Feedstocks: Characteristics, Pre-Treatments

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Des Devlin

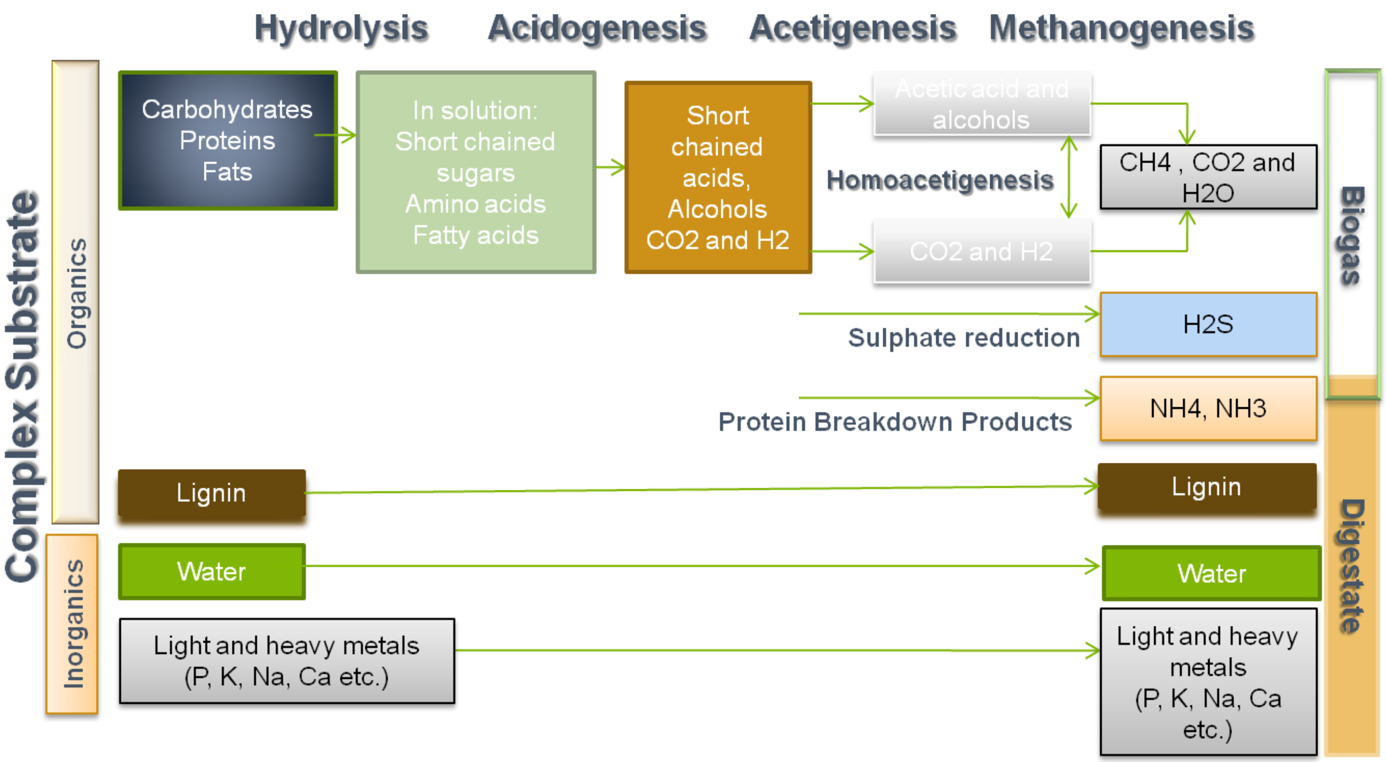
Inaugural Bio-Methane Regions Event
Training the Trainers
26-27th May 2011 - University of Glamorgan, South Wales

Overview

- Examples of feedstocks
- Feedstock characterisation
- Gas yields (Buswell equation)
- Anaerobic biodegradability testing
- pre-treatments
- examples (percolation, chemical pretreatment)

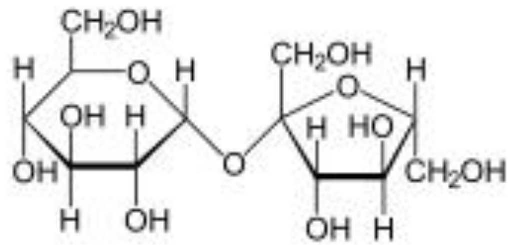
Feedstocks for AD

- •Maize
- •Wheat
- •Sugarbeet
- •Grass
- •Silage
- •Whey
- •Spent Grain
- •Paper
- •DAF
- •Agricultural Waste
- •Abattoir Waste
- •Commercial Waste
- •Municipal Wastes
- •Foodwaste
- •Chicken Litter
- •Cow / Pig Slurry
- •Sewage Sludge

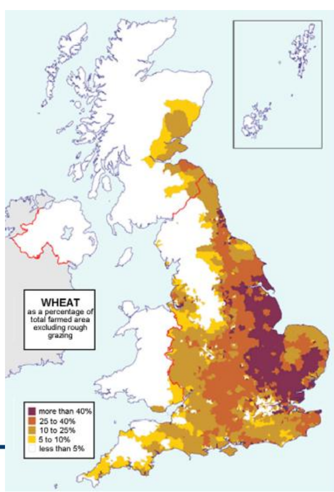


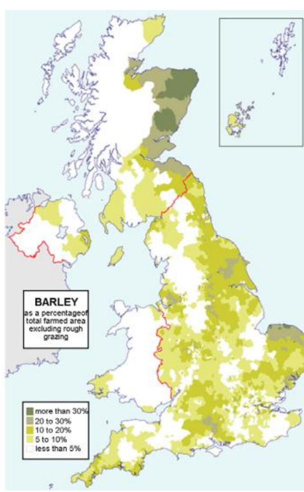
Molasses

Main components	soluble sugar



Total solids	50-60%
VS	>98% of TS
Methane yield	300 m^3 t^{-1} TS
Availability	commodity £150 / t





Energy crops

Main components	sugars, starch cellulose, hemicellulose
Total solids	30 – 35%
Volatile solids	90 – 98% of TS
Methane yield	300-400 m^3 t^{-1} TS
Availability (Wales)	10,000 ha @17-21 TS ha^{-1} (maize) seasonal

Data compiled from;
Charlton et al., 2009. Chem Eng Res Design 87:1147–1161
Welsh Assembly Government, 2007
http://www.statswales.wales.gov.uk
Big East Biogas Handbook

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Grass / silage

Main components	sugars, cellulose , hemicellulose
Total solids	30-35%
Volatile solids	90-98%
Methane yield	260-400 $m^3\ t^{-1}$ TS
Availability (Wales)	1,009,700 ha @ 10 t TS ha^{-1}
Value	£20 – 40 / tonne

Data compiled from;
http://www.statswales.wales.gov.uk
Big East Biogas Handbook

By-products (e.g. Wheatfeed)

Physical properties of the wheatfeed	Chemical composition
Bulk density = 3.6 Kg L^{-1} Weight = 3 ± 0.34 g Dimensions D = 0.8 ± 0.025 cm L = 2.1 ± 0.2 cm	Carbohydrates = 85% (20% Starch , 65% holocellulose) Water =15% Protein = 2%

Main components	starch, cellulose, fibre
Total solids	85%
Volatile solids	90-95 % of TS
Methane yield	320-400 m^3 t^{-1} TS
Availability	31,200 t / year (from one local plant)
Wholesale as feed	£165 / tonne

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Hawkes et al., 2008 Bioresource Technology 99: 5020–5029
G. Shipley – personal communication

Municipal and C&I wastes

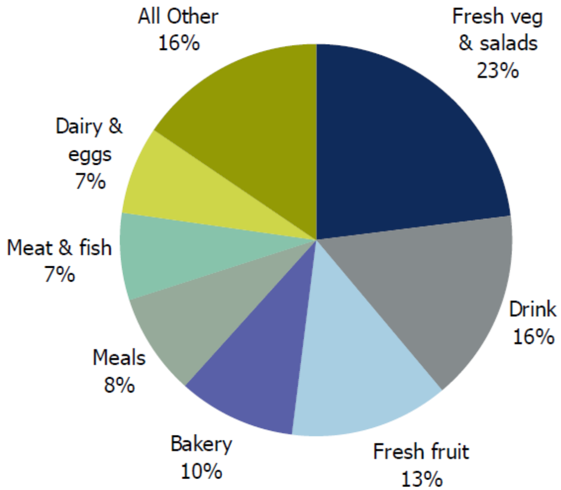
Main components - Vegetable peelings, bakery, teabags, meat, paper

Availability (Wales) 870,000 t / year

Methane yield 400 $m^3\ t^{-1}$ TS

Gate fees / waste permits / ABPR / PAS110

Figure F: Proportion of weight of all food and drink waste, split by food group



Data amalgamated from:
- Environment Agency Wales C&I survey 2007
- WRAP 2009 The composition of municipal solid waste in Wales
- http://www.statswales.wales.gov.uk
- Big East Biogas Handbook

Animal slurry / sewage

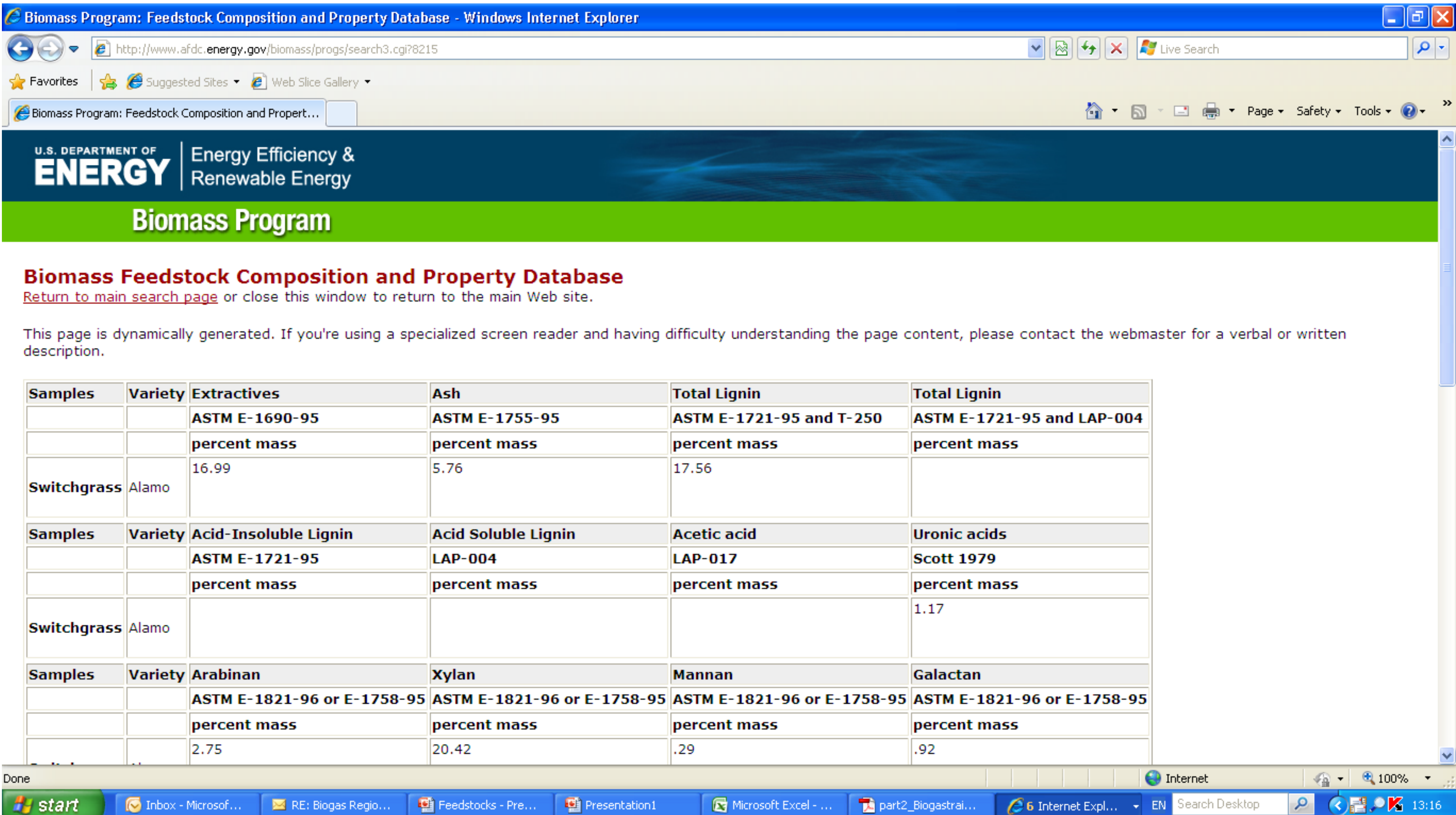
Components	undigested material
Total solids	5 -15%
Volatile solids	70–85% TS
Availability	5,929,600 t slurry (18%) 96,000 t sewage sludge
Methane yield	180-200 m^3 t^{-1} TS

Suitable for co-digestion

Waste regulations

Data from:
Renewable Energy Route Map for Wales
Big East Biogas Handbook

Online compositional databases



Biomass Feedstock Composition and Property Database

Return to main search page or close this window to return to the main Web site.

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Samples	Variety	Extractives	Ash	Total Lignin	Total Lignin
		ASTM E-1690-95	ASTM E-1755-95	ASTM E-1721-95 and T-250	ASTM E-1721-95 and LAP-004
		percent mass	percent mass	percent mass	percent mass
Switchgrass	Alamo	16.99	5.76	17.56	
Samples	**Variety**	**Acid-Insoluble Lignin**	**Acid Soluble Lignin**	**Acetic acid**	**Uronic acids**
		ASTM E-1721-95	LAP-004	LAP-017	Scott 1979
		percent mass	percent mass	percent mass	percent mass
Switchgrass	Alamo				1.17
Samples	**Variety**	**Arabinan**	**Xylan**	**Mannan**	**Galactan**
		ASTM E-1821-96 or E-1758-95	ASTM E-1821-96 or E-1758-95	ASTM E-1821-96 or E-1758-95	ASTM E-1821-96 or E-1758-95
		percent mass	percent mass	percent mass	percent mass
		2.75	20.42	.29	.92

Biomass datapage Phyllis - Windows Internet Explorer

ECN P H Y L L I S

the composition of biomass and waste

home | general information | how to use Phyllis | definitions used in Phyllis | preferences

composition of a single material | average composition of a group of materials | selection via NTA 8003 | search for materials

General information

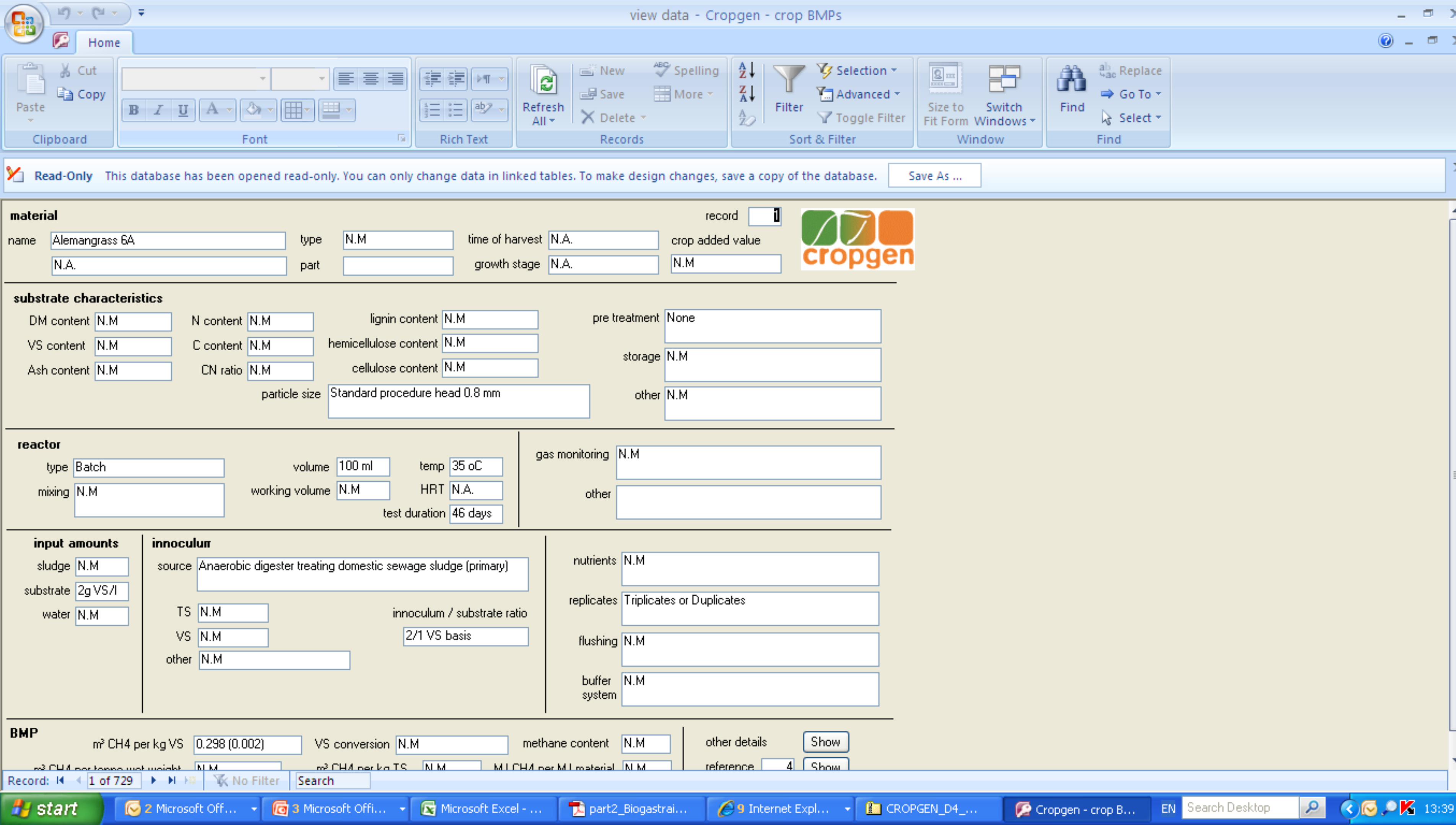
Sample information	
Group	RDF and MSW
Subgroup	MSW
Material	MSW
ID-number	1518
Reference:	K. R. G. Hein: Combined combustion of biomass/sewage sludge and coals; Clean Coal Technology Programme 1992-1994, Stuttgart, IVD, ISBN 3-928123-16-5 (1994).
Remarks:	MSW from Germany

Material composition

Proximate analysis (wt. %)			
	dry	daf	ar
Ash	44.2		27.2
Water			38.5
Volatiles	-	-	-
Calorific value (kJ/kg)			

Ultimate analysis (wt. %)				
	dry	daf	ar	
C	30.8	55.1	18.9	Msr
H	0.96	1.7	0.6	Msr
O	21.5	38.5	13.2	Msr
N	1.09	1.95	0.67	Msr
S	0.78	1.4	0.48	Msr

Elemental analysis (mg/kg sample (dry))								
Al	-	ND	Fe	-	ND	Pb	-	ND
As	-	ND	Hg	-	ND	Sb	-	ND
B	-	ND	K	-	ND	Se	-	ND
Ba	-	ND	Mg	-	ND	Si	-	ND
Ca	-	ND	Mn	-	ND	Sn	-	ND
Cd	-	ND	Mo	-	ND	Sr	-	ND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Sort & Filter
Size to Fit Form
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Replace
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Select
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Read-Only This database has been opened read-only. You can only change data in linked tables. To make design changes, save a copy of the database.
Save As ...
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record 1
name Alemangrass 6A
N.A.
type N.M
part
time of harvest N.A.
growth stage N.A.
crop added value
N.M
cropgen
substrate characteristics
DM content N.M
VS content N.M
Ash content N.M
N content N.M
C content N.M
CN ratio N.M
lignin content N.M
hemicellulose content N.M
cellulose content N.M
particle size Standard procedure head 0.8 mm
pre treatment None
storage N.M
other N.M
reactor
type Batch
mixing N.M
volume 100 ml
working volume N.M
temp 35 oC
HRT N.A.
test duration 46 days
gas monitoring N.M
other
input amounts
sludge N.M
substrate 2g VS/l
water N.M
innoculum
source Anaerobic digester treating domestic sewage sludge (primary)
TS N.M
VS N.M
other N.M
innoculum / substrate ratio
2/1 VS basis
nutrients N.M
replicates Triplicates or Duplicates
flushing N.M
buffer system N.M
BMP
m³ CH4 per kg VS 0.298 (0.002)
VS conversion N.M
methane content N.M
other details Show
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Feedstock Characterisation - Why

- To ensure the correct treatment option is chosen
- To make sure the plant runs smoothly
- Correctly size plants
- Assess feedstock variability
- Need for dilution, additional nutrients/chemicals
- Potential odour and gas cleanup problems
- Quality of the resulting digestate

Feedstock Characterisation - Sampling

- Care should be taken
- Representative sample is essential
- Fresh is best
- Think about volume/mass required
- Sub sampling techniques

Feedstock Characterisation - Sampling

Sample as received

Large contaminants removed (bones, string, plastic, large paper, metal)

1st stage homogenisation – chopping using food processor

2nd stage homogenisation – blending using food liquidiser

Feedstock Characterisation - Units

- Wet Chemistry

g/l, g/kg, g/%TS

g/% VS, kg/m^3, kg/ton

- Gas Production

Biogas or methane?

ml/l, ml/g VS Added

ml/g VS Destroyed

m^3/tonne material added

Feedstock Characterisation – Basic Parameters

- TS
- VS
- pH
- Temperature
- Alkalinity
- HRT
- Gas production
- Gas Composition

Feedstock Characterisation – Chemical Analysis

- COD – Chemical oxygen demand
- Ammonia
- Carbohydrate
- Lipid
- Protein
- VFA – volatile fatty acids
- NDF – neutral detergent fibre
- ADF – Acid detergent fibre
- Lignin
- Nutrients and trace metals
- Elemental Analysis (CHNSO)
- Pathogen
- Siloxane content
- Inhibitory Compounds or elements

Feedstock Characterisation – Chemical Analysis

Type of feedstock	Organic content	C:N ratio	DM %	VS % of DM	Biogas yield m^3*kg^{-1} VS	Unwanted physical impurities	Other unwanted matters
Pig slurry	Carbohydrates, proteins, lipids	3-10	3-8	70-80	0,25-0,50	Wood shavings, bristles, water, sand, cords, straw	Antibiotics, disinfectants
Cattle slurry	Carbohydrates, proteins, lipids	6-20	5-12	80	0,20-0,30	Bristles, soil, water, straw, wood	Antibiotics, disinfectants, NH_4^+
Poultry slurry	Carbohydrates, proteins, lipids	3-10	10-30	80	0,35-0,60	grit, sand, feathers	Antibiotics, Disinfectants, NH_4^+,
Stomach/intestine content	Carbohydrates, proteins, lipids	3-5	15	80	0,40-0,68	Animal tissues	Antibiotics, disinfectants
Whey	75-80% lactose 20-25% protein	-	8-12	90	0,35-0,80	Transportation impurities	
Concentrated whey	75-80% lactose 20-25% protein	-	20-25	90	0,80-0,95	Transportation impurities	
Flotation sludge	65-70% proteins 30-35%lipids	-				Animal tissues	Heavy metals, disinfectants, organic pollutants
Ferment. slops	Carbohydrates	4-10	1-5	80-95	0,35-0,78	Non-degradable fruit remains	
Straw	Carbohydrates, lipids	80-100	70-90	80-90	0,15-0,35	Sand, grit	
Garden wastes		100-150	60-70	90	0,20-0,50	Soil, cellulosic components	Pesticides
Grass		12-25	20-25	90	0,55	Grit	Pesticides
Grass silage		10-25	15-25	90	0,56	Grit	
Fruit wastes		35	15-20	75	0,25-0,50		
Fish oil	30-50% lipids	-					
Soya oil/margarine	90% vegetable oil	-					
Alcohol	40% alcohol	-					
Food remains			10	80	0,50-0,60	Bones, plastic	Disinfectants
Organic household waste						Plastic, metal, stones, wood, glass	Heavy metals, organic pollutants
Sewage sludge							Heavy metals, organic pollutants

AL Seadi (2001)

Feedstock Characterisation – Buswell Equation

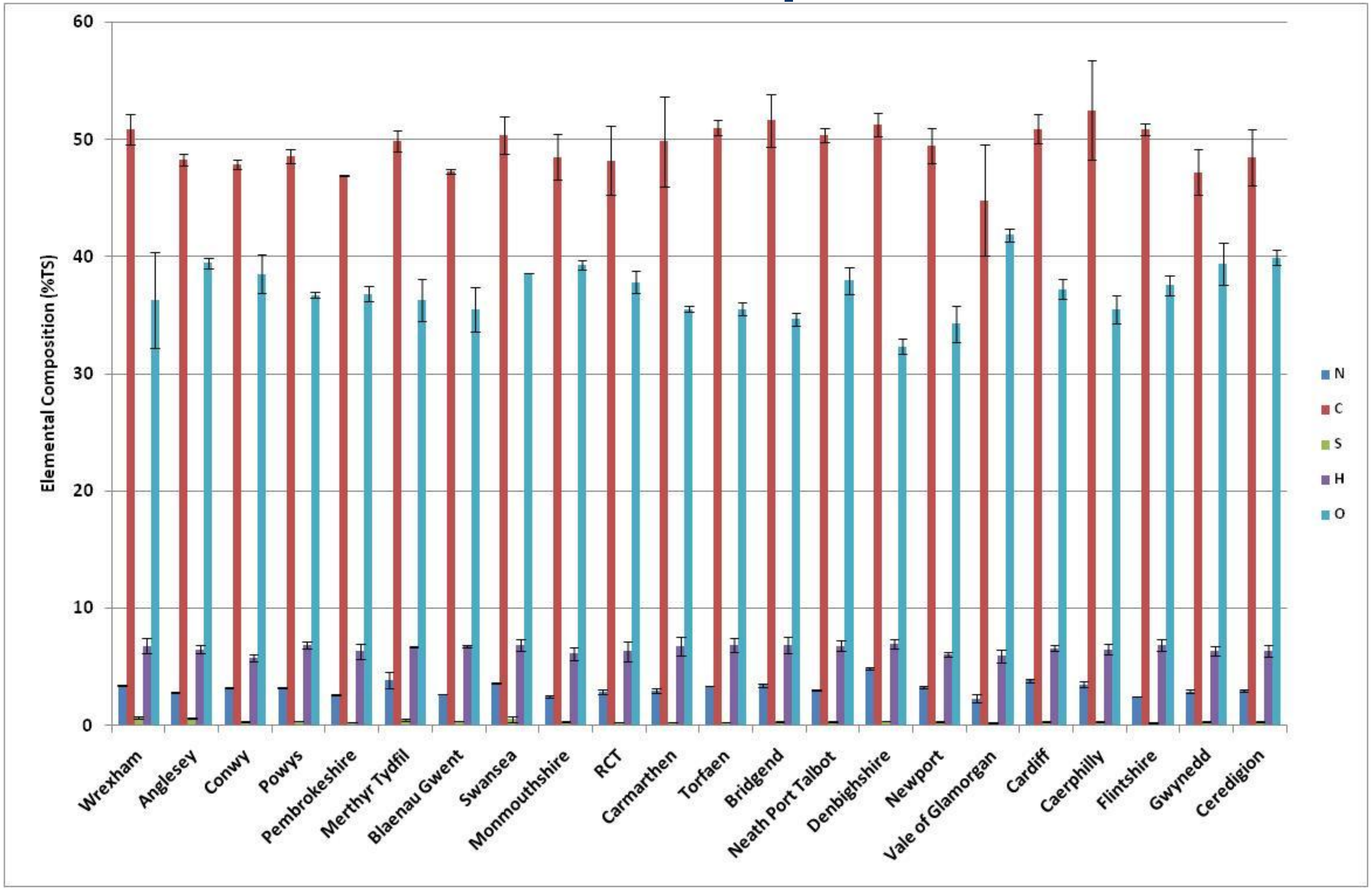
•Theoretical maximal biogas and biomethane production

$$C_cH_hO_oN_nS_s + \left(c - \frac{h}{4} - \frac{o}{2} + \frac{3n}{4} + \frac{s}{2}\right)H_2O \rightarrow \left(\frac{c}{2} + \frac{h}{8} - \frac{o}{4} - \frac{3n}{8} - \frac{s}{4}\right)CH_4 + \left(\frac{c}{2} - \frac{h}{8} + \frac{o}{4} + \frac{3n}{8} + \frac{s}{4}\right)CO_2 + nNH_3 + sH_2S$$

•Does not take into account the solubility of gasses
•Assumes all VS is available for conversion into biogas
•Does not account for any inhibition

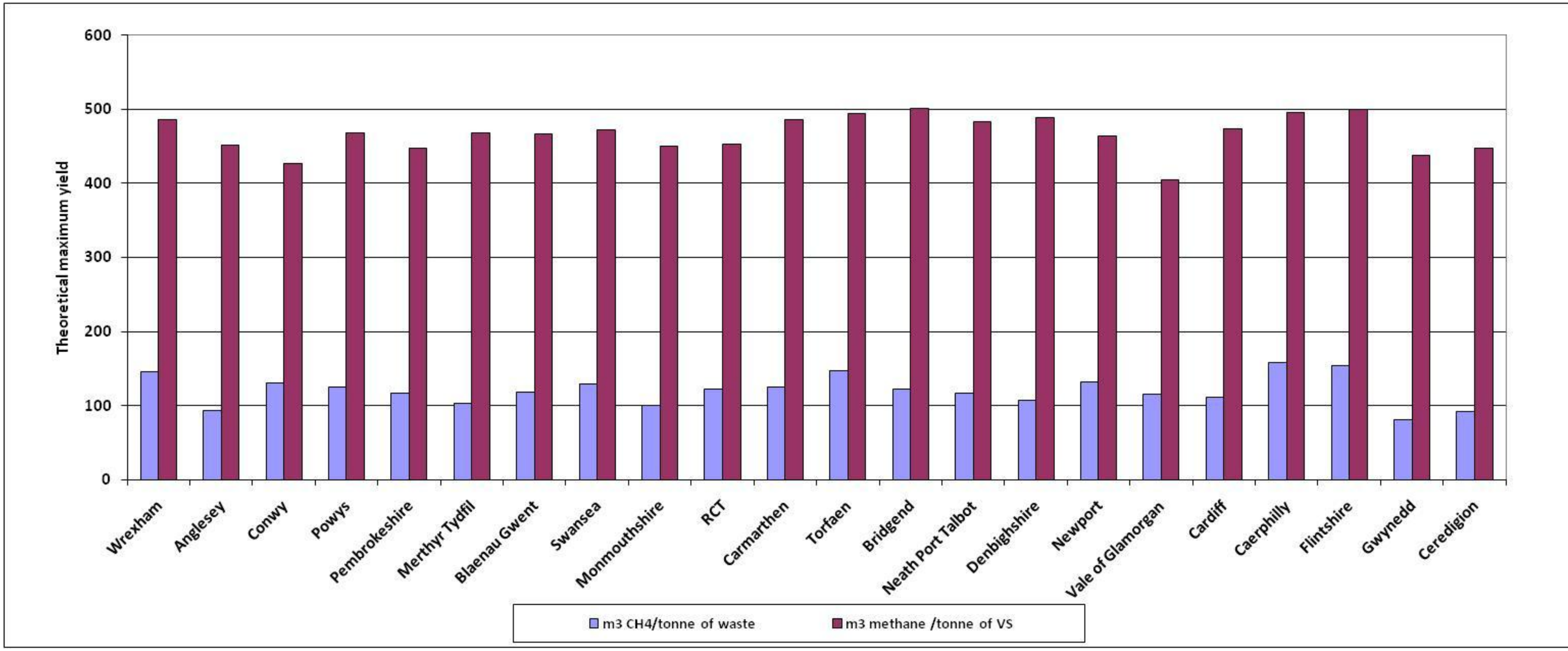
•Useful as a guide

Feedstock Characterisation – Buswell Equation



Esteves and Devlin (2010)

Feedstock Characterisation – Buswell Equation



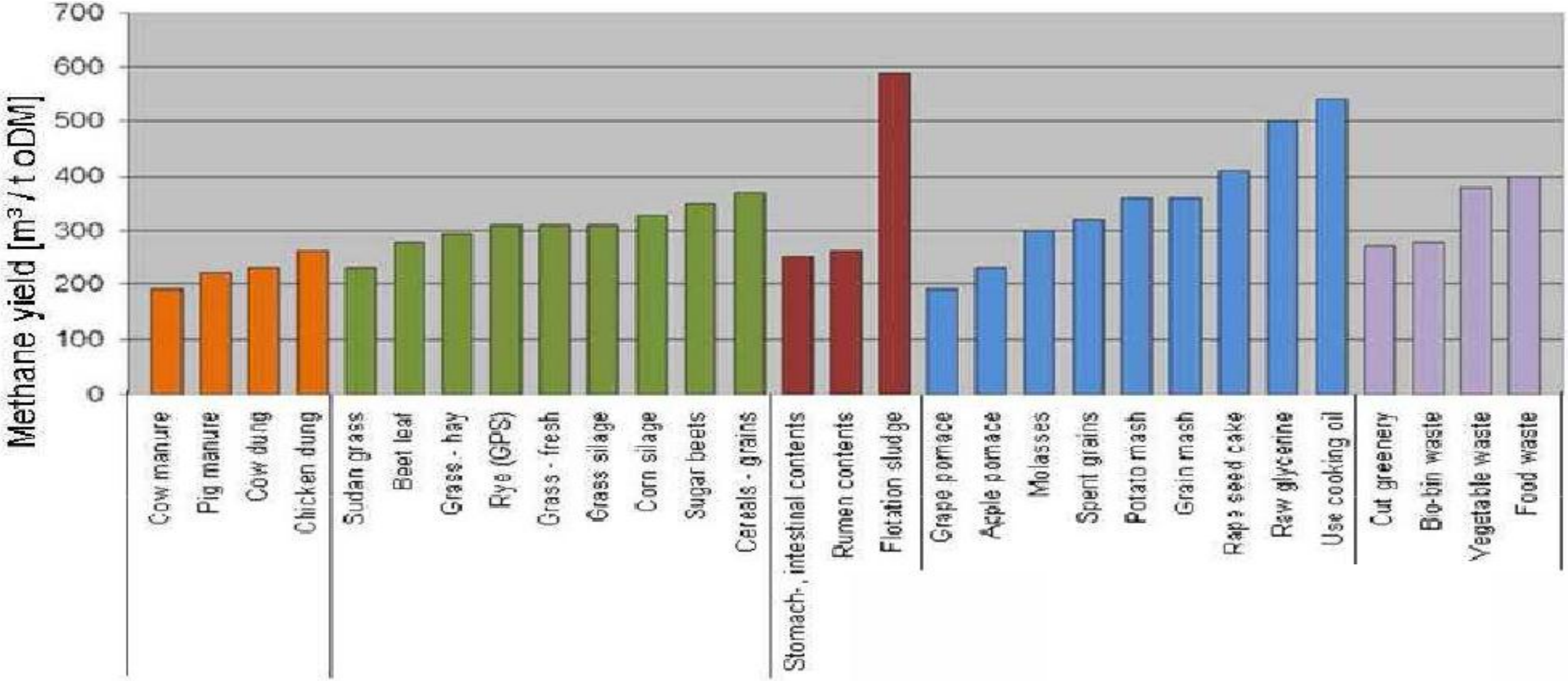
Esteves and Devlin (2010)

Feedstock Characterisation – Other Estimations

Substrate	Biogas (Nl/kg TS)	CH4%
Carbohydrate	700-720	70-71
Lipid	1200-1430	67-70
Protein	790-830	50
COD	545-660	55

Feedstock Characterisation – Other Estimations

- From the literature



Big East Handbook (2008)

Feedstock Characterisation – Digestibility Testing

Batch

- Relativly heap
- Relatively fast – 30 days
- Small scale so more tests can be carried out
- Standardisation is debated i.e. Seed to substrate ratio
- Provides details on maximum biogas and or biomethane production
- Not representative of the full scale process

Continuous

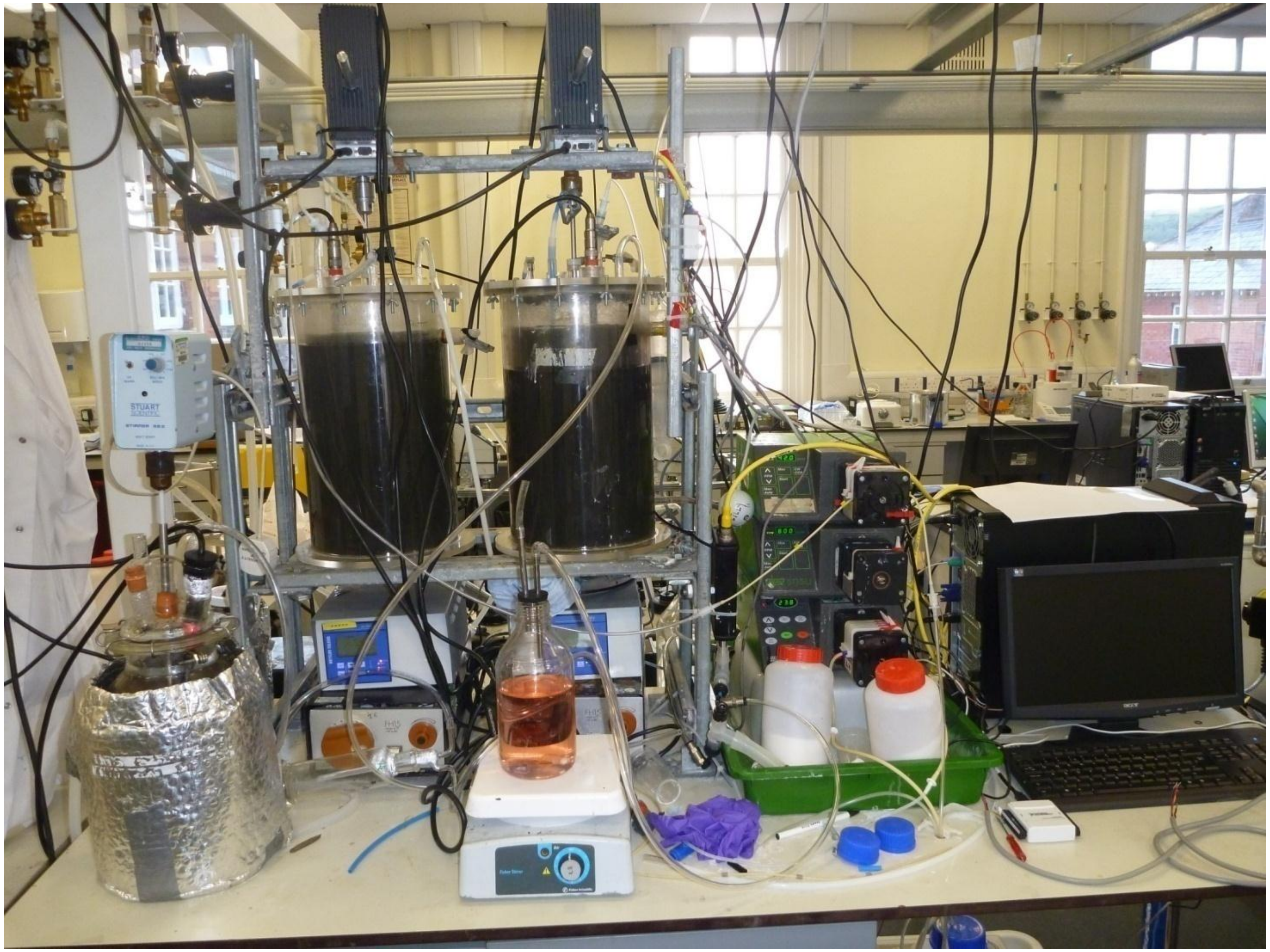
- Expensive
- At least Four HRT’s required
- In depth gas analysis can be carried out (e.g.Siloxanes, sulphur compoounds)
- Produces representative digestate, liquours and gas production as full scale plants
- Dewatering can be evaluated

Feedstock Characterisation – Digestibility Testing

Oxitop Batch Reactor

Automated Methane Potential Test System (AMPTS) Batch Reactor

Feedstock Characterisation – Digestibility Testing



Custom Built 10 l batch Reactor

Feedstock Characterisation – Digestibility Testing

Three Semi Continuous Reactors

Feedstock Characterisation – Digestibility Testing

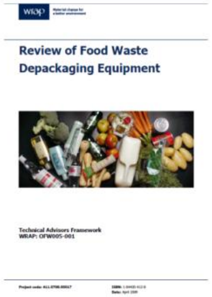
Semi Continuous Reactor

Feedstock Characterisation – Digestibility Testing

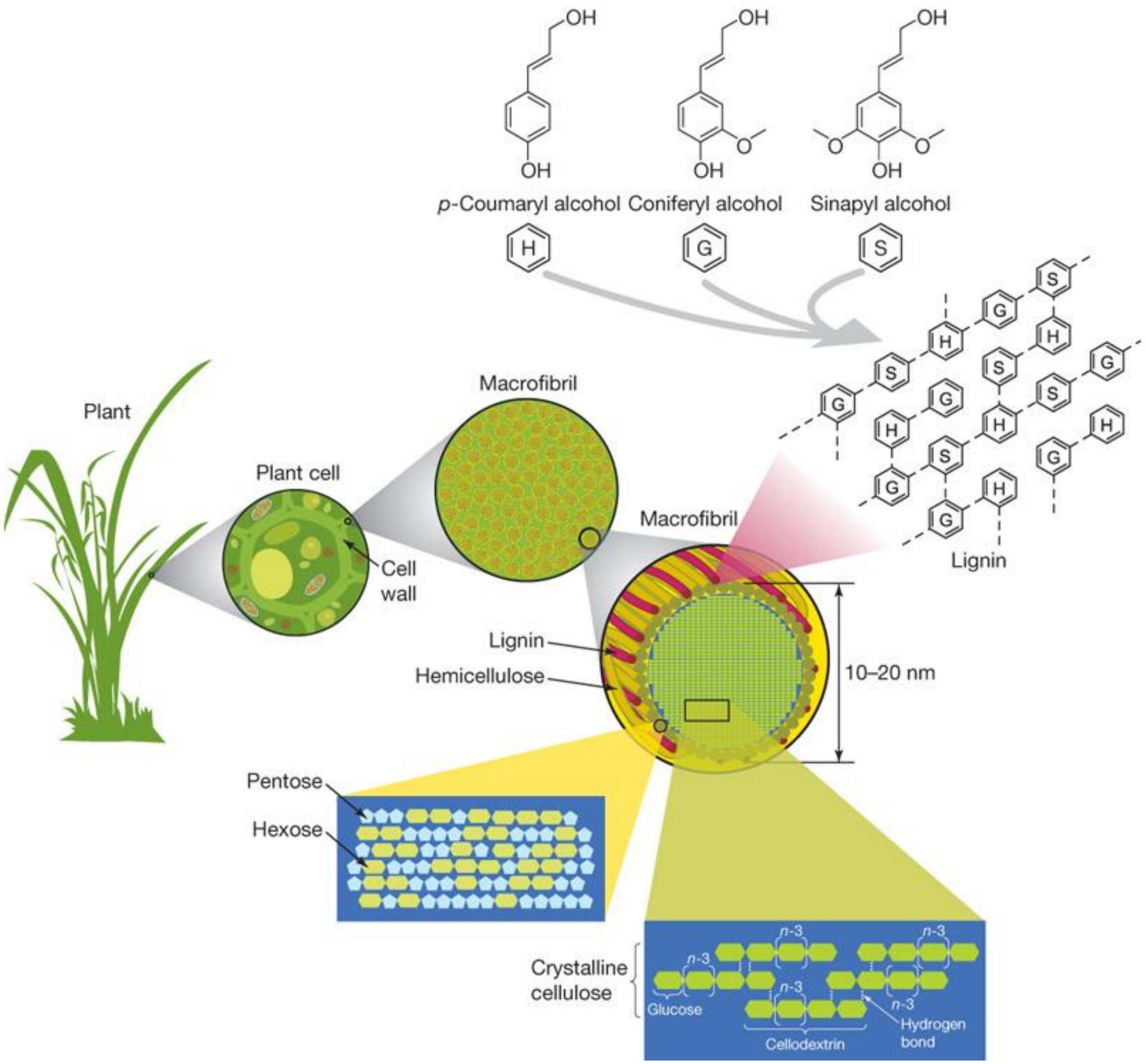
Continuous Reactor

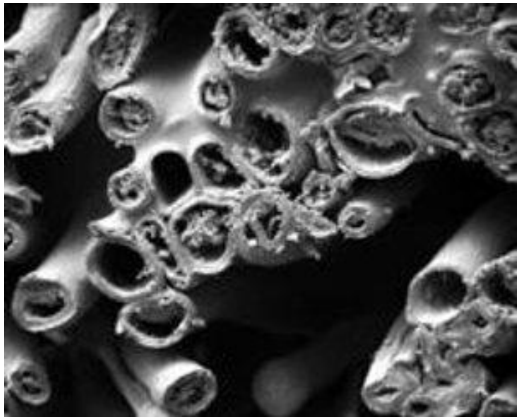
Mechanical pretreatment

- Screens
- Depackaging
- Hammer mills
- Trommel sieves / communiting drums
- Rotating drum pulverisers
- Air classifiers
- Magnetic separators
- Hydro-pulpers / separators
- Degritter
- Homogenization



Ligno-cellulosic feedstocks





EM Rubin *Nature* **454**, 841-845 (2008) doi:10.1038/nature07190

Pretreatment methods

Pretreatment	Mode of action (in addition to increasing the surface area)	Potential sugar yield	Inhibitor formation	Residue formation	Need for recycling chemicals	Low investment costs	Low operational costs	Applicable to various biomass	Proven at pilot scale	Additional remarks
Mechanical		--	++	++	++	+	-	+	+	
Liquid hot water	• Removal of hemicellulose	++	-	++	++	+			++	
Weak acid	• Removal of hemicellulose (major) • Alteration lignin structure (minor)	++	-	-	-	+/-	+	+	++	Specially suitable for biomass with low lignin content
Strong acid	• Hydrolysis of cellulose and hemicellulose	++	-	-	-	-	+/-	++	++	Strong acid is hazardous, toxic and corrosive.
Alkaline	• Removal of lignin (major) and hemicellulose (minor)	++	++	-	-	++		+/-	+/-	
Organosolv	• Removal of lignin (major) • Removal of hemicellulose (minor), depending on solvent used	++	++	+	-	-	-	+	++	High quality lignin Solvent used may be inhibitor for cell growth
Wet oxidation	• Removal of lignin (major) • Dissolve hemicelluloses • Decrystallization cellulose	+/-	++	+	++	+			-	
Steam explosion	• Removal hemicellulose (major) • Alteration lignin structure (minor)	+	-	+	++	+	+	+/-	++	Low environmental impact
AFEX	• Removal of lignin (major) and hemicellulose (minor) • Decrystallization cellulose	++	++		-			-		No need for small particle size for efficacy
CO_2 explosion	• Removal of hemicellulose • Decrystallization cellulose	+	+	++	++	-			-	More cost effective than AFEX
Combined mechanical/ alkaline	• Removal of lignin (major) and hemicellulose (minor)	++	++	-	-	+/-	+/-	+	+	

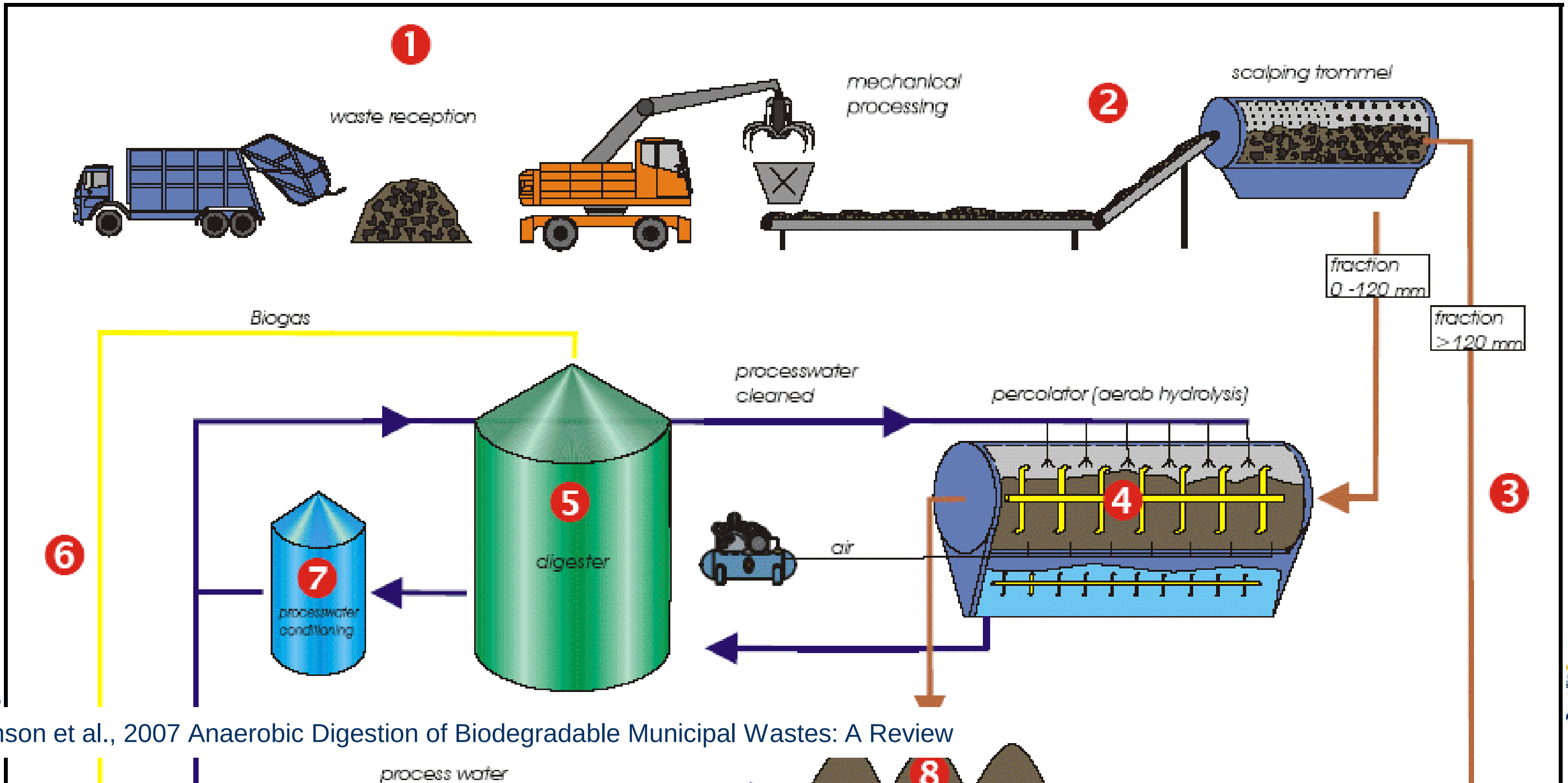
\+ = positive characteristic: E.g. high yield of fermentable sugars, no or low fermentation inhibitors, no residue formation, no or low need for recycling of chemicals, low investment costs, high applicability to different biomass types, proven at pilot scale, low operational costs

\- = negative characteristic: E.g. low yield of fermentable sugars, high amount of fermentation inhibitors, high residue formation, need for recycling of chemicals, high in vestment costs, low applicability to different biomass types, not (yet) proven at pilot scale, high operational costs

Taken from - Harmsen et al., 2010. Literature Review of Physical and Chemical Pretreatment Processes for Lignocellulosic Biomass . ECN

OFMSW - MBT (ISKA GmbH)

Buchen 165,000 tpa
Heilbronn MBT, 88 tpa
Physical sorting / separation
>120 mm fraction to percolation -> AD
<120 mm fraction to compost



Taken from Monson et al., 2007 Anaerobic Digestion of Biodegradable Municipal Wastes: A Review

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Taken from Monson et al., 2007 Anaerobic Digestion of Biodegradable Municipal Wastes: A Review

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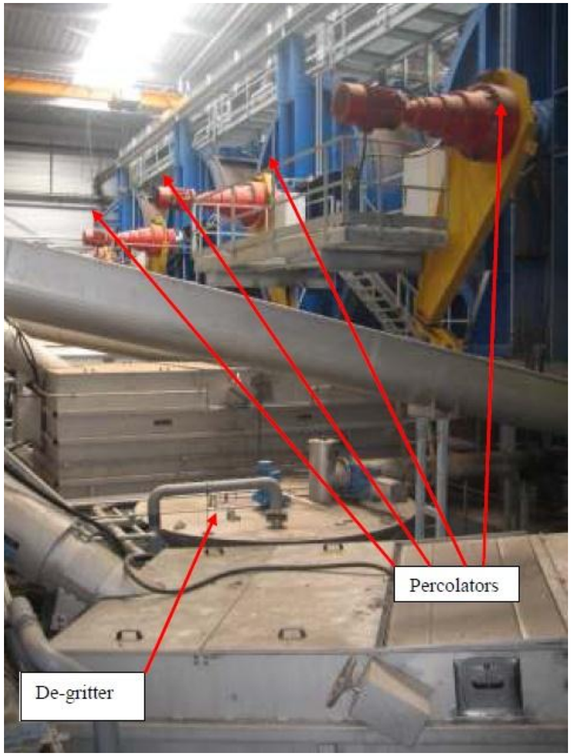
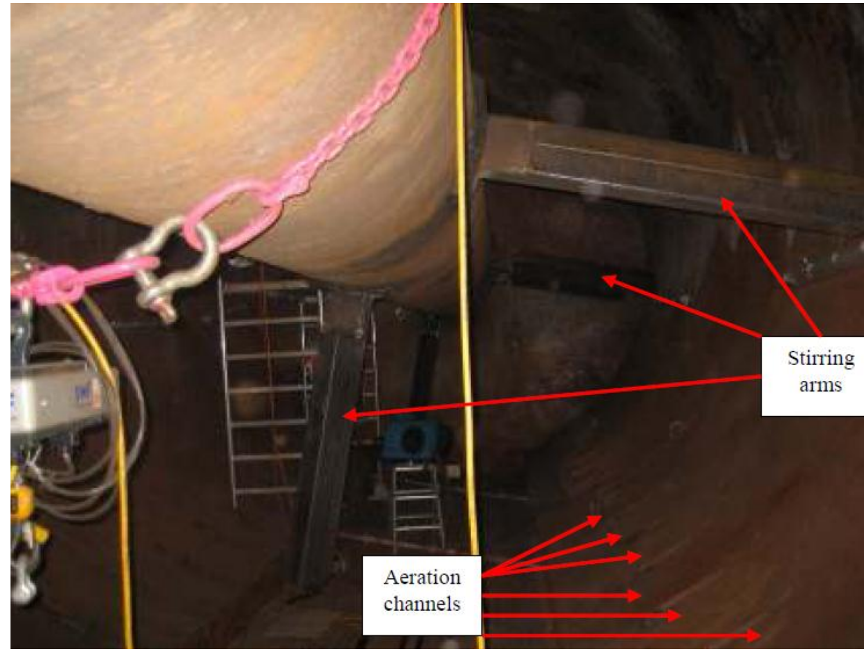
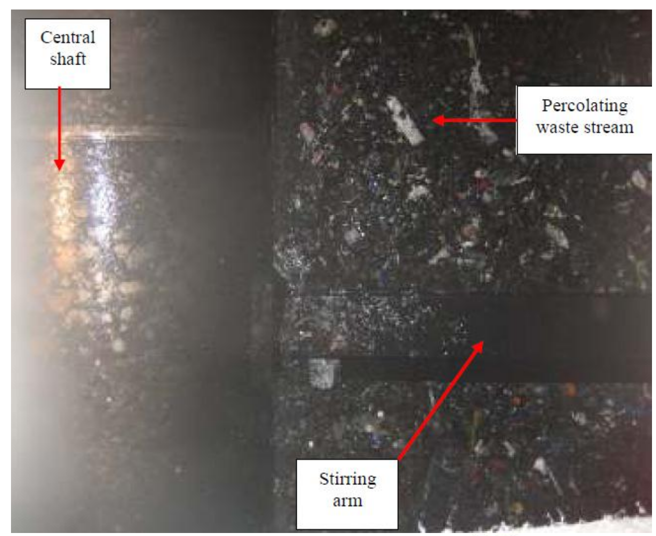
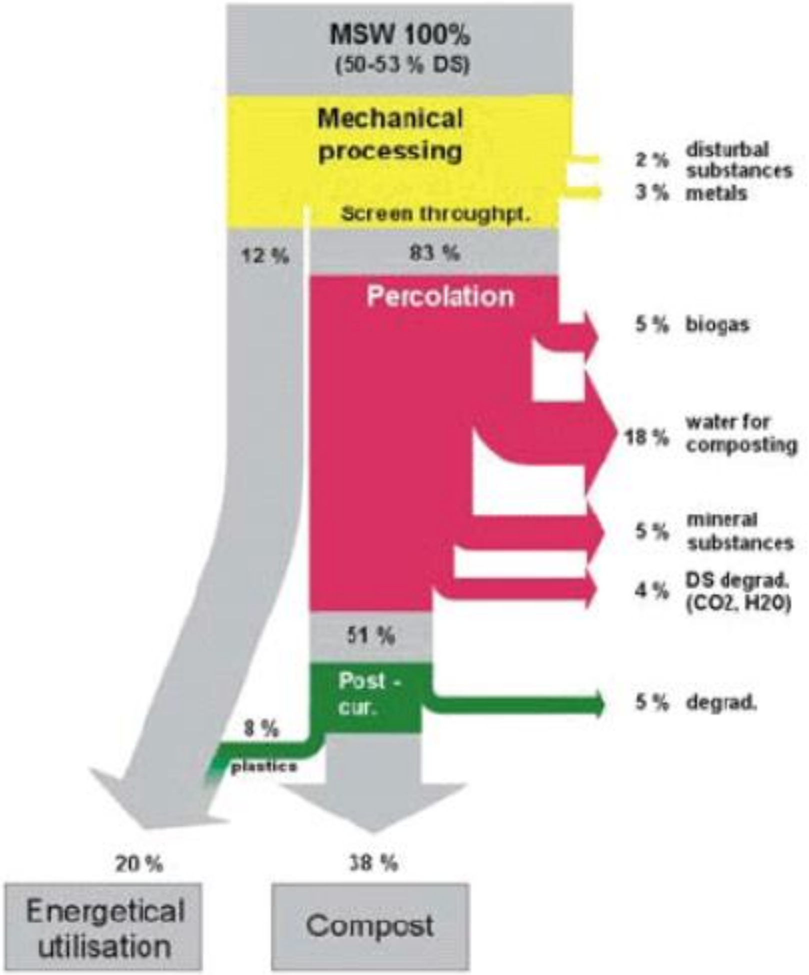






Taken from Monson et al., 2007 Anaerobic Digestion of Biodegradable Municipal Wastes: A Review

Percolation



OFMSW < 120mm continuously fed through system with stirring

Hot water added from top

3 days residence at 38^{o}C,

Degritting

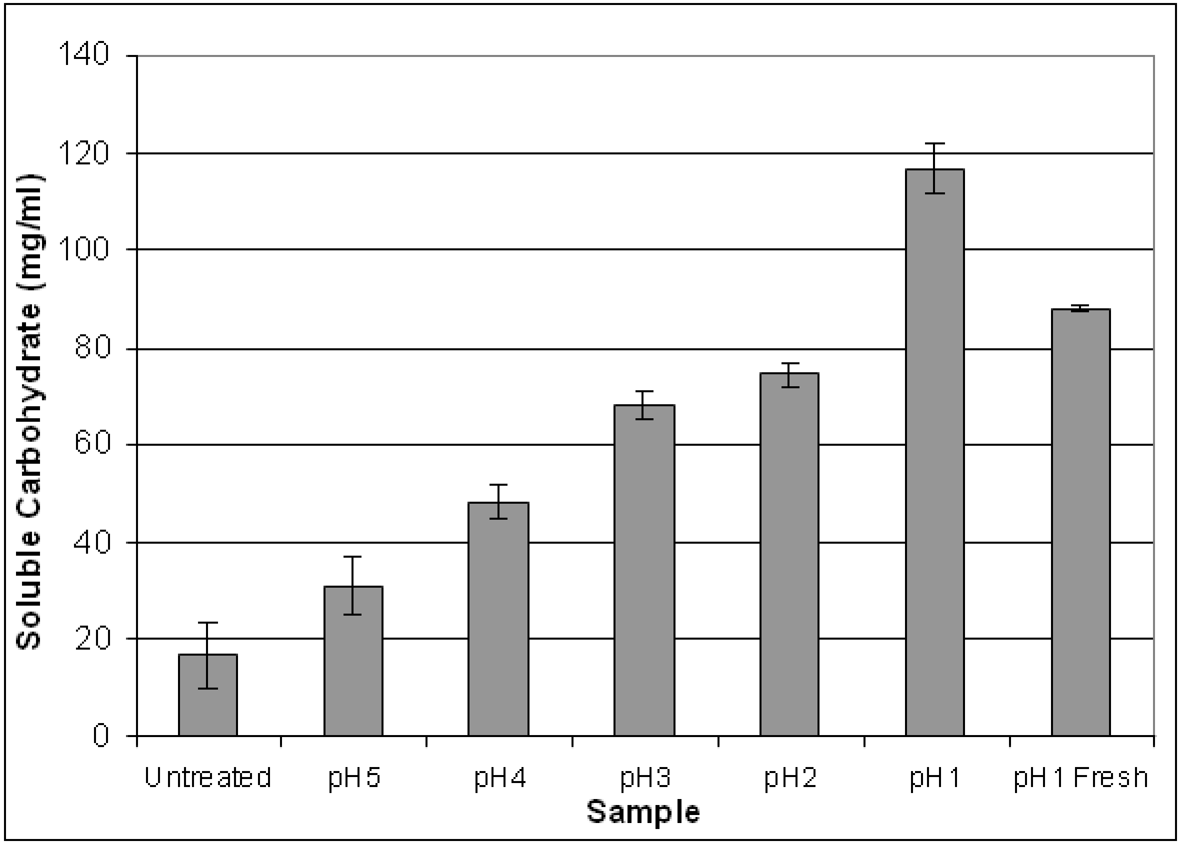
Screw press to separate solids

Percolate liquor COD 200-250 kg/t

5% mass conversion to biogas

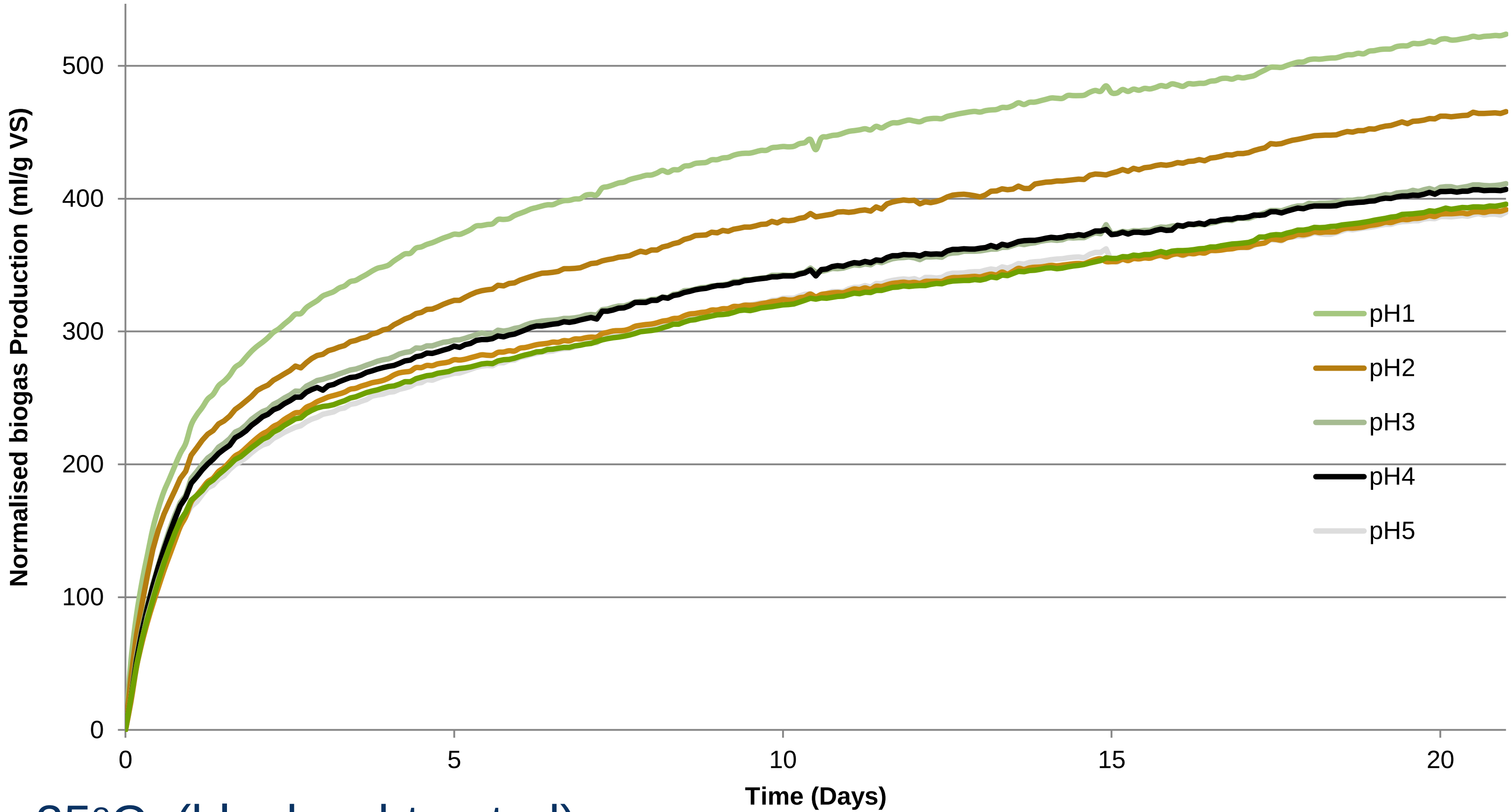
Water recycling from digestate

Acid pre-treatment of SAS



5 % TS SAS acidified with conc HCl for 24 hrs then neutralised with NaOH.

Gas production after acid pretreatment of secondary sewage sludge



Oxitop 35^{o}C (blank subtracted)
100 ml inoculum 0.4 g VS substrate
Topped up to 150 ml with DI water

Devlin *et al* (2011)

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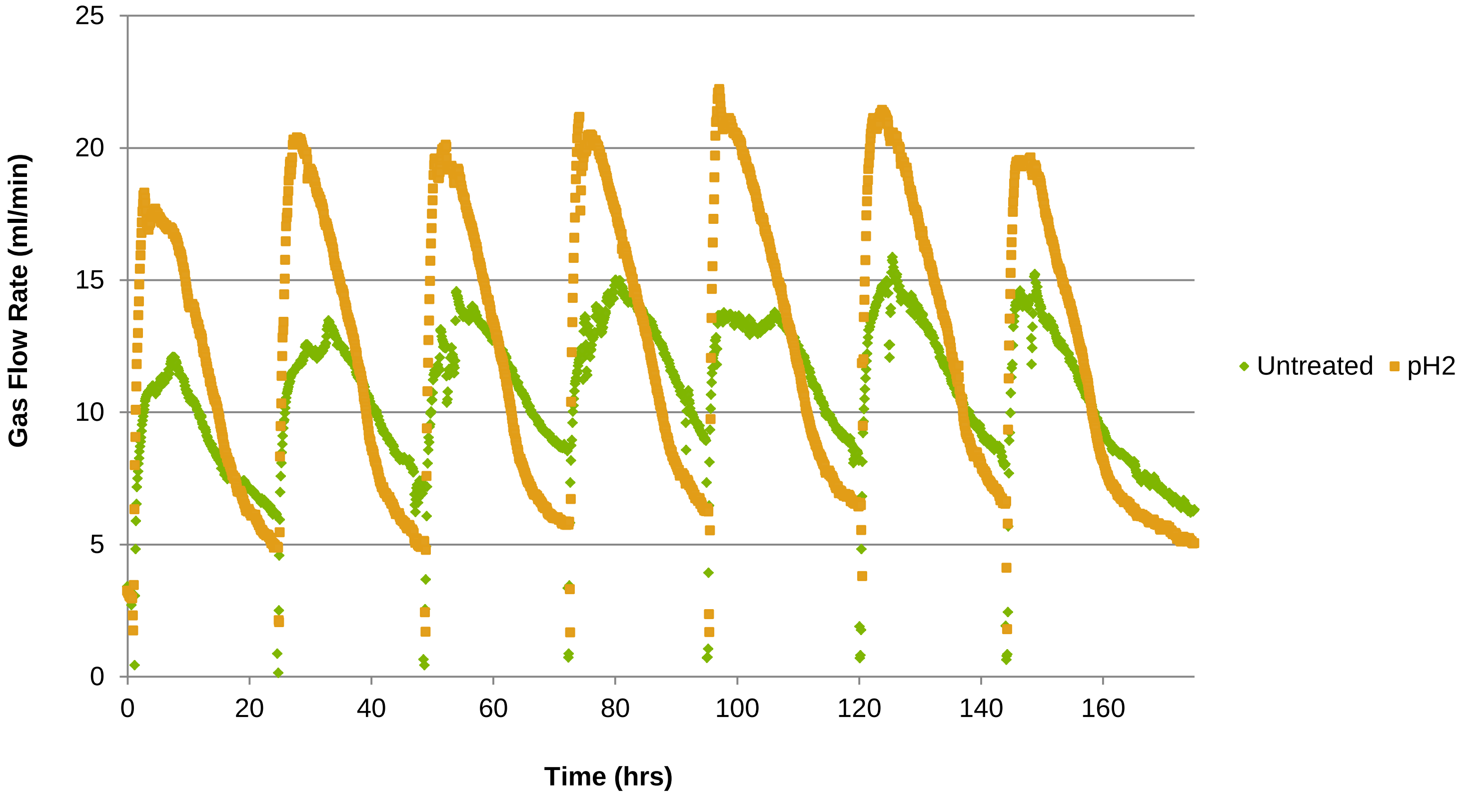
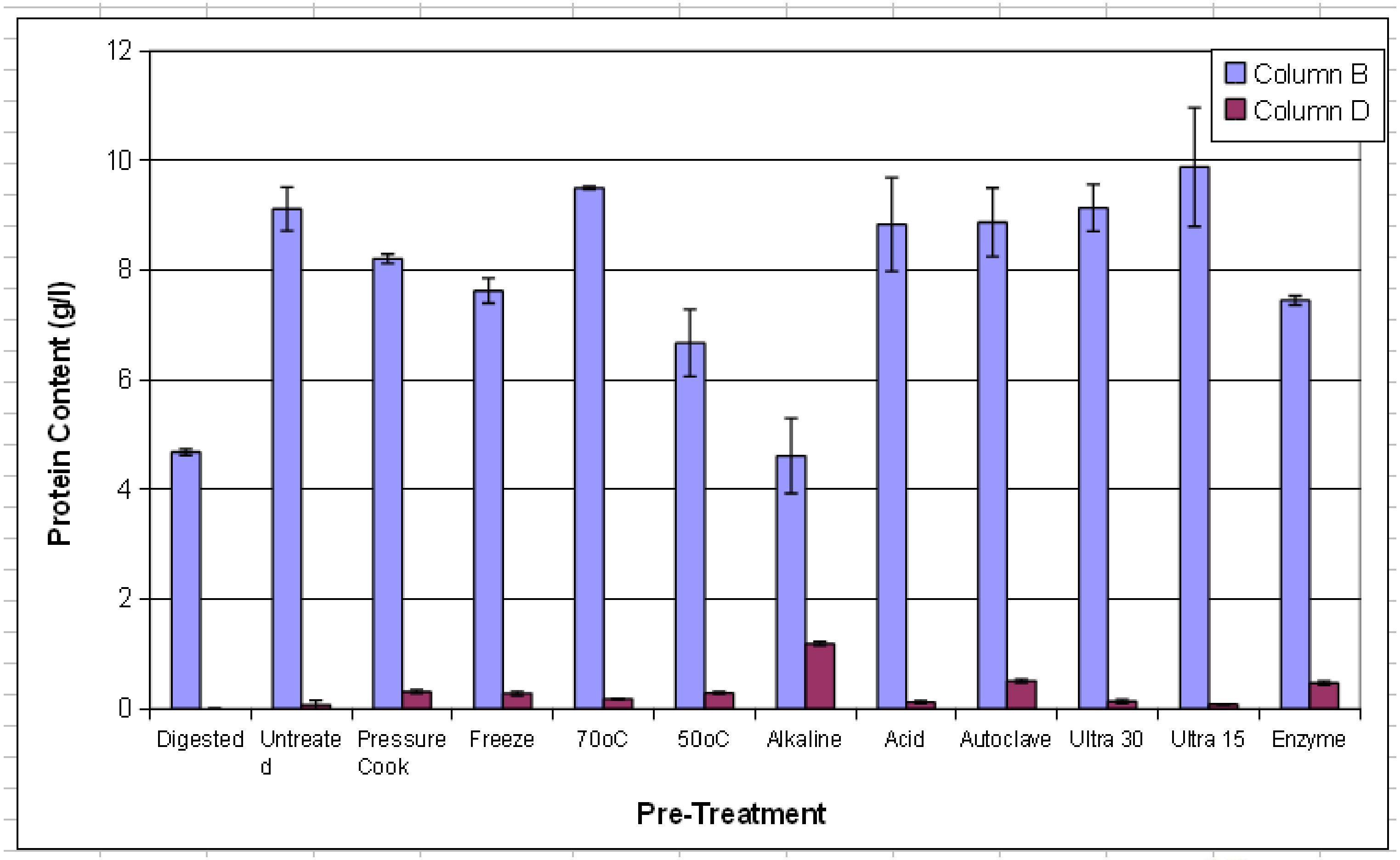
Semi-continuous feeding acid pre-treated secondary sewage sludge

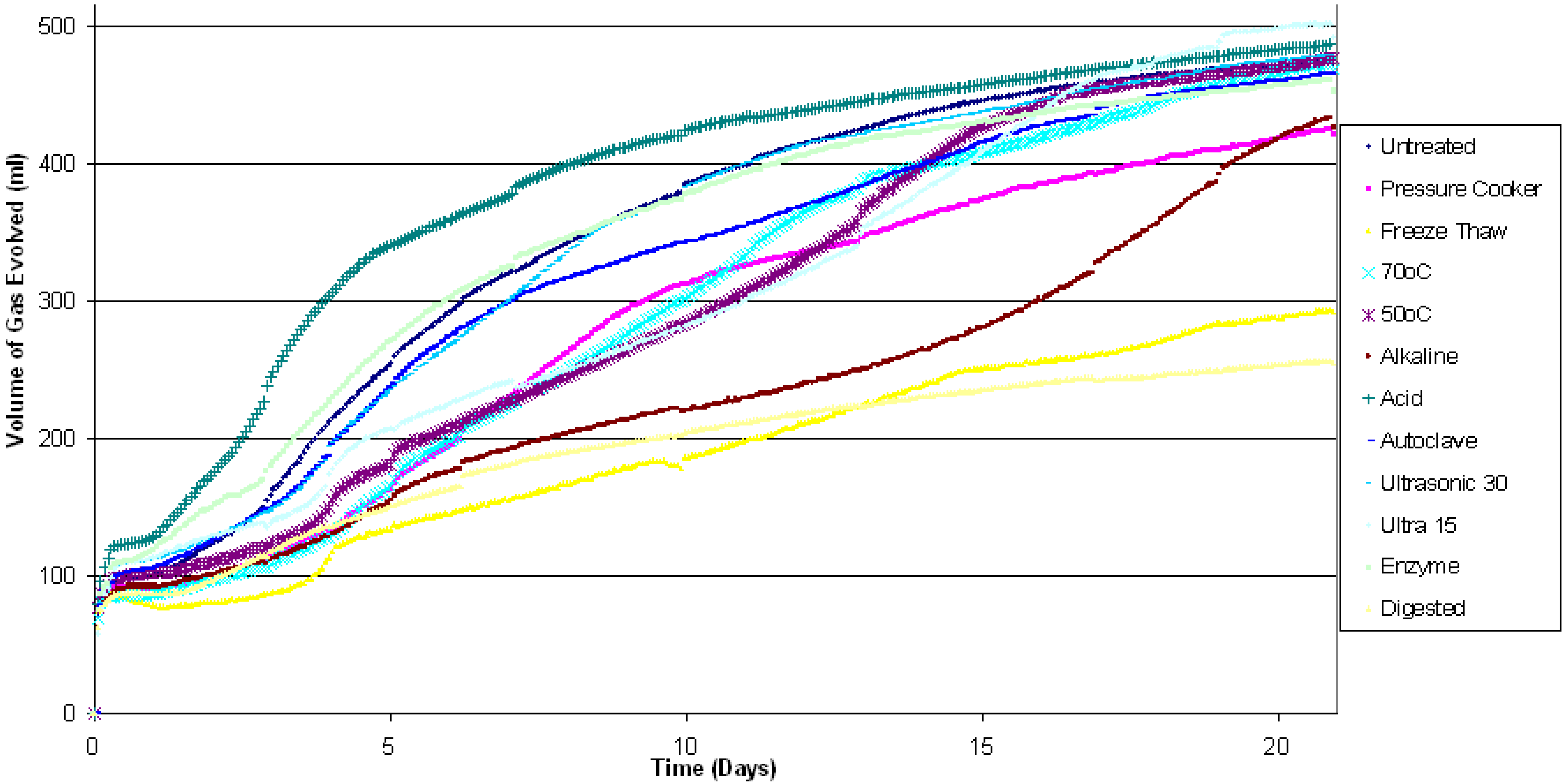


12 day HRT, 35ºC

Effect of pretreatments on solubilisation of protein

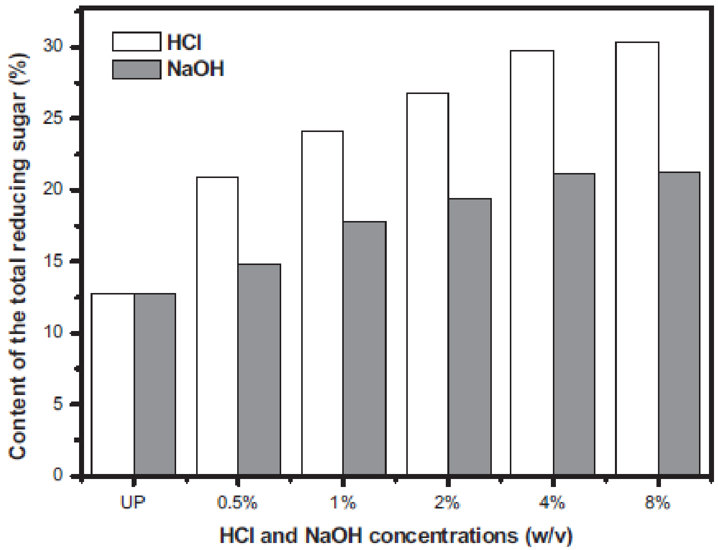


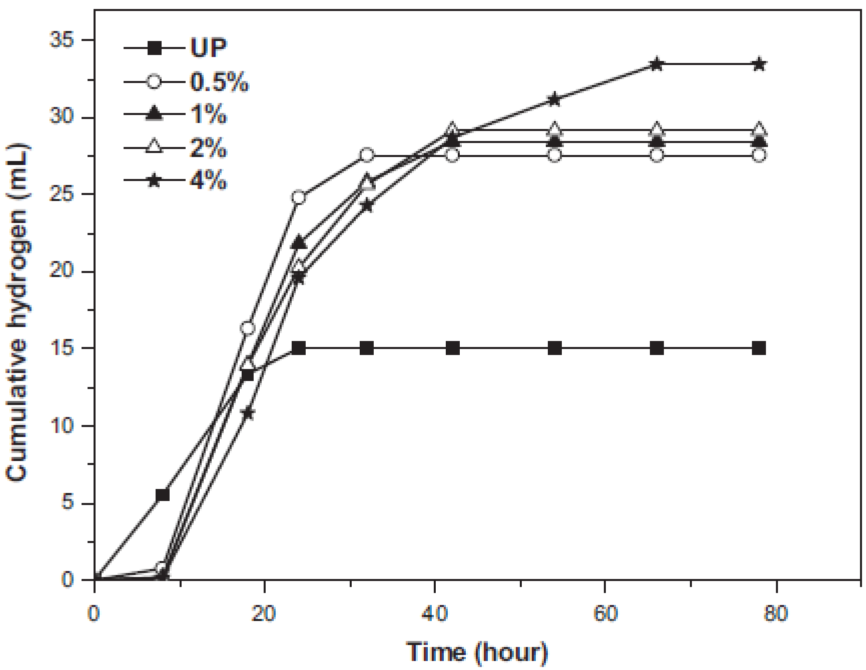
Effect of various pretreatments on gas production



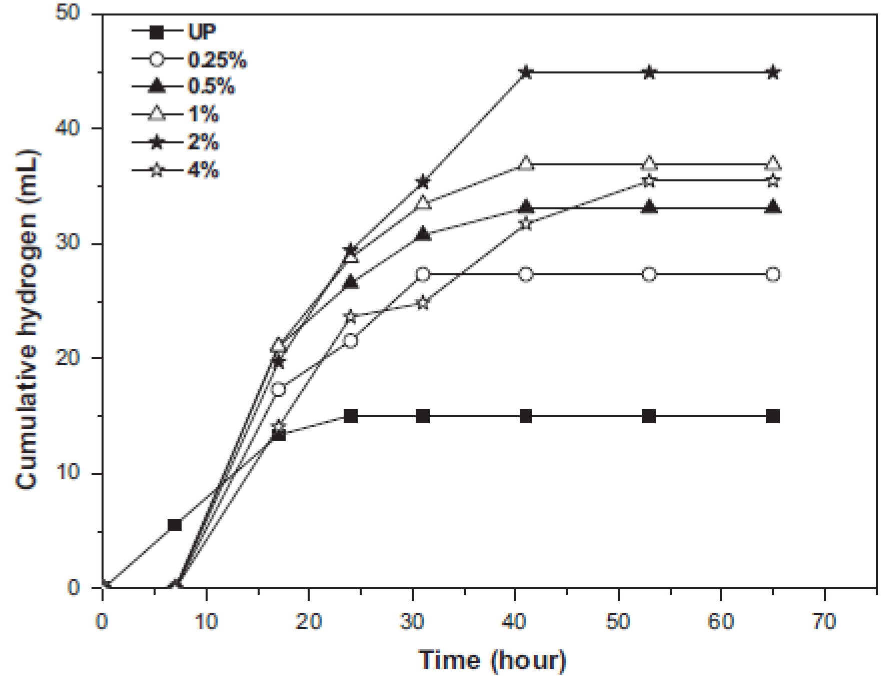
70:30 primary: secondary sludge in terms of VS

Acid / Alkali pretreatment of poplar





Enzymatic pretreatment of poplar



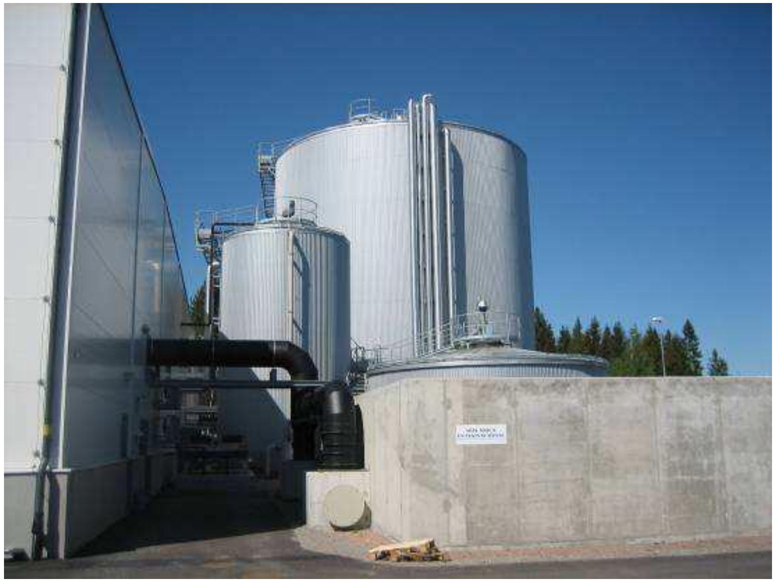
Taken from; Cui et al., 2010 Int. J. Hydrogen Energy 35:4041-4047

Conclusions

- A wide variety of materials can be used as feedstocks for AD.
- Consider availability, cost, handling and storage requirements, composition and biodegradability.
- Proximate analysis and chemical analysis is useful in ensuring the plant is operating efficiently.
- The Buswell equation - theoretical energy yield.
- Digestability testing to confirm gas yields.
- Pretreatments can aid processing and enhances gas production.

Thank You

Questions



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