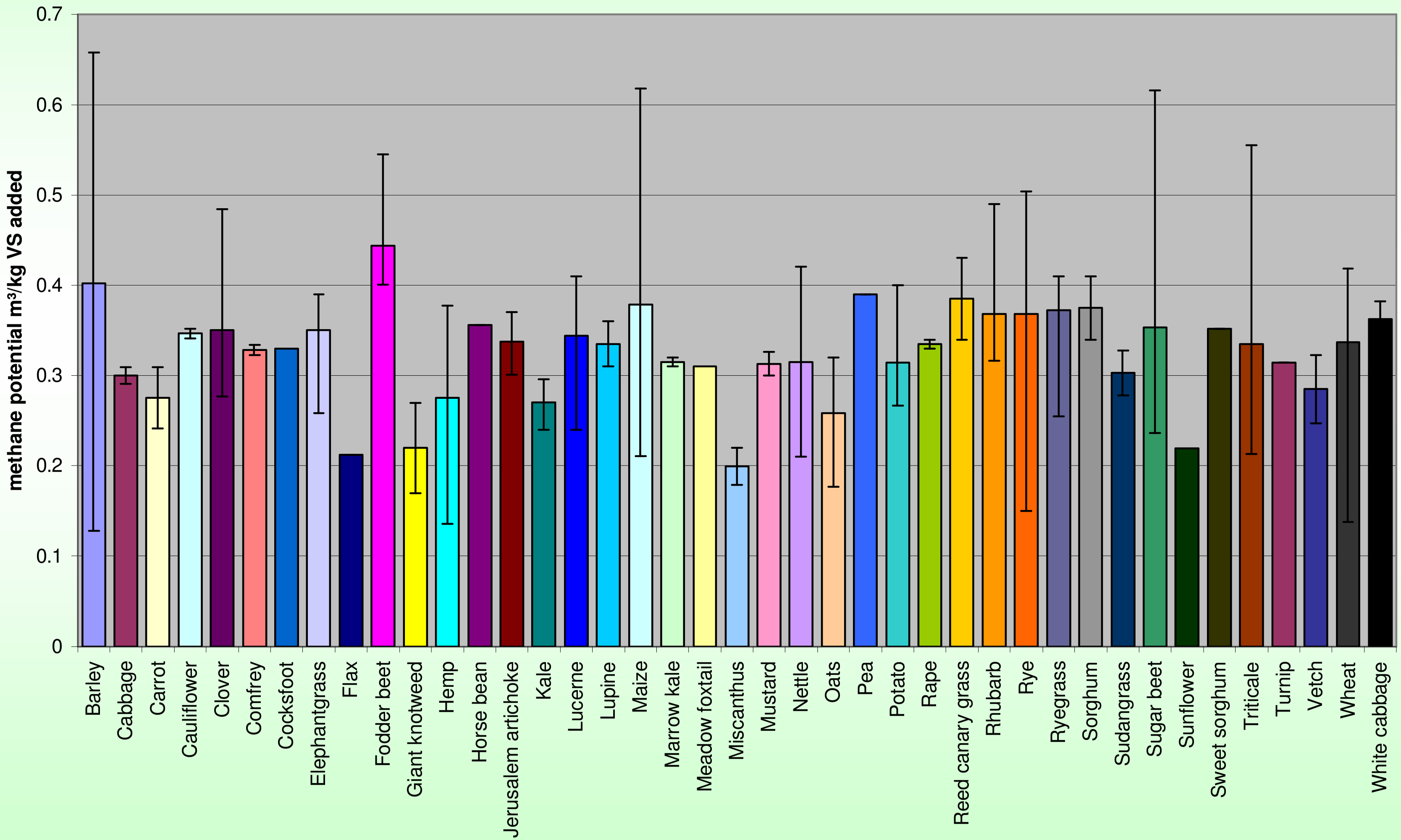
Which crops?



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CO_2 and energy cycles