An industrial perspective of Valorgas - an international collaboration on Food Waste Collection, Anaerobic Digestion, Biogas Production and Upgrading

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&
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VALORGAS

SEVENTH FRAMEWORK PROGRAMME

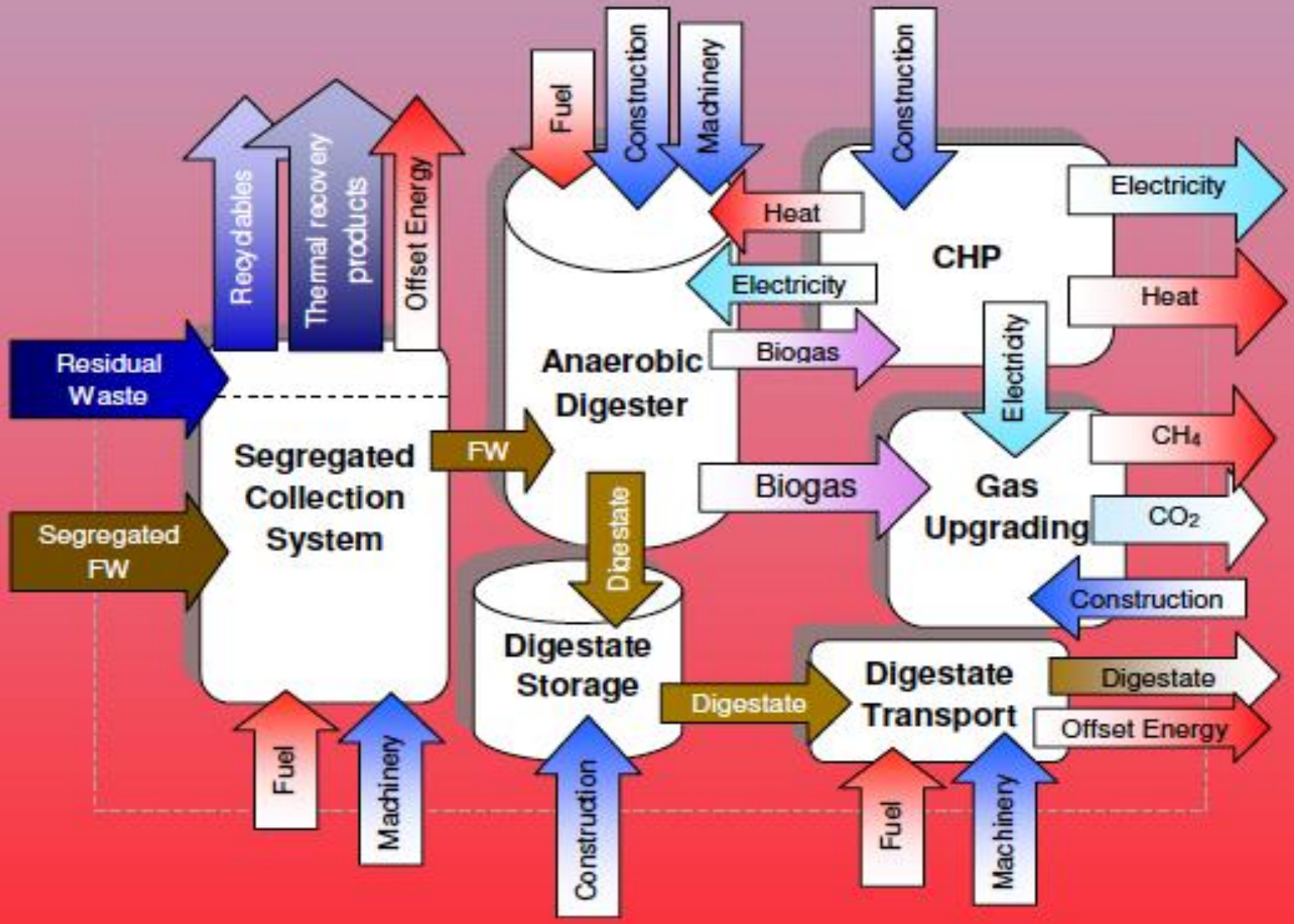
Valorgas Objectives

- To evaluate source segregated food waste collection.
- To determine the energy and carbon footprint of the biowaste-to-energy.
- To optimise pre-treatment of source segregated waste stream for biogas production and biosecurity.
- To improve biogas productivity and added value of the digestate product.
- To gain deeper understanding of the chemical and microbiological factors affecting substrate, and develop practical operational protocols for stable and effective digestion.
- To carry out mass and energy balances of full-scale digesters
- To develop low-cost small-scale biogas upgrading technologies and storage
- To invetigate scale of digestion facilities.
- To evaluate the potential for food waste digestion as a second generation biofuel source.

Funded by EU FP7 Programme.
€3.5 million

SEVENTH FRAMEWORK PROGRAMME

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Recyclables
Thermal recovery products
Offset Energy
Residual Waste
Segregated FW
Segregated Collection System
Fuel
Machinery
FW
Fuel
Construction
Machinery
Anaerobic Digester
Heat
Electricity
Biogas
Digestate
Digestate Storage
Construction
Construction
CHP
Electricity
Heat
Electricity
Biogas
Gas Upgrading
CH_4
CO_2
Construction
Digestate
Digestate Transport
Offset Energy
Fuel
Machinery

The Work Packages

Waste Collection & Segregation Systems

Pre-treatment & Technical-Scale Trials

Small Scale Biogas Upgrade & Storage Systems

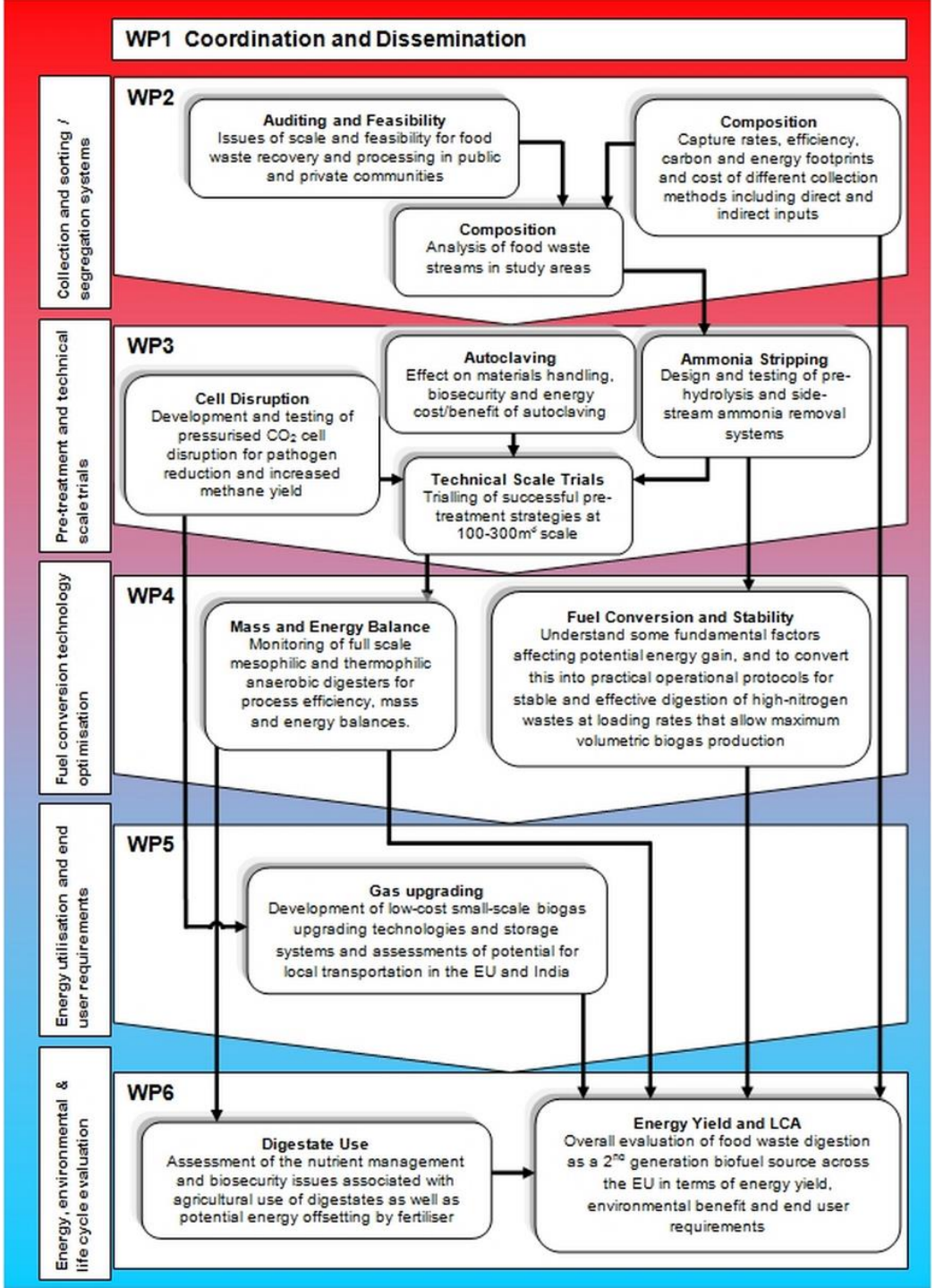
Optimisation of Technology & Nutrient Recovery

Energy, Environmental & Life Cycle Evaluation



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Work Package Integration



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The World of AD on a Single Site

www.valorgas.soton.ac.uk

Journal Papers

JyU SummerSchool materials

IIT Gas Upgrading Seminar

Software

All the investigation reports

and much, much more….



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Collection & Segregation Systems



- Examined capture rate and efficiency of different collection schemes
- Composition and physio-chemical characterisation
- Internet survey of food waste collection across EU27
- Energy and carbon footprint of collection and transport
- Impact on residual waste stream

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In the field…

Waste characterisation campaigns








Sorting food waste samples at Valorsul

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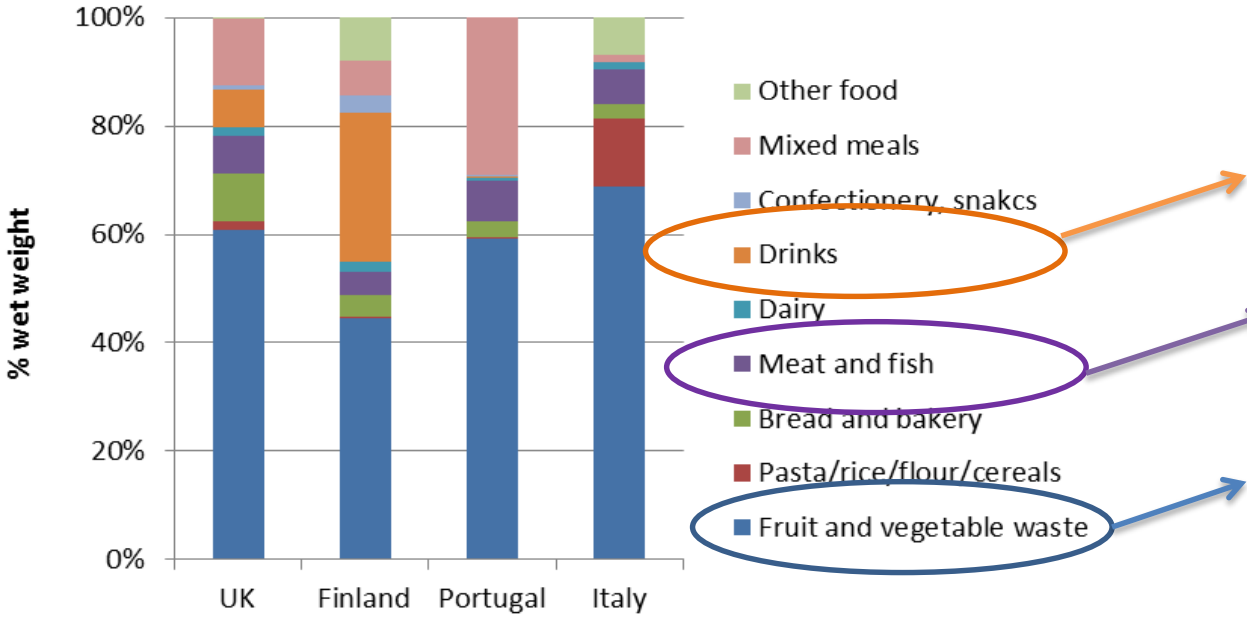
Methods

Comparison of 4 waste characterisation systems

WRAP revised (2009)	WRAP original (2008)	VALORSUL	VALORGAS	Greenfinch
1 Fresh vegetables and salads 3 Fresh fruit 8 Processed vegetables and salad 14 Processed fruit	7 Vegetables 5 Fruit 6 Salads	1 Vegetables 13 Fruit 3 Salads	1 1a Fruit and vegetable waste 1b Fruit and vegetables (whole) 1c Large stones, seeds and fibrous materials	1 Fruit & veg peelings 2 Fruit & veg whole 17 Seeds & stones
10 Staple foods	4 Dried foods/powders	8 Dried foods/powders	2 Pasta/rice/flour/cereals	3 Pasta/rice/flour 9 Cereal
4 Bakery	1 Bakery	10 Bakery	3 Bread and bakery	4 Bread and bakery
6 Meat and fish	2 Meat and fish	9 Meat and fish 32 Special - bones	4 4a Meat and fish 4b Bones	5 Meat and fish 6 Bones
7 Dairy and eggs	3 Dairy	7 Dairy	5 5a Dairy 5b Egg shells	8 Dairy 7 Eggs
2 Drinks	9 Drinks	4 Drinks	6 Drinks	10 Tea bags & coffee
13 Confectionery and snacks 11 Cake and desserts	8 Confectionery and snacks 11 Desserts	5 Snacks	7 7a Confectionery and snacks 7b Desserts	11 Sweets & desserts
9 Condiments, sauces, herbs and spices 5 Meals (homemade and pre-prepared)	10 Condiments, sauces, herbs and spices 12 Mixed foods	12 Condiments, sauces, herbs and spices 6 Mixed meals	8 8a Condiments 8b Mixed meals	16 Mixed meals
15 Other 12 Oil and fat	13 Other	11 Other food	9 Other food	12 Other food material
			10 Biodegradable bags	14 Biodegradable bags
		2 Garden waste	11 Garden waste	13 Non food biodegradable w
		14 Paper 15 Cardboard - packaging 16 Cardboard - non packaging	12 Paper and card	
		17 Plastic - film bags 18 Plastic - bottles 19 Plastic - polystyrene 20 Plastic - other 23 Ferrous metals 24 Non ferrous metals 21 Glass - packaging 22 Glass - non packaging 25 Composites 26 Textiles 27 Sanitary textiles 28 Combustibles - wood 29 Combustibles - other 30 Incombustibles 31 Special - packaged organics 33 Special - other	1313a Plastic containers 13b Plastic film (non-biodegradable) 13d Metals 13e Glass 13f Miscellaneous	

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Waste Characterisation



7% tea bags in the UK, ~25% coffee in Finland

Similar in all countries → main contributor to nitrogen content in the AD process

Represents 45-70% of the total wet weight

- Compositional & physio-chemical analysis undertaken from 23 collections in 15 cities from 4 countries.
- Shows key similarities and cultural differences between consumer (or waste producer) behaviour in different countries
- Different degrees of contamination were found in different collection schemes, but common country to country

Physico-chemical Characterisation of Food Waste

	Eastleigh, UK	Forssa, FI	Treviso, IT
pH	5.7	5.34	6.16
TS, %WW	28.62±0.07	27.02±0.12	27.47±0.03
VS, %WW	26.83±0.16	24.91±0.05	23.60±0.09
VS, %TS	94.18±0.42	92.26±0.26	86.60±0.40
TKN, % TS	2.74±0.05	2.39±0.04	2.55±0.03
TKN, g Kg^{-1}WW	7.84±0.16	6.45±0.1	7.02±0.1
CV, KJ g^{-1}TS	21.32+±0.08	21.39±0.11	20.50±0.11
Lipids, gkg^{-1}VS	152.2±2	156±0.5	202±0.5
Crude protein, gkg^{-1}VS	183±4	162±0.4	186±3
TKN, gkg^{-1}TS	27.4±0.5	23.9±0.4	25.5±0.3
TP, gkg^{-1}TS	2.94±0.01	2.73±0.05	3.47±0.06
TK, gkg^{-1}TS	11.2±0.2	10.0±0.2	10.0±0.1

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Internet Surveys of 27 EU States

Table 1. Example of information collected in survey

Local Authority	Name	Unit		Contents
LA Characteristics	Type		2	e.g. District Council, Borough Council, London Borough Council, Metropolitan Borough Council, County Council, Unitary Authority (UK categories)
			3	e.g. collection, disposal, unitary (UK categories)
			4	e.g. E Midlands, Eastern, London, North East, North West, South east, south West, West Midlands, Yorkshire and Humberside (UK regions)
	Area	km2	5	no.
	Population	no.	6	no.
	Population density	person/km2	7	no.
General waste	Household - total waste	tonnes/person-year	8	no.
	Household waste sent for recycling/composting/reuse	tonnes/person-year	9	no.
		% total	10	no.
Socio-economic	Indices of Multiple	Average Score	11	no. (UK category)
	Deprivation	Rank	12	no. (UK category)
Separate FW collection?	Type		13	e.g. None, with GW, FW-only
	Status		14	e.g. Opt-In, compulsory, NS (not stated)
	Comment		15	
Collection frequency	Separate FW Collections		16	e.g. Weekly, Fortnightly, Other, None, NS
	Residual waste collection		17	e.g. Weekly, Fortnightly, Other, None, NS
	Separate Recyclables		18	e.g. Weekly, Fortnightly, Other, None, NS
	Separate Green waste		19	e.g. Weekly, Fortnightly, Other, None, NS
	Comment		20	
Materials	Bonks		21	Yes, No, NS
	Eggshells		22	Yes, No, NS
	Paper/ card		23	Yes, No, NS
	Shredded paper		24	Yes, No, NS
	Liquid		25	Yes, No, NS
	Oil / fat		26	Yes, No, NS
	Faecal		27	Yes, No, NS
	Plant		28	Yes, No, NS
	Biodeg bags		29	Yes, No, NS
	List accepted		30	Yes, No, NS
	Accept		31	Provide list from website
	List rejected		32	Yes, No
	Reject		33	Provide list from website
	Comment		34	
Containers	Caddies (e.g. 5-10 litres)	yes/no	35	Yes, No, NS
		size (l)	36	no.
	Buckets (e.g. 10-25 litres)	yes/no	37	Yes, No, NS
		size (l)	38	no.
	Wheeled bins	yes/no	39	Yes, No, NS
		size (l)	40	no.
	Other bins	yes/no	41	Yes, No, NS
		type	42	
		size (l)	43	no.
	Biodegradable bags	yes/no	44	Yes, No, NS
		user pays?	45	Yes, No, NS
		Comment	46	
	Wrap in newspaper		47	Yes, No, NS
	Comment		48	
Destination plant	Plant		49	Yes, No, NS
			50	Name
	Treatment type		51	Composting, AD, NS
	Treatment comment		52	
Information provided	Promote home composting?		53	Yes, No
	Gives reasons for collection?		54	Yes, No
	Comments		55	



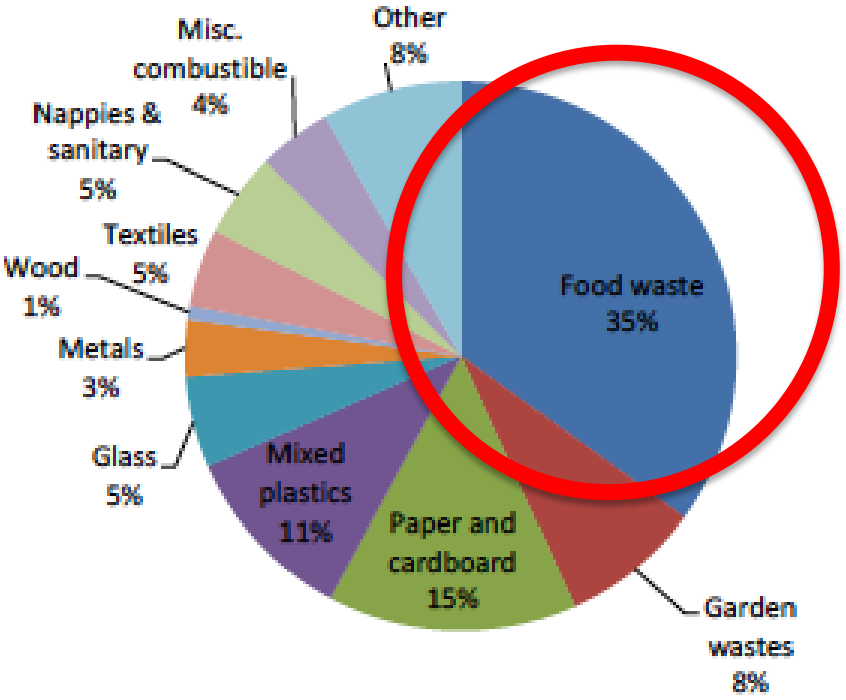




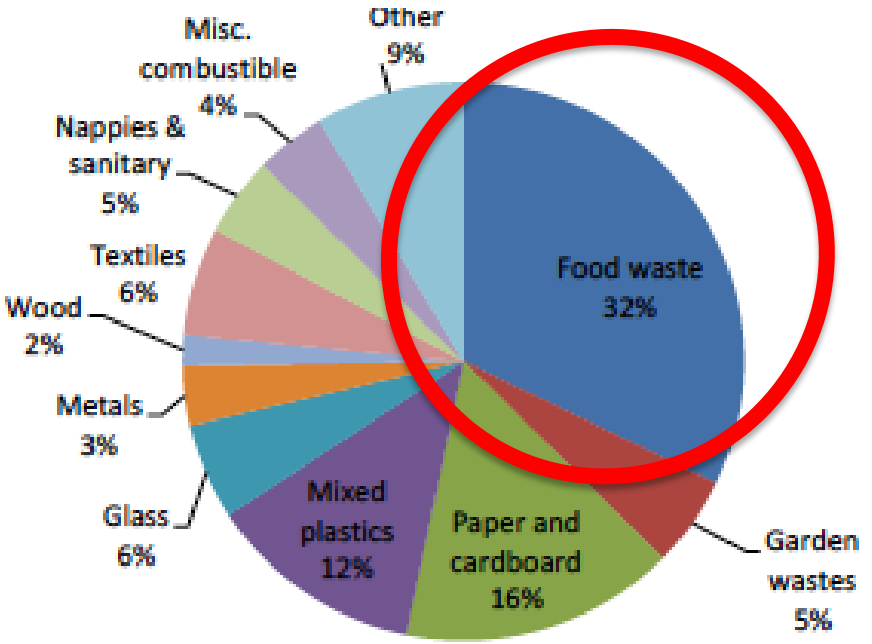
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Residual Waste Analysis

Before FWC



After FWC



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Comparison Summary

Parameter	**England** various authorities	**Netherlands** Gouda & Apeldoorn	**Spain** Catalonian authorities	**Sweden** various authorities	**Portugal** Portela district
Quantity of residual household waste, kg/pp-wk *before FWC*	4.3 (+/-1.1)		10.2 (+/-5.7)	7.6 (+/-1.7)	4.2 (+/-0.3)
Quantity of residual household waste, kg/pp-wk *after FWC*	3.6 (+/-1.4)	4.5 (+/-0.6)	6.9 (+/-4.3)	5.0 (+/-1.1)	3.7 (+/-0.2)
Theoretical net CV of residual, MJ/kg *before FWC*	9.6 (+/-1.5)		10.3 (+/-1.1)	10.3 (+/-0.6)	9.7 (+/-0.3)
Theoretical net CV of residual, MJ/kg *after FWC*	11.7 (+/-1.7)		11.8 (+/-1.5)	12.5 (+/-1.5)	9.1 (+/-0.6)
Average proportion of FW in residual, *before FWC*	34 (+/- 4) %		35 (+/-10) %	44 (+/-4) %	40 (+/-2) %
Average proportion of FW in residual, *after FWC*	25 (+/-5) %		28 (+/-8) %	28 (+/-9) %	44 (+/-3) %
Decrease in average weekly mass of residual	16%		33%	34%	12%
Increase in average theoretical net CV of residual	23%		15%	30%	- 6%
Decrease in average % of food waste in residual stream	9%		7%	16%	- 4%

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Waste Collection Assessment Tool (WasteCAT)

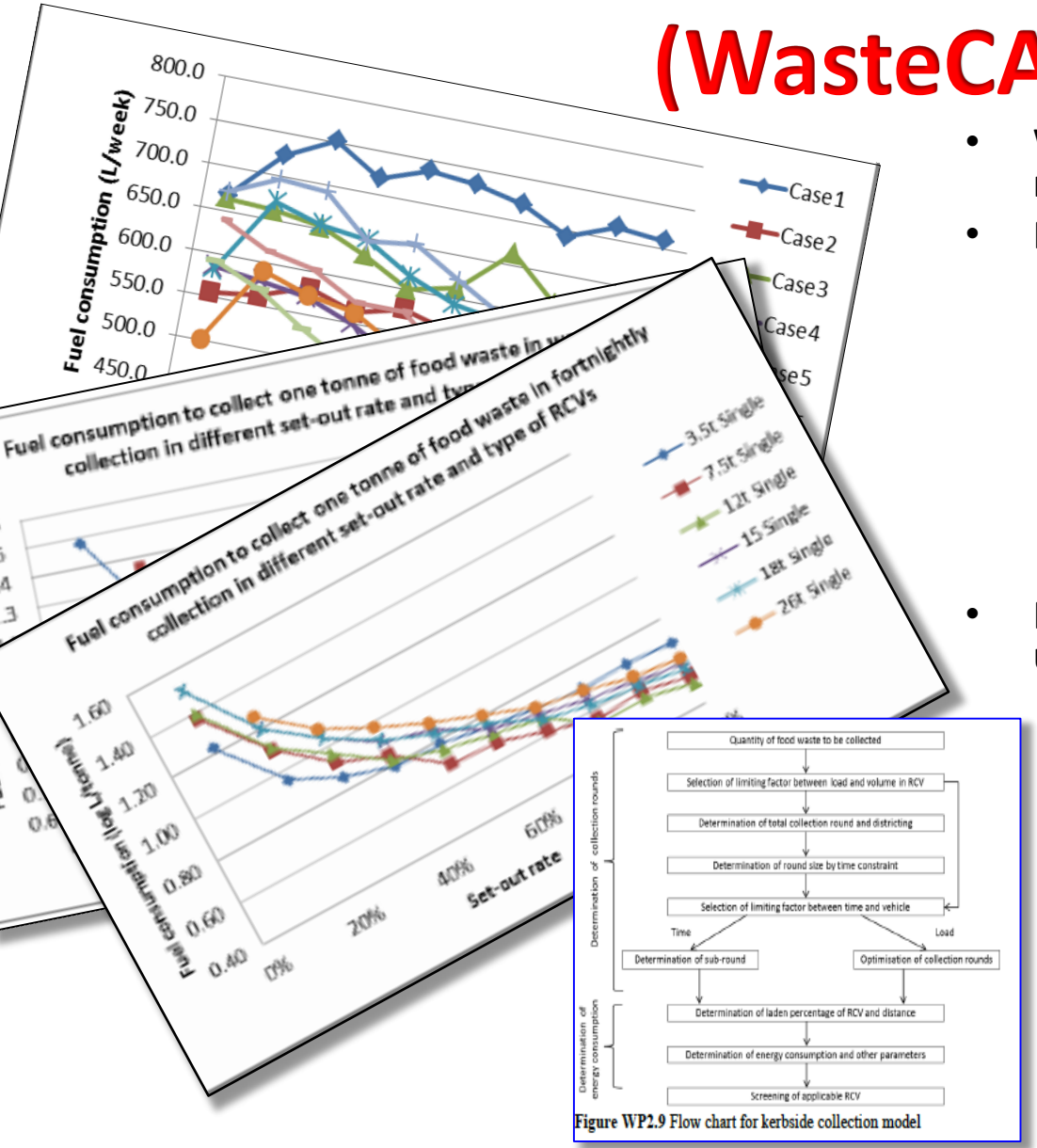
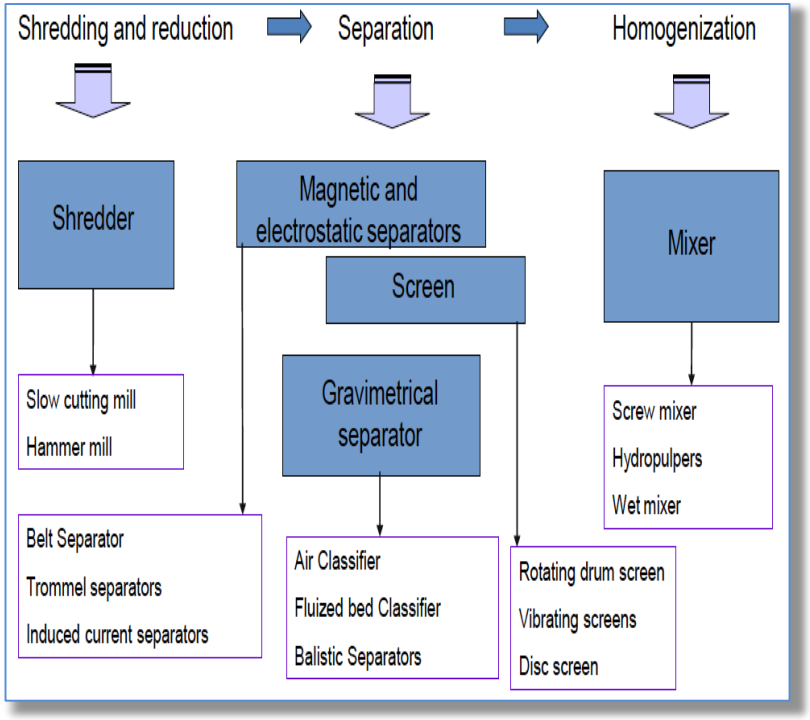


Figure WP2.9 Flow chart for kerbside collection model

- WasteCAT - powerful, robust, mechanistic model
- Main uses:
  - Model alternative options for new collection schemes
  - Benchmark the effectiveness of a current scheme against a modelled output
  - Provide a decision support tool for planners and operators to determine optimal rounds for their individual situations
- Primary use is to evaluate energy usage of collection schemes
  - “Typical” energy costs per tonne of waste collected
  - Outputs include fuel consumption, staff time & vehicle numbers
  - Specific user-specified vehicles included in the model

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Pre-Treatment & Scale Trials



To optimise pre-treatment of source segregated food waste for biogas production and biosecurity of the residual product.

- **Autoclaving**
- **Cell disruption**
- **Two-phase biohythane production**
- **Ammonia stripping**

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Pre-Treatment Key Results

Autoclaving

- Significant reduction in ammonia & H_2S in biogas
- improves biosecurity & useful with high protein wastes under thermophilic conditions
- Reduces biogas yield
- Residue waste stream is lignocellulosic-rich



CO_2 cell disruption bypressurisation

- Discounted

Ammonia Removal

- Carried out at laboratory scale
- Side stripping successfully reduced TAN by 46 - 70%, controlling NH_3 inhibition
- Potential stabilisation of thermophilic food waste digestion
- No microbial inhibition

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Pre-Treatment Key Results

Bio-hythane Production

- Investigated the optimisation of two-phase thermophilic anaerobic digestion process for hydrogen and methane production.
- Dark fermentation in the first reactor was optimised without any reagent addiction for pH control, with no previous treatment of inoculum.
- Recirculation of rejected wastewater after anaerobic digestion was sufficient to keep the process at ideal condition for hydrogen production with pH 5.5.
- The highest H_2 yields of two digesters were identified
- The full-scale feasibility for the process implementation was assessed and show an increase in electrical output of 57% compared with the mesophilic digester, giving potential payback in 2 years operation.

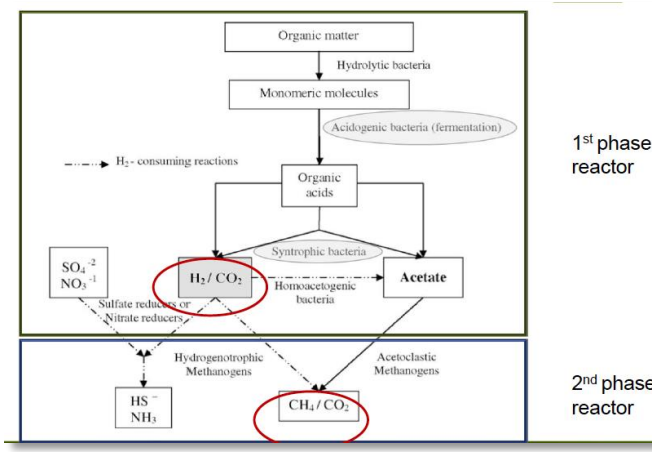




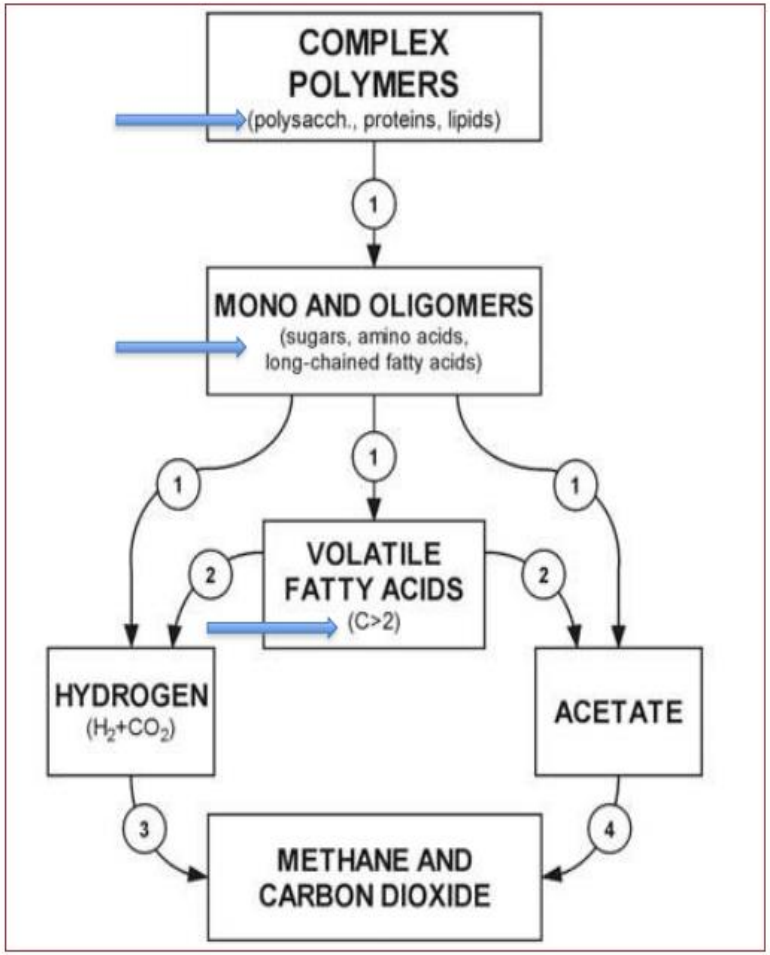
Figura 1: Fase 1 di acidogenesi (Volume: 200L)

Process Optimisation

Work Package Objectives

- Optimisation of the AD of food waste & alleviation of operational problems
  - Maximise organic loading rates
  - Enhance process stability
  - Enhance understanding of microbial population structures
  - Enhance nutrient recovery
  - Assess mass & energy balances

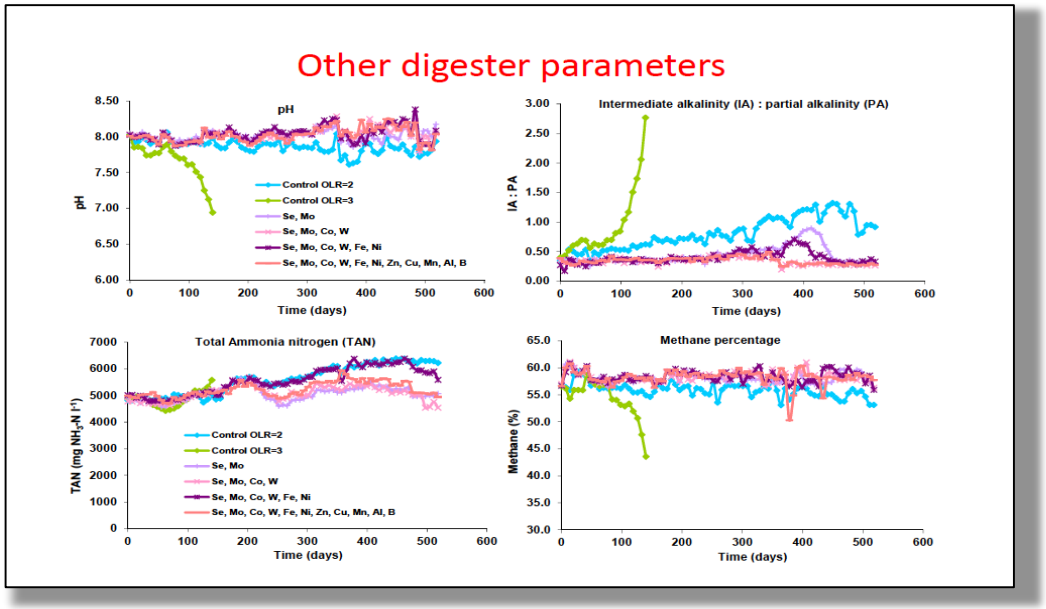
Key area where research has led to operational scale enhancement in the UK & Europe



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Process Optimisation – Key Results

- **Nutrient recovery through precipitation reactions**
  - Truvite precipitation is feasible but requires high magnesium presence
- **Mass and Energy Balances**
  - Common platform for data collection, processing and analysis
  - Demonstrated at Valorsul and Ludlow accounting for 96% of mass flow
  - Existing literature is inconsistent and a protocol is needed to provide clarity for accurate technical comparison



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Monitoring & Assessment of Existing Schemes - Valorsul AD, Portugal (Thermophilic)

Valorsul





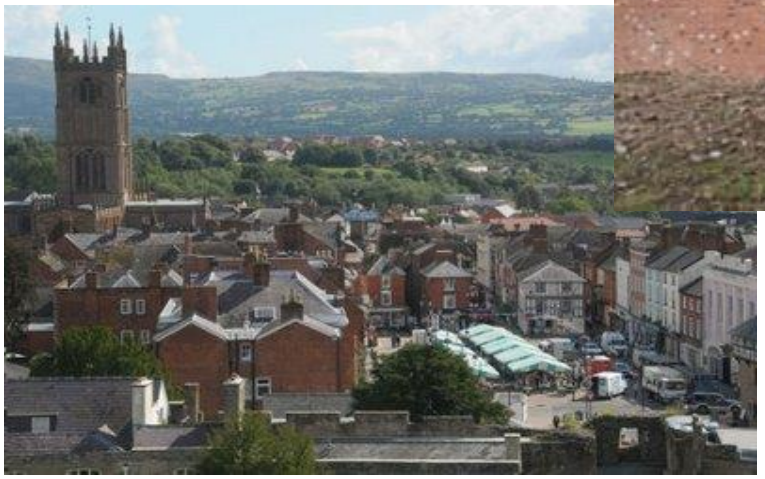
Lisbon 1871 collections
Lourdes & Odivelas 531 - 538 collections
Amadora 158 – 163 collections
276 domestic properties in 3 locations (new since 2010).

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Monitoring & Assessment of Existing Schemes - South Shropshire Biowaste Digester (SSBD), UK (Mesophilic)

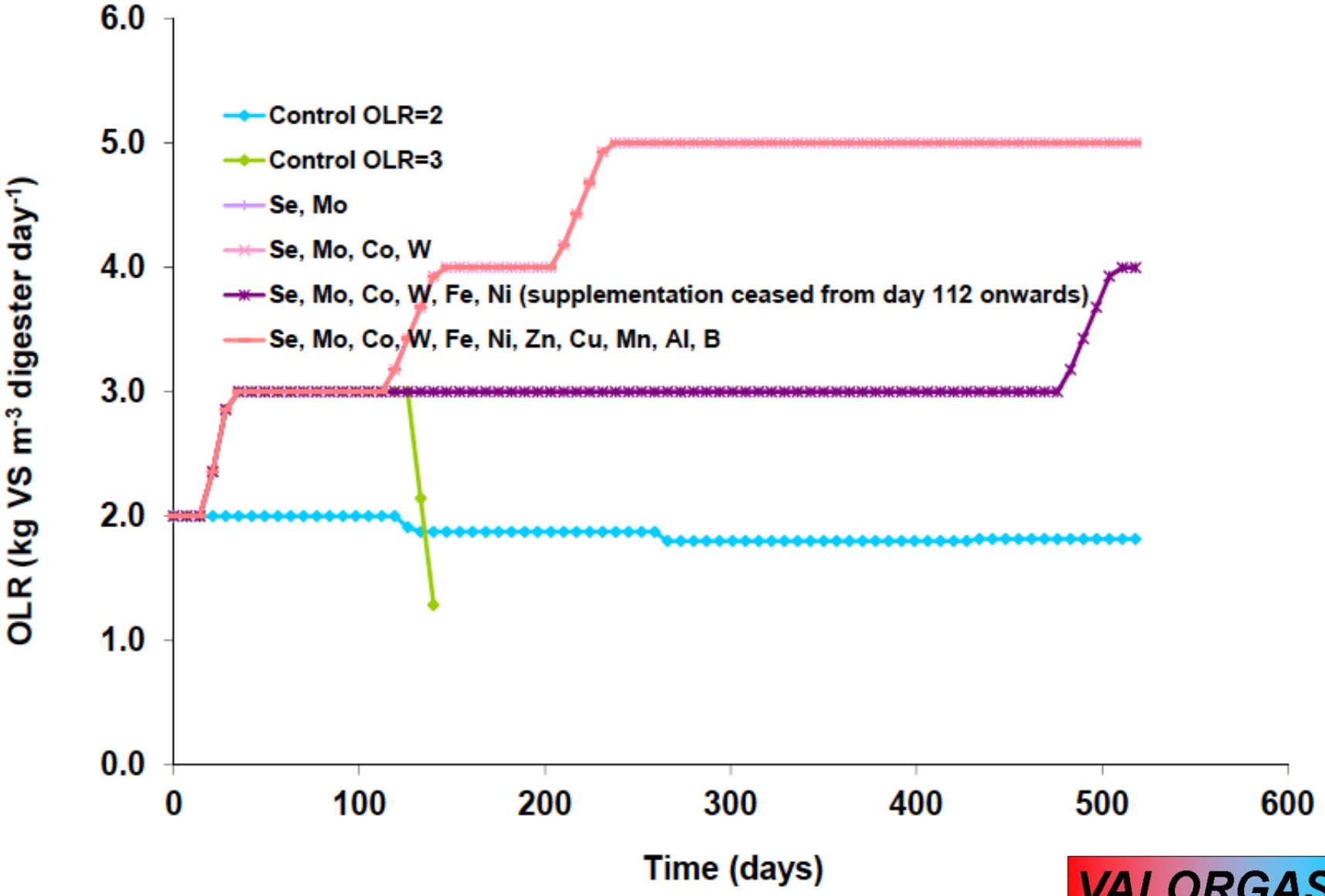






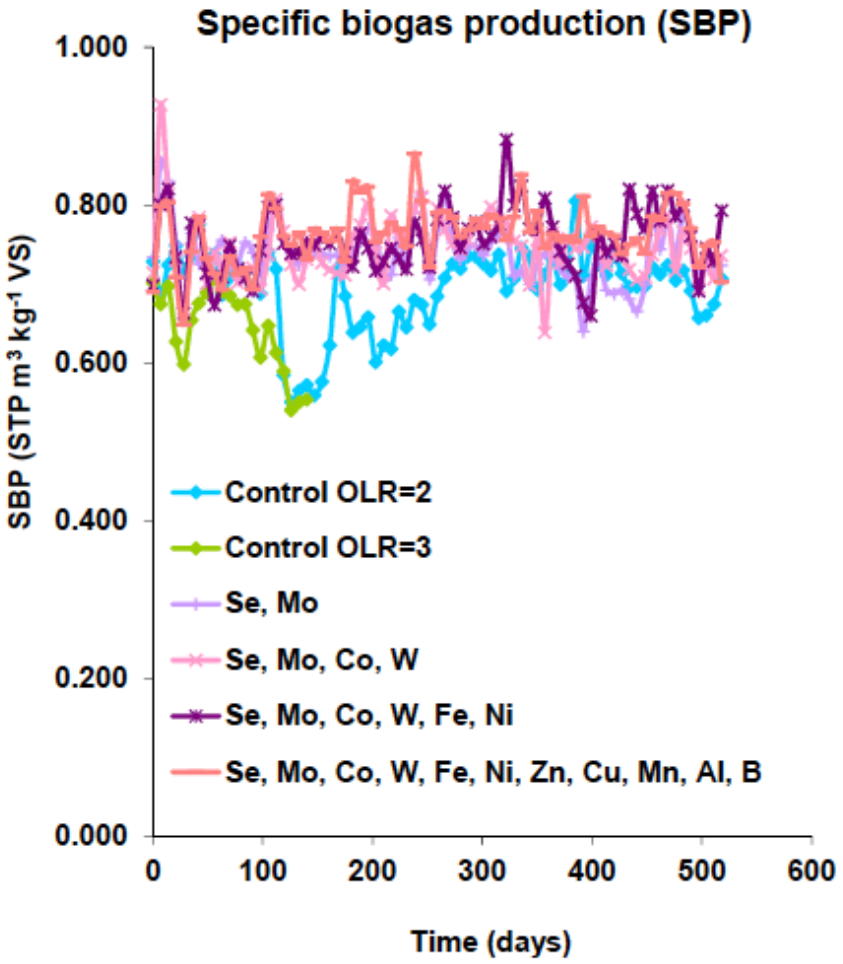
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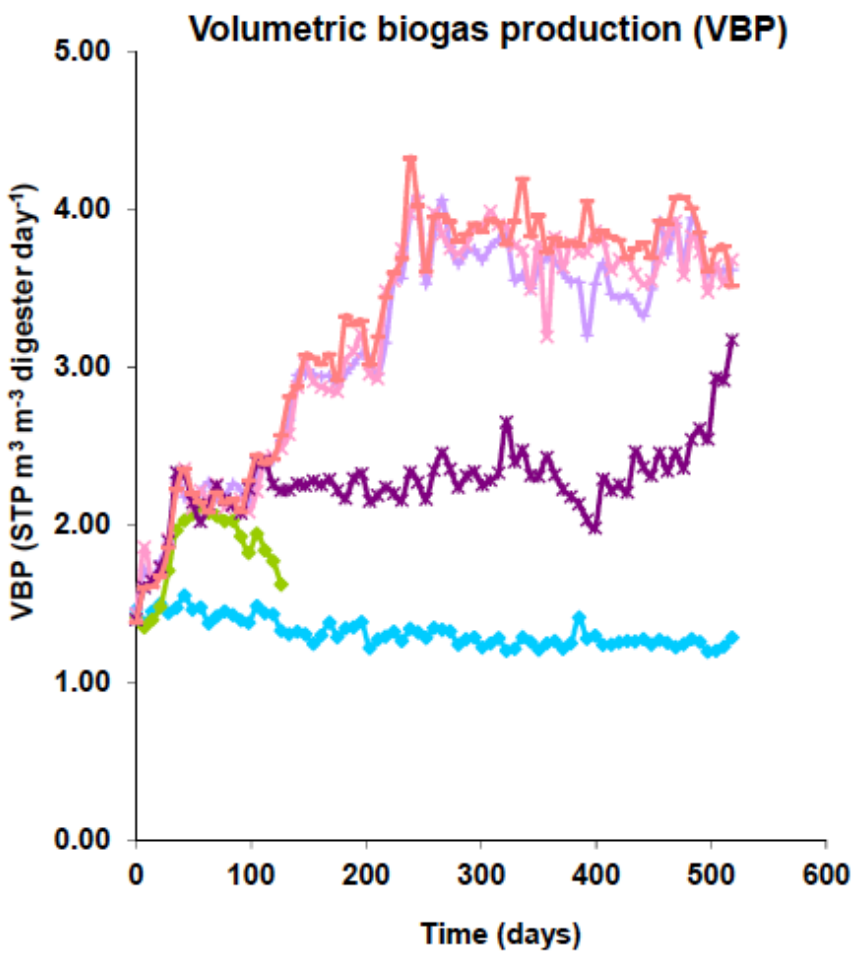
Organic loading rate (OLR)



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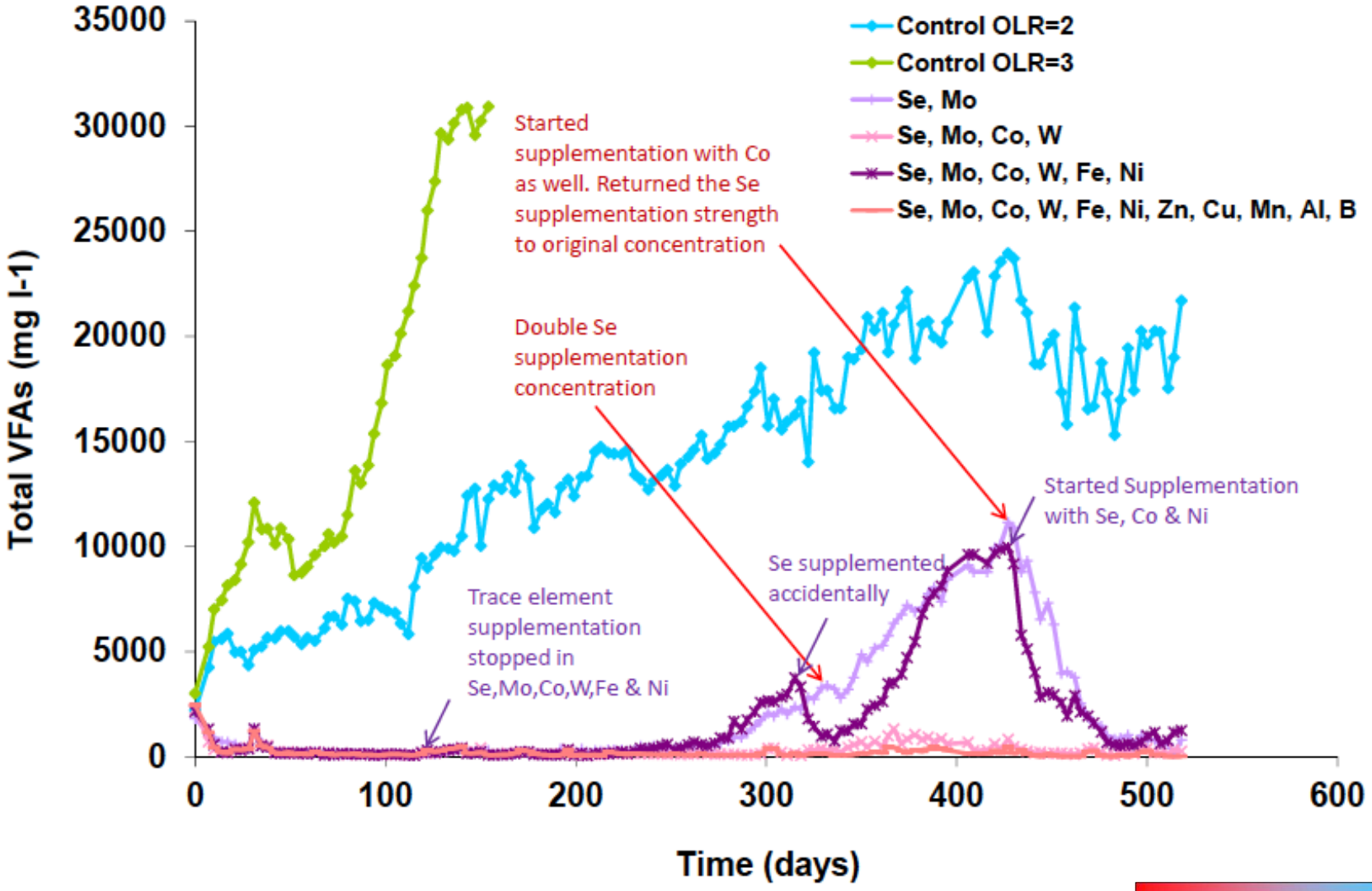
Digestion efficiency





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Volatile fatty acids profiles

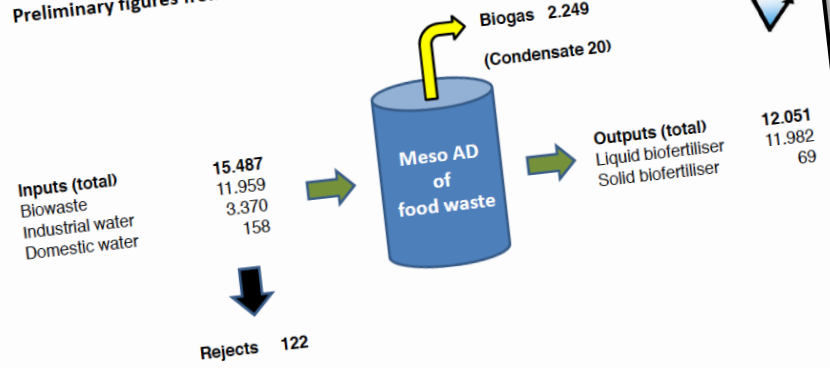


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Mass & Energy Balance

MASS BALANCE

Preliminary figures from Greenfinch (tonnes/year)



Key figures

Specific biogas production 160 Nm^3/tonne or 0.65 Nm^3/kgVS

VS removal up to 84%

24

ADSW&EC Vi

ENERGY BALANCE

The average yearly data for Biogen Greenfinch in Ludlow (UK) are

Electricity Generated	2.329	MWh
Parasitic	782	MWh
Imported Electricity	211	MWh
Net Electricity Output	1.547	MWh
Generated	194kWh/tonne	
Consumed	23kWh/tonne	
Energy Index (Ge	8,5	

90% digester mix & CHP
10% fans and S/L separation

How much energy can we get from AD?

- Up to 75~85% conversion of organic fraction into biogas
- It has a methane content of 50-60% (but will depend on substrate)
- Biogas typically has a thermal value of about 22 MJ m^{-3}
- The thermal value of methane is 36 MJ m^{-3}



Process Optimisation – Conclusions

Mesophilic Digestion

Identified key trace elements necessary for long-term stability of food waste digestion

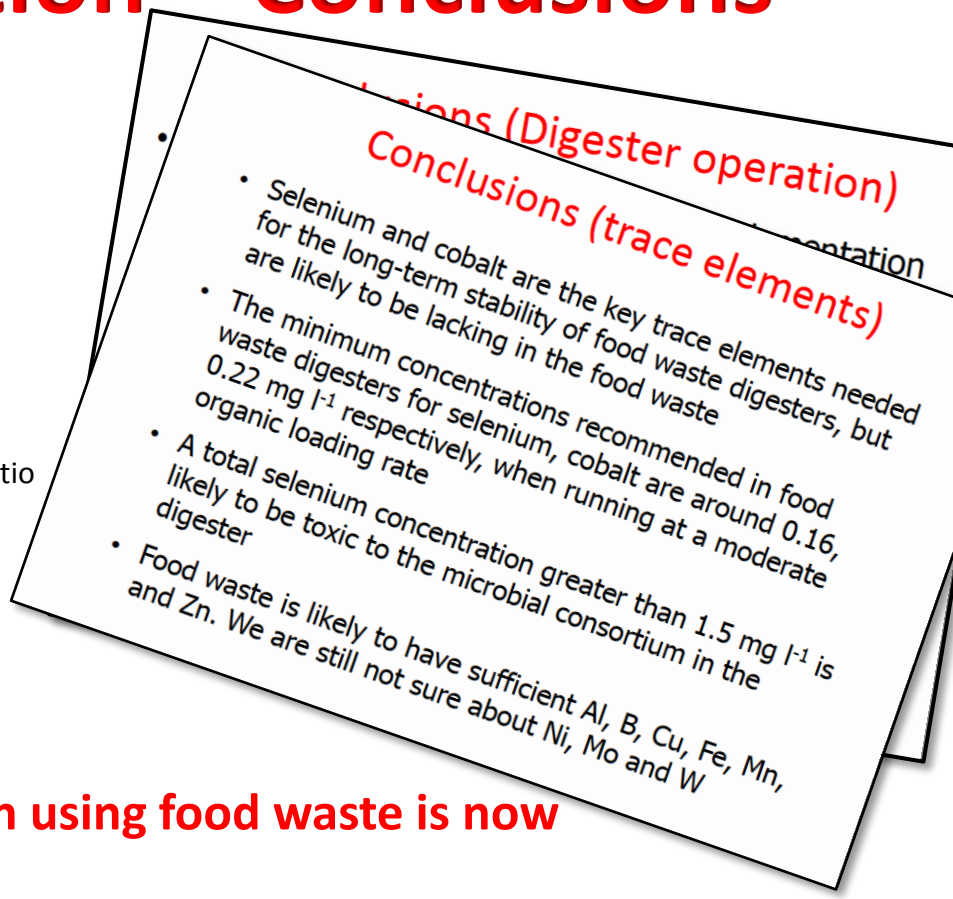
Supplementation of trace elements gives increased tolerance to ammonia

Thermophilic Digestion

Food waste digestion is possible by substrate must be diluted to keep TAN < 2.5 g/l – approx 1:1 ratio

Failure occurs at ≥ 2.5 g/l

Trace element supplementation is not effective in controlling VFA accumulation in thermophilic digesters



- **Conclusions**
  - **Long-term stable operation using food waste is now possible**
  - **Trace element supplementation a four-fold increase in organic loading rate**
  - **Adding trace elements increases biological resitance to variable loadings**
  - **Now adopted commercially in UK**

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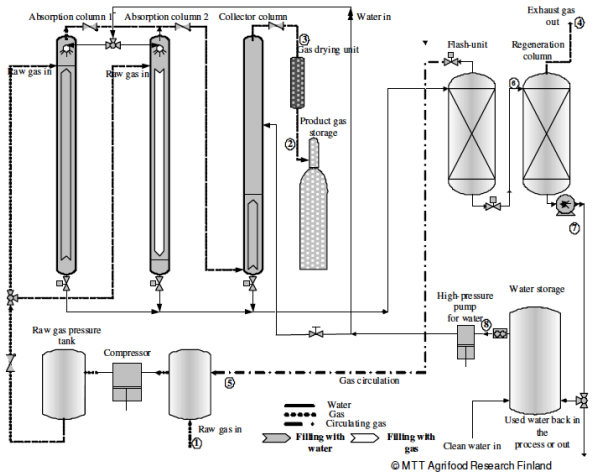
Small Scale Biogas Upgrade & Storage

Work Package Objective

To further develop low-cost, small scale biogas upgrading technologies and storage systems for:

- Transportation
- Local low-pressure distribution systems

Process:







Volvo S60 Bi-fuel receiving biomethane

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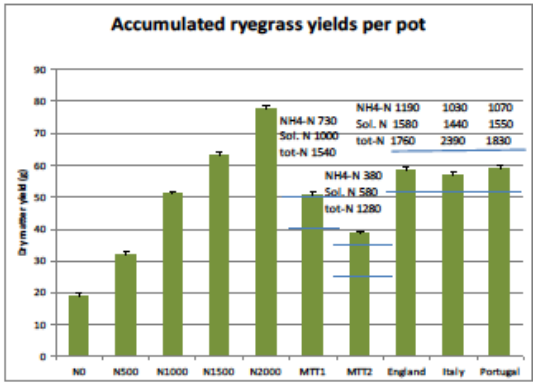
Small Scale Biogas Upgrade & Storage

Results

- Successful development of a low-pressure, low cost upgrading system for biogas flows of 10 – 60 cu.m/hour:
  - Excellent performance & energy efficiency
  - Containerised, using plumbing and agricultural fittings to permit local maintenance
  - Commercially viable for small-scale markets – rural, off-grid.
- Influenced Indian policy
  - Contributed to upgrading and bottling industry in India
  - Contributed to development of new automated small-scale biomethane upgrade system meeting Indian standard
- Recommendations made for promotion of biomethane for transport in EU

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Digestate Quality, Security & Agronomic Value



Work Package Objectives

- To determine the quality, biosecurity & agronomic value of digestates

Significant findings

- Rye grass laboratory trials confirm FW digestates of high agronomic benefit
- Autoclaving offers same pathogen protection as pasteurisation
  - Also changed properties of food waste resulting in formation of unmineralised nitrogen & a 30% reduction in fertiliser value

Post treatments to reduce volume, increase ease of application & digestate properties are of interest

Results now informing UK approach to EU End-of-Waste policy (particularly important in Southern Europe)

References

- University of Jyväskylä, Finland Located at the (Mustankorkea) landfill site, High pressure and counter current water scrubbing systems (6 Nm^3/h)



- High pressure system was commissioned in nothern China (40 Nm^3/h) Vehicle fuel and cooking fuel



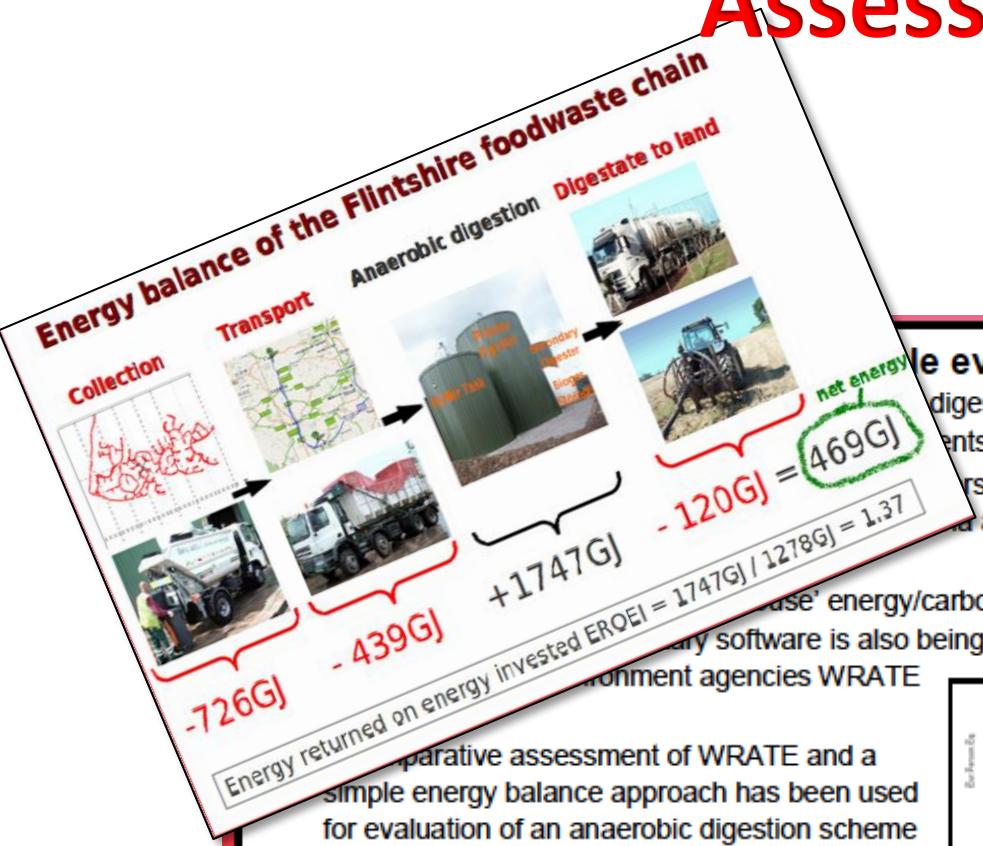
- 25- 40 Nm^3/h unit at Kalmari farm (Central Finland) with modern automatic fueling station 30 vehicles are fueled





Metener Ltd
Environmental & Energy Technology

Energy, Environment & Life-Cycle Assessment



le evaluation

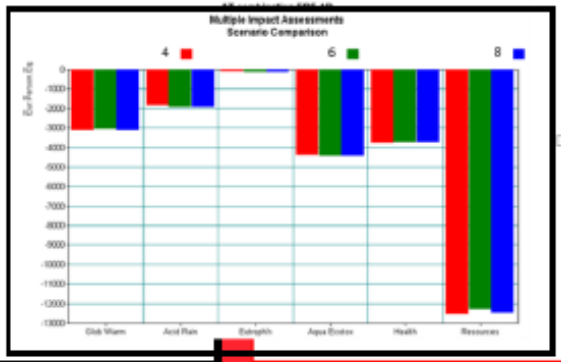
digestates has
nts

rs has been
a purpose

use' energy/carbon/nutrient
ry software is also being used,
ronment agencies WRATE

parative assessment of WRATE and a simple energy balance approach has been used for evaluation of an anaerobic digestion scheme

- The reproducibility of a testing protocol for digestate stability has been statistically evaluated



WRATE scenario map and graphic output showing impacts for an AD scheme

Conclusions

- Very successful programme
- Huge amount of information generated
- Practical results that have already impacted the industry
- Developed models, procedures and recommendations that are freely available and can improve the design & operation of anaerobic digestion
- Its all on the website:

www.valorgas.soton.ac.uk

The Culture of Food Waste Collection



Thank You





www.valorgas.soton.ac.uk