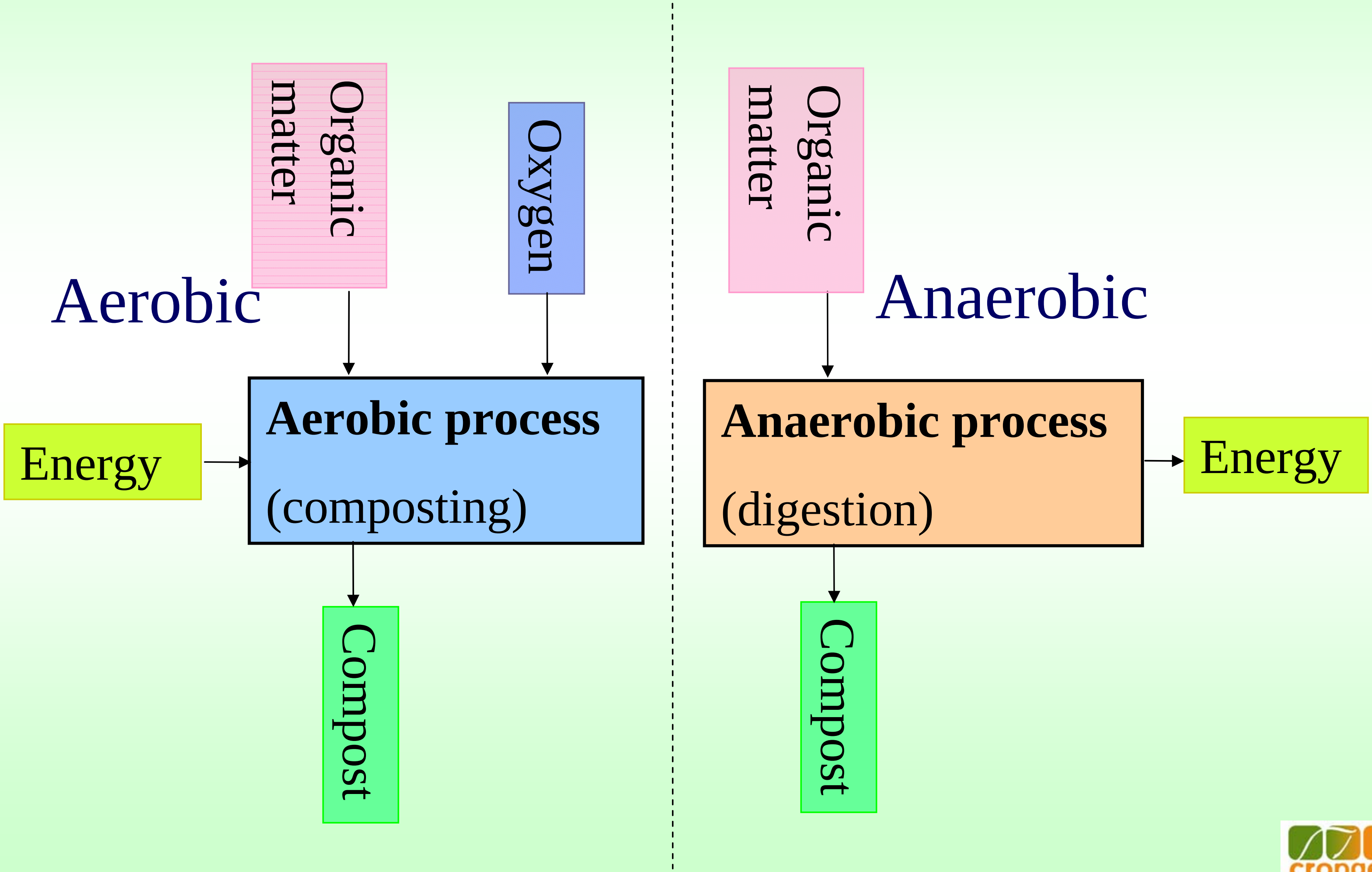
Renewable energy from crops and agrowastes

Outline of presentation

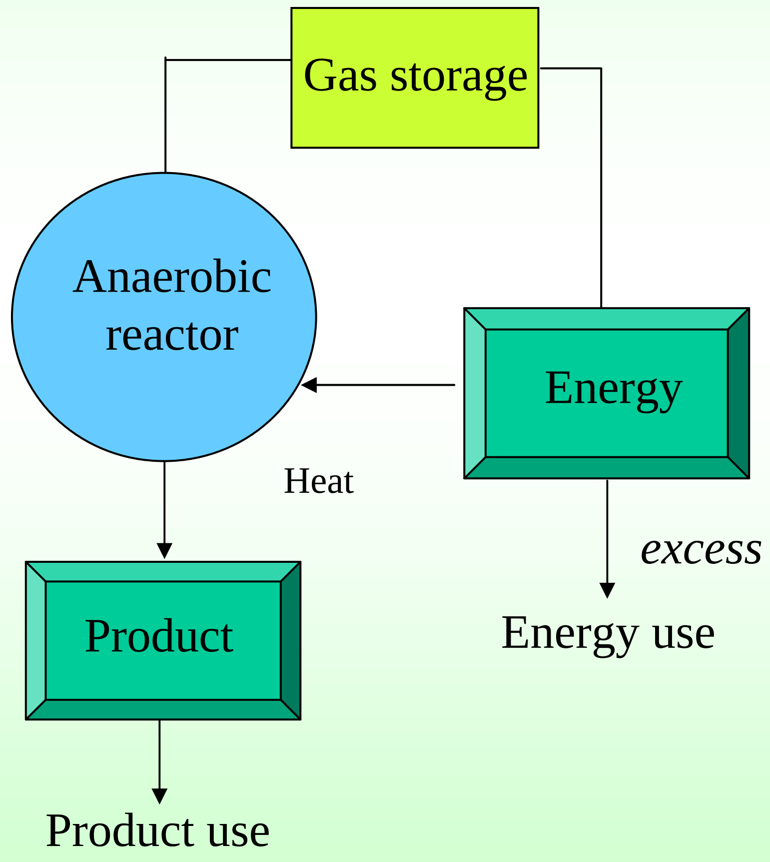
- Brief background to anaerobic digestion processes
- Potential of energy crops and agrowastes for sustainable energy production: targets and objectives
- Brief details of proposal and integration of activities

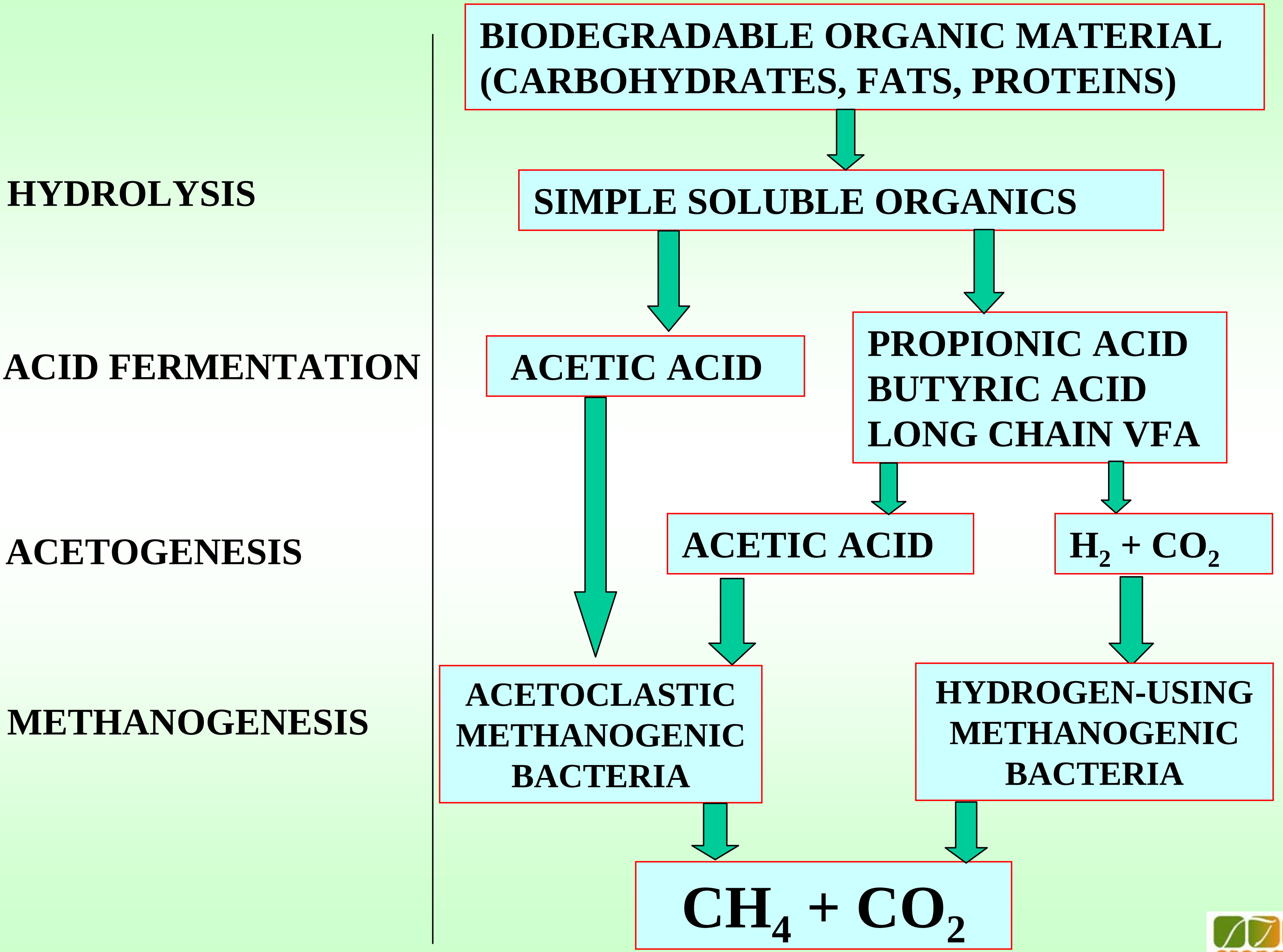
Bioprocesses for organic material



Controlled AD

- Closed reactor
- System of gas collection
- Utilisation of the energy
- CO_2 emission (but not additional)




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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History of use

- Anaerobic digestion has been used for several decades to stabilise sludge residues from wastewater treatment
- Growing use in Europe as a means of treating and recovering value from MSW
- In engineering terms a tried and tested process, and energy yields for sewage sludge are well established

Process types

Wet

Dry

Mesophilic

Thermophilic

Multi-stage

One stage

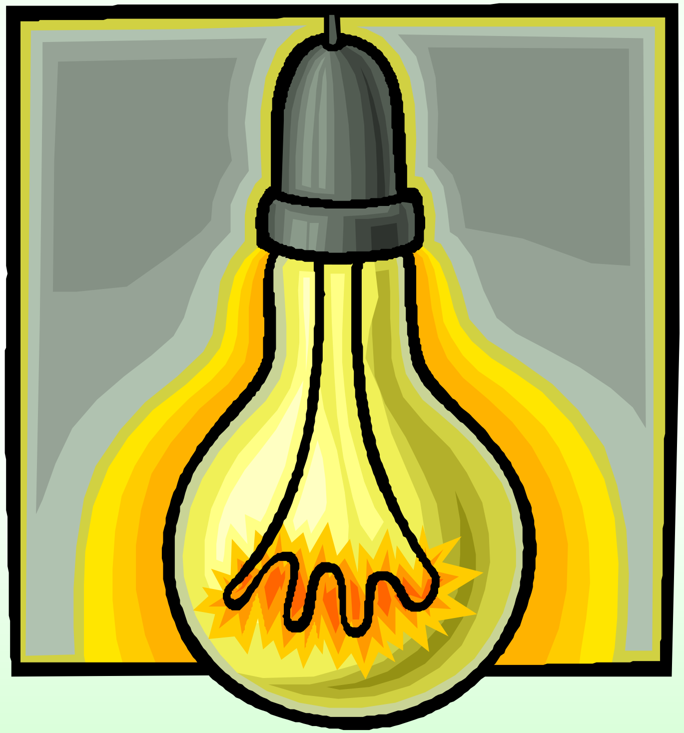
Process differences

Wet Process	*Dry Process*
• 3 - 5 % solids feed conc.	• 20 - 40% solids feed conc.
• one or several stages	• usually one stage
• usually operate at 35^{o}C	• can operate at 35^{o}C or 55^{o}C
• requires water addition or recycle	• minimal water addition
• larger reactor	• Smaller reactor
• proven technology for sewage sludge digestion	• becoming most popular choice for MSW
• more applicable to co-digestion with other waste	• more data and reference plants needed

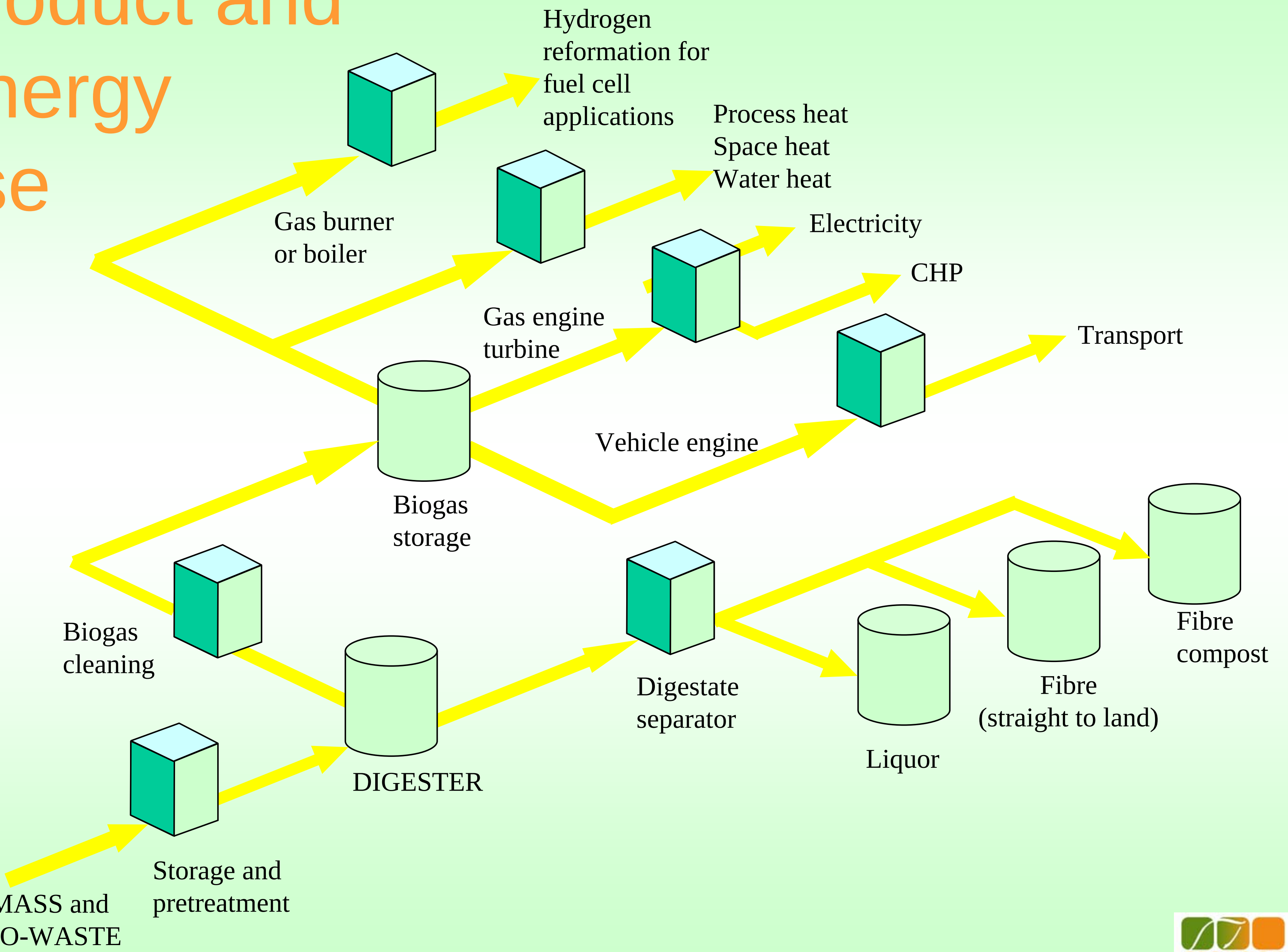
Instantly recognisable!

Energy production

- Up to 75% conversion of organic matter into biogas
- Biogas has a methane content of between 50 - 70% with a thermal value 36 MJ m^{-3} (methane)



Product and Energy use



Energy crops – targets and performance

Biogas energy: an example

- European Energy Crops InterNetwork quotes yields of 100 t ha^{-1} for sweet sorghum (grown for ethanol production), equal to 29 t dry matter ha^{-1}

- Gas Research Institute (USA) gives BMP of sweet sorghum as 0.39 m^3 kg VS $^{-1}$

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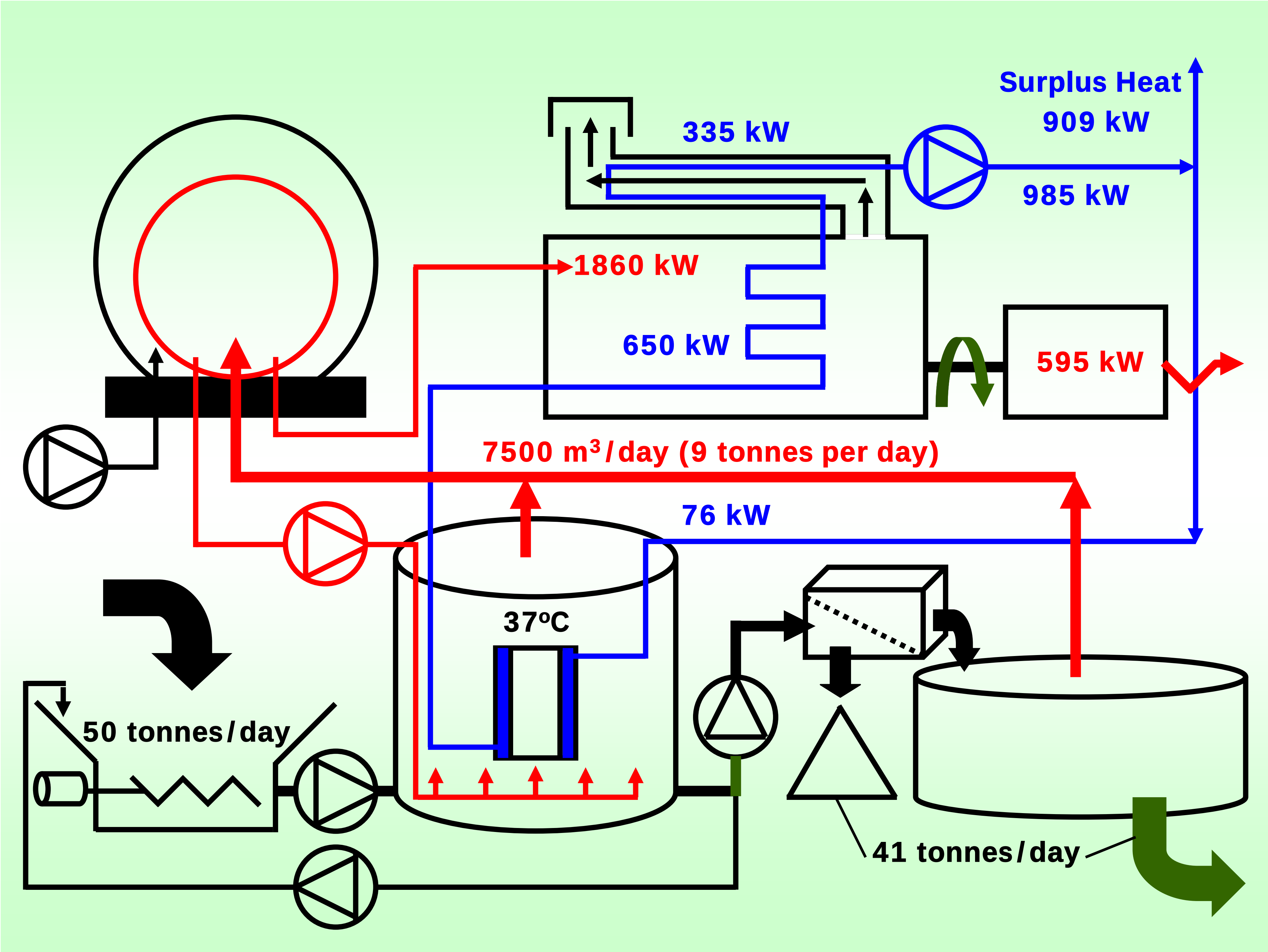
Energy yields

- 9048 m^3 ha^{-1} of methane with energy yield 353 GJ (based on 80% volatile solids)
- Energy value of ethanol from the same crop 137 GJ
- Both the above values ignore any energy inputs

PROCESS ENERGY LOSSES and YIELDS

- Biomass feedstock (50 T per day)
- 30% dry matter
- 90% volatile solids
- 66% volatile solids destruction
- Methane yield 0.5m^3 per kg VS destroyed (=0.33m^3 per Kg VS added)
- Digester volume 3000m^3
- Retention time 60 days



Surplus Heat
909 kW
335 kW
985 kW
1860 kW
650 kW
595 kW
7500 m³/day (9 tonnes per day)
76 kW
37ºC
50 tonnes/day
41 tonnes/day

Economics (based on CHP)

• Cost of plant	€1.32 million
• ANNUALCOST OF REPAYMENT (15 years)	€140K
• Annual operating cost (labour, maintenance, crop production)	€400K
• TOTAL ANNUAL COST	€540K
• Annual value of electricity (€0.12/kWh)	€560K
• Annual value of heat (€0.4 / litre oil equivalent)	€190K
• Annual value of digestate (€20 /Tonne)	€60K
• TOTAL ANNUAL INCOME	€810K
• ANNUAL PROFIT	€270K

Digestion in an integrated farming environment

Uptake across Europe

- The degree of adoption of AD on farms across the EU varies considerably.
- Some states such as Germany, Austria and Denmark have adopted the technology, mainly as a result of governmental subsidies, while in others such as the United Kingdom, Ireland and France on-farm digestion is uncommon.

Uptake across Europe

COUNTRY	Farm related digestion capacity	Factors influencing the adoption of AD technology
Austria	139 + 50 under construction	• Regional and national government support for a renewable energy policy • Guaranteed purchase of biogas produced electricity at preferential rates: 0.165 - 0.103 € kWh^{-1} (depending on size of installation)
Germany	2500 (~4000 expected by end 2005) Anticipated installed electrical generating capacity of 950 MW by end 2005	• Renewable energy resources act ('feed in laws') • Guaranteed priority purchase of biogas produced (and other renewable) electricity at preferential rates for a 20 year period, base price paid ranges from 0.084 - 0.115 € kWh^{-1} • Bonuses for electricity produced from energy crops, use of CHP, and use of new technologies; these can add a further 0.1€ kWh^{-1} • Scale-down in subsidies from 2005 to encourage efficiency and process development

Uptake across Europe

COUNTRY	Farm related digestion capacity	Factors influencing the adoption of AD technology
Denmark	22 CAD receiving mainly (80%) animal slurry + 40 farm-scale digesters.	• Investment grants to help meet capital costs (currently 20%) • Long term loans at low interest rates • Legislative requirement for 9 month storage for slurry • Favourable prices for biogas produced electricity • Exemption from energy taxes • Demonstration programmes and research support • Opportunities for district heating
Sweden	10 CAD co-digestion plants + 5 farm-scale plants	• Encouragement of the use of biogas as a vehicle fuel through low taxation
Switzerland	69 farm-scale digesters	• Subsidy of biogas derived electricity prices at 0.10 € kWh^{-1} • Grants of up to 8% of installation costs

Co-digestion

- Most farm-based and CAD facilities in Europe use animal slurry as the major substrate, often supplemented with other organic wastes or energy crops.
- In most plants the basic substrate is cattle or pig slurry.
- In Germany ~94% of agro-biogas plants use co-digestion for more efficient gas production. Over 30 different organic by-products and wastes from food- and agro-industries are used, but energy crops and crop residues are most common as importing wastes onto the farm leads to reduced subsidies.
- Economic digestion of manure without co-substrate can only be achieved in large-scale farming.

Crops

- Most conventional crops can be co-digested as the yield of CH_4 per tonne of organic dry matter (ODM) is similar (usually 350-450 m^3/t ODM)
- Maize and grass are the most common energy crops, because maize has a high methane yield per hectare and grass is characterized by low input costs.
- Very few biogas plants are operated with mono-fermentation of crops. Process control is more difficult due to the low buffer capacity; biogas productivity is sometimes inhibited due to the accumulation of salts and ammonia nitrogen from process water recycling.

Crops – a reminder

Substrates	Dry matter content (DS%)	Organic dry substance in DS%	Biogas Yield Nm3/T substrate	Methane content (%)
Dairy cow slurry	8	85	20	55
Fattening cattle slurry	10	85	34	55
Pig slurry	5	85	18	60
Chicken manure	25	75	93	65
Meadow grass average from 3-4 cuts/year	18	91	98	54
Maize silage	33	96	190	53
Grass silage average from 3-4 cuts/year	35	89	183	54
Grain milled	87	98	597	53
Corn-Cop-Mix, 5,3% fibre	60	98	391	53
Total plant grain silage	40	94	195	53
Potato distillery residues	6	87	35	56
Vegetable residues	6	87	35	56
Rape seed cake	91	93	612	63
Canteen residues high fat	18	92	90	68
Canteen residues low fat	14	82	44	69
Flotation fat	12	90	108	68

Farm digester types

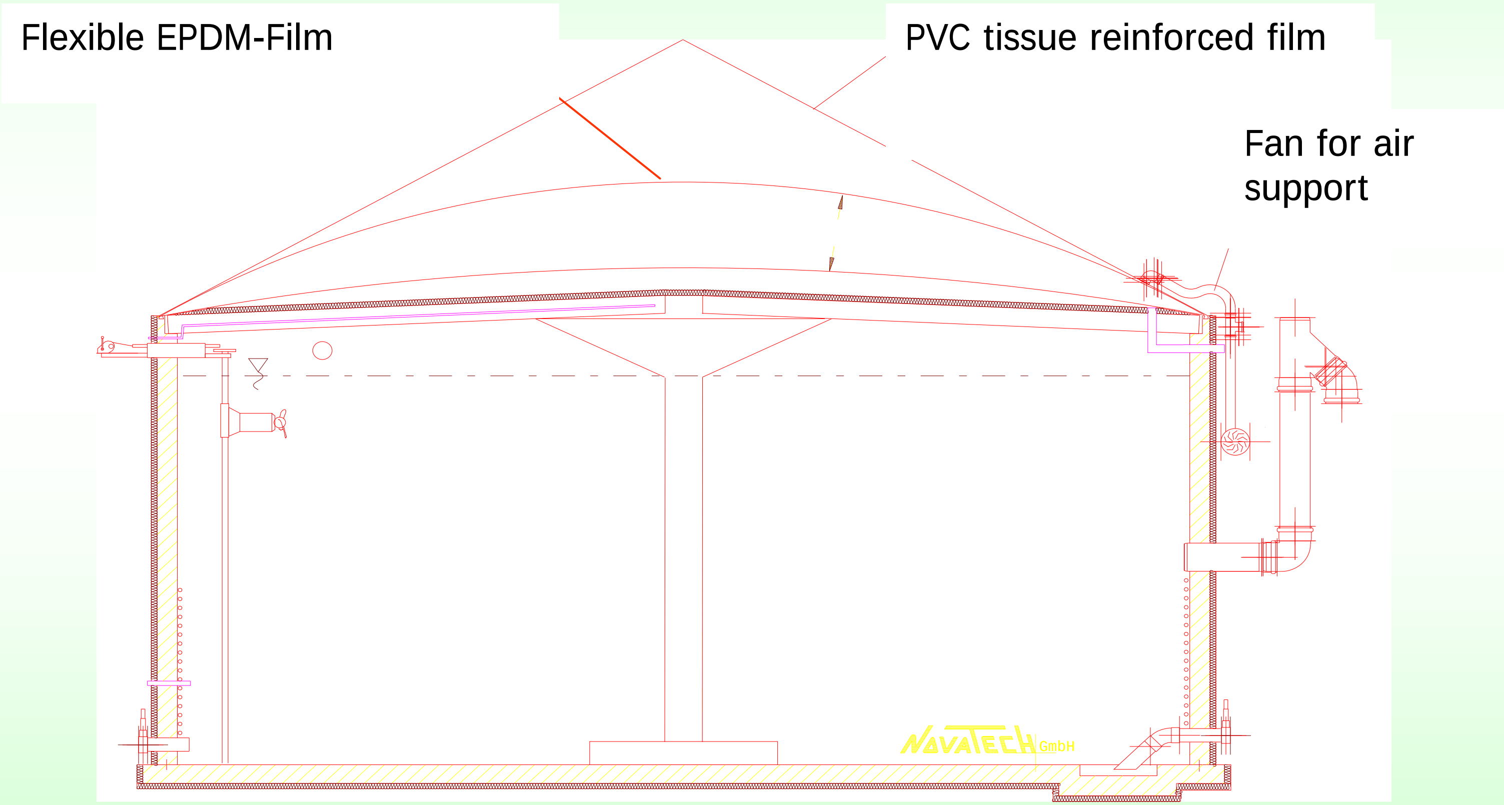
Digester types

- Continuously operated wet systems are the most common on continental farms, with only a few dry systems at demonstration or pilot plants.
- Most common are vertically mounted cylindrical digesters of 800-1500 m^3, or 2000-5000 in CAD plants.
- Horizontal plug flow is mainly used in low capacity systems or for high solids substrates, with a typical volume of 150-600 m^3.

Digester construction

- To reduce construction costs digesters of up to 1000 m^3 are often fitted with a double membrane for gas storage. The inner flexible membrane is the gas-holder, and the outer one the weather cover. A blower maintains a slightly elevated air pressure in the space between membranes to support the structure.
- Approximately 30% of plants also use a membrane roof for the storage tank, to collect gas from post-digestion, as 5-20% of the formed gas is generated here. This concept is important for reducing the emission of greenhouse gases.

Digester construction



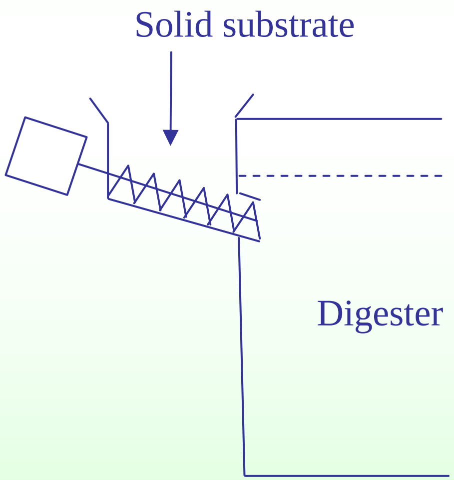
Digester construction

Feeding systems

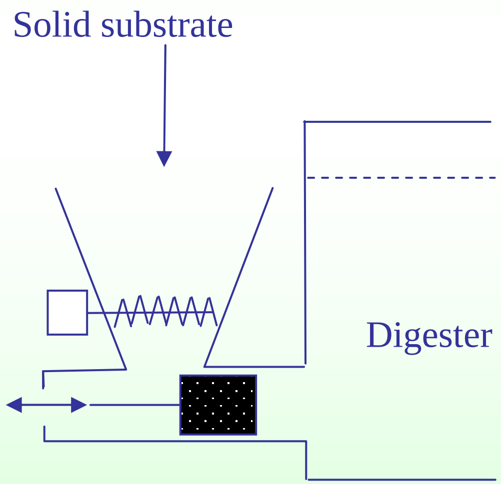
- In Germany, mixing tanks for blending crops and slurry have mainly been replaced by direct charging systems. This reduces energy costs and also odours.
  - Screw feeders are at the top of the reactor just below the liquid level and can be used for fibrous and bulky substrates.
  - Piston feeding systems are liquid-tight and can enter the bottom of the digester. They give better substrate mixing and easier charging of the system. Solids are carried into the digester by two contra-rotating screws and a hydraulic piston.
  - Flushing systems have a mobile nozzle to flush substrate via an entry chute into the digester. This technology can be applied to solid, paste and sticky materials but odours can escape from the feed chute.

Feeding systems

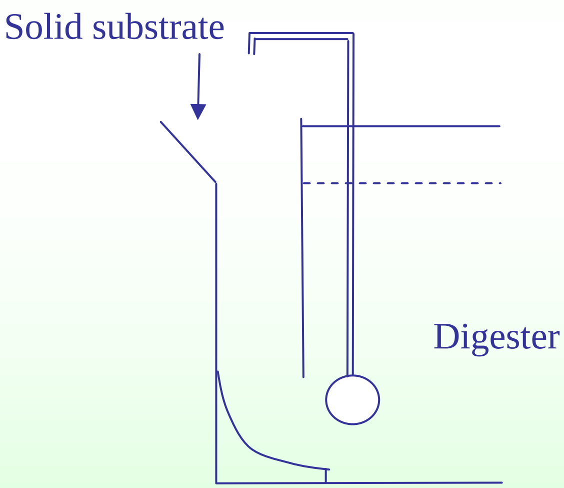
Screw Feed



Piston Feed



Flush Feed



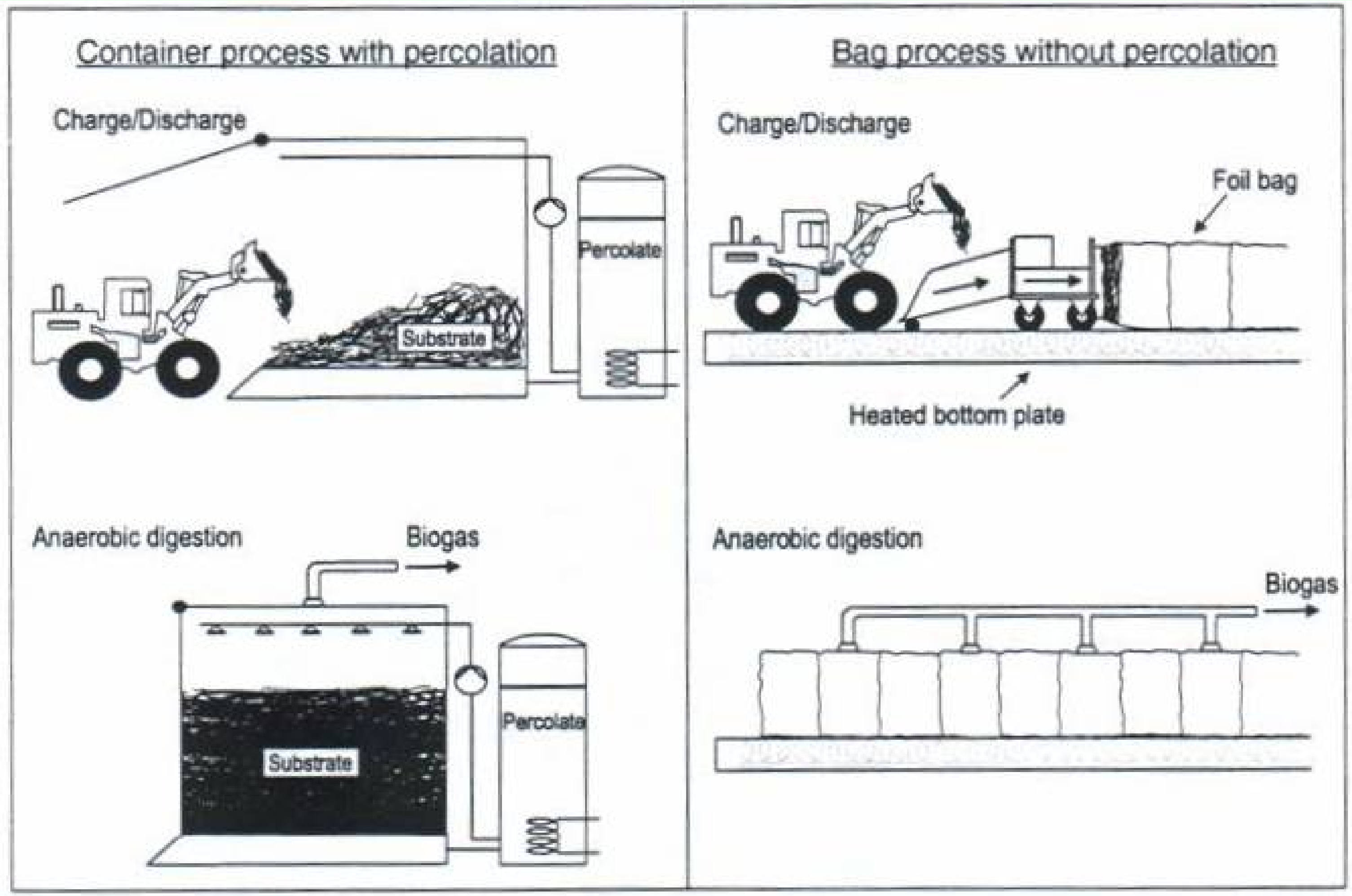
Small-scale dry systems

- Dry fermentation systems are of increasing interest in Germany for mono-fermentation of energy crops and also treatment of yard manure and bedding from cows, pigs and poultry.
- Several batch processes without mechanical mixing have been developed, but only few have been operated at farm-scale.
- Two different process types have recently been tested and are examples of dry fermentation with and without percolation.

Small-scale dry systems

- For the percolation process a gas tight fermenter box with a typical volume of about 150 m^3 is used coupled with a tank for storage and heating the percolation water.
- The bag process uses a gas-tight foil bag normally used for ensiling forage crops. The bag is located on a heated base. The bag is filled with a mixture of fresh substrate and treated material for inoculation. The ratio of fresh and digested material has to be carefully defined to avoid uncontrolled acidification.

Small-scale dry systems

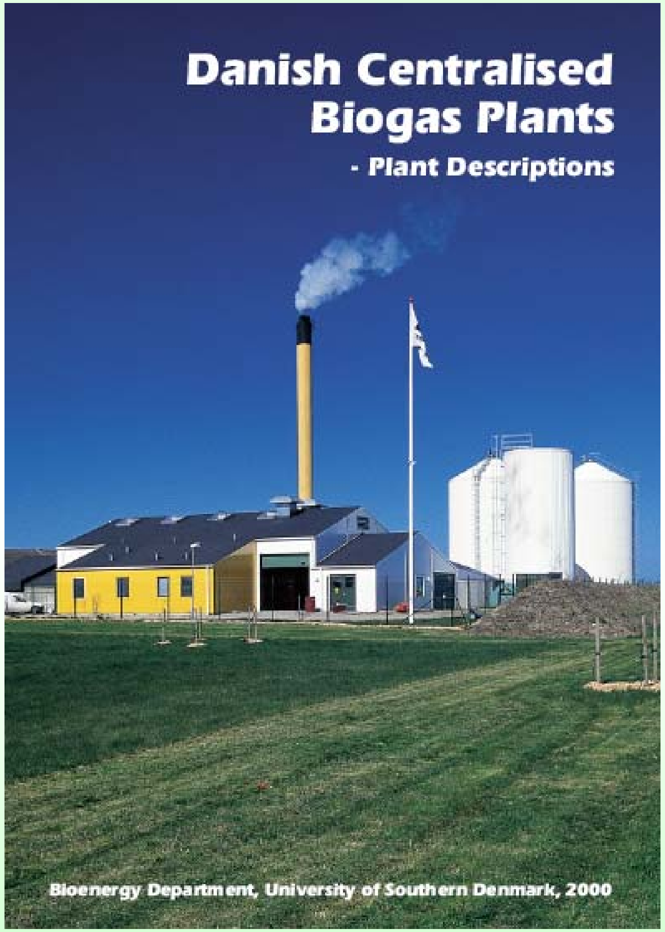


Farm CAD

- The Danish Biogas Programme is a good example of an ambitious and consistent government policy for farm management and nutrient control.
- This includes 6-9 month manure storage capacity, plus restrictions on application and on landfilling organics.
- Economic incentives included grants, low-rate long-term loans, tax exemptions and subsidies for bio-electricity currently of 0.079 € kWh^{-1} for established plants (but reducing to 0.053 € kWh^{-1} in 2014).
- Heat sales are also possible through widely available district heating networks for 6-9 months per year.

Farm CAD

- There are currently 18 centralised biogas plants large enough to be included in the survey carried out by the Bioenergy Department of the University of Southern Denmark
- The plants are mostly co-operatives involving farmers, municipalities and/or private organisations, with from 5 to 80 farmers involved.



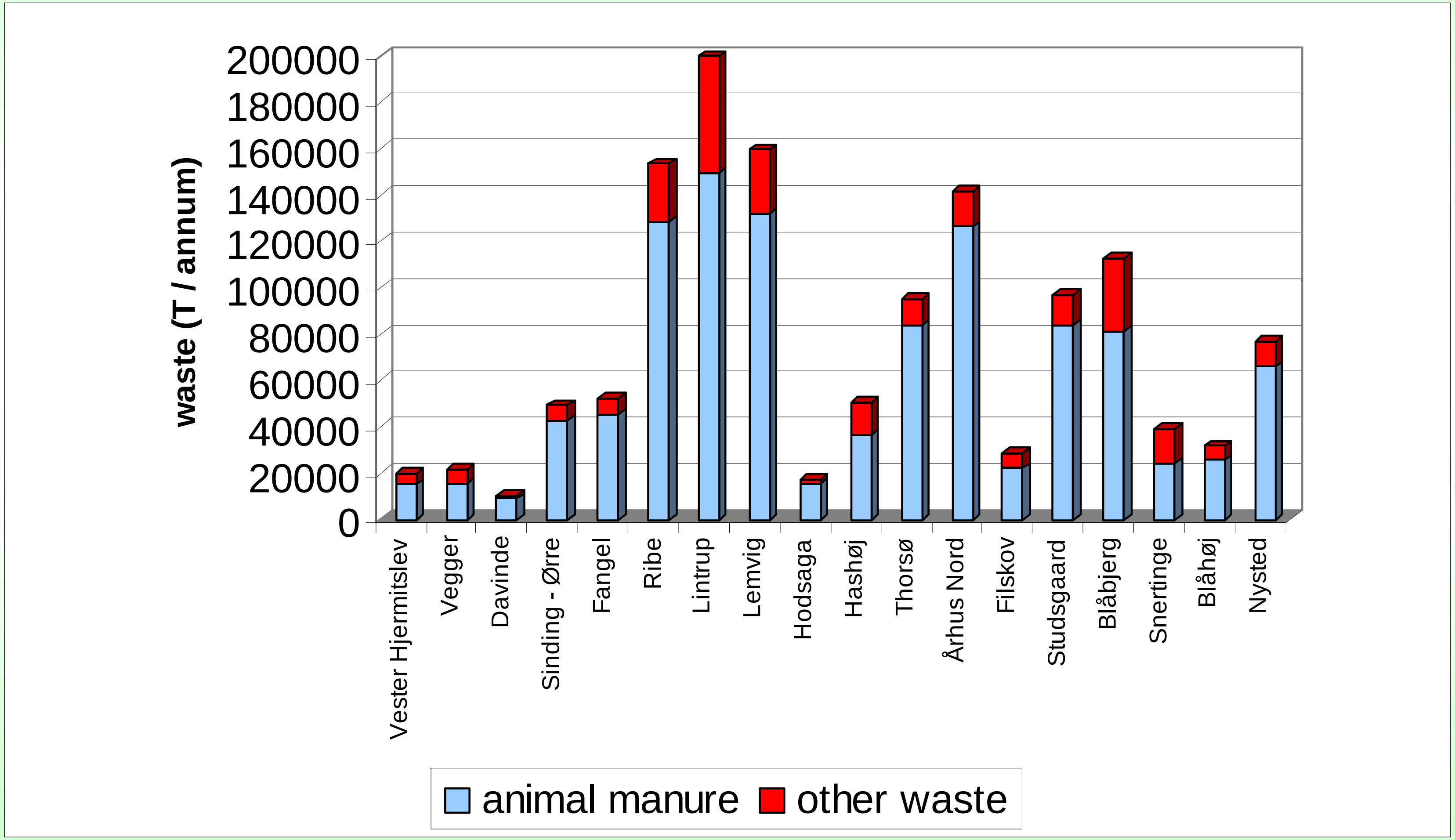
Farm CAD

- 7 operate at mesophilic and the remainder at thermophilic temperatures.
- The plants have been supplied by different manufacturers but all are based on a wet completely mixed single phase digestion system.
- Sizes range from 10,000 to 200,000 tonnes in relation to the waste tonnage that can be accepted.
- Feedstock is mainly animal slurry from pigs and cattle, supplemented in all cases by other organic wastes from food processing.

Farm CAD

- These include animal wastes such as intestinal contents (27%), fat and flotation sludge from food or fodder processing (53%), and wastes from fruit & vegetable processing, dairies and other industries.
- On average about 23% of the waste is not from farms, but this ranges from 12 to 64% for individual plants.
- Approximately 1.1 million tonnes of manure is treated with 255,000 tonnes of other organic waste.
- This yielded 50 million m3 of biogas with an average yield of 36.8 m3 tonne^{-1} (wet weight).
- Biogas yield is therefore considerably higher than the normal 20 m^3 tonne^{-1} for slurry alone.

Farm CAD



waste (T / annum)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Vester Hjermitslev
Vegger
Davinde
Sinding - Ørre
Fangel
Ribe
Lintrup
Lemvig
Hodsaga
Hashøj
Thorsø
Århus Nord
Filskov
Studsgaard
Blåbjerg
Snertinge
Blåhøj
Nysted
animal manure
other waste

Farm CAD

Location	Animal manure tons/day	Other biomass tons/day	Biogas production $Nm^3 \times 10^6 yr^{-1}$	Digester capacity m^3	No of reactors	Biogas / m^3 digester	Process temp °C
Vester Hjermitslev	41	13	1	1500	3	666.67	37
Vegger	42	17	2.1	920	4	2282.61	55
Davinde	25	3	0.3	750	1	400.00	36
Sinding - Ørre	117	18	2.4	2250	3	1066.67	36
Fangel	124	19	2.2	3750	3	586.67	37
Ribe	352	68	4.8	5235	3	916.91	53
Lintrup	410	137	5.7	7200	3	791.67	53
Lemvig	362	75	5.4	7600	3	710.53	53
Hodsaga	42	6	0.7	880	2	795.45	37
Hashøj	100	38	3	3000	1	1000.00	37
Thorsø	230	31	2.9	4650	2	623.66	53
Århus Nord	346	42	3.8	8500	3	447.06	53
Filskov	61	18	1.3	880	2	1477.27	53
Studsgaard	230	36	5.7	6000	2	950.00	53
Blåbjerg	222	87	3.1	5000	2	620.00	53
Snertinge	66	42	1.6	3000	3	533.33	53
Blåhøj	70	17	1.4	1320	2	1060.61	53
Nysted	180	31	2.6	5000	1	520.00	38
Total	3020	698	50	67435		741.45	
Average	167.78	38.78	2.78	3746.39			
Biogas per ton biomass	36.84						