UNIVERSITY OF Southampton

Lab scale studies to troubleshoot instability issues in food waste digesters

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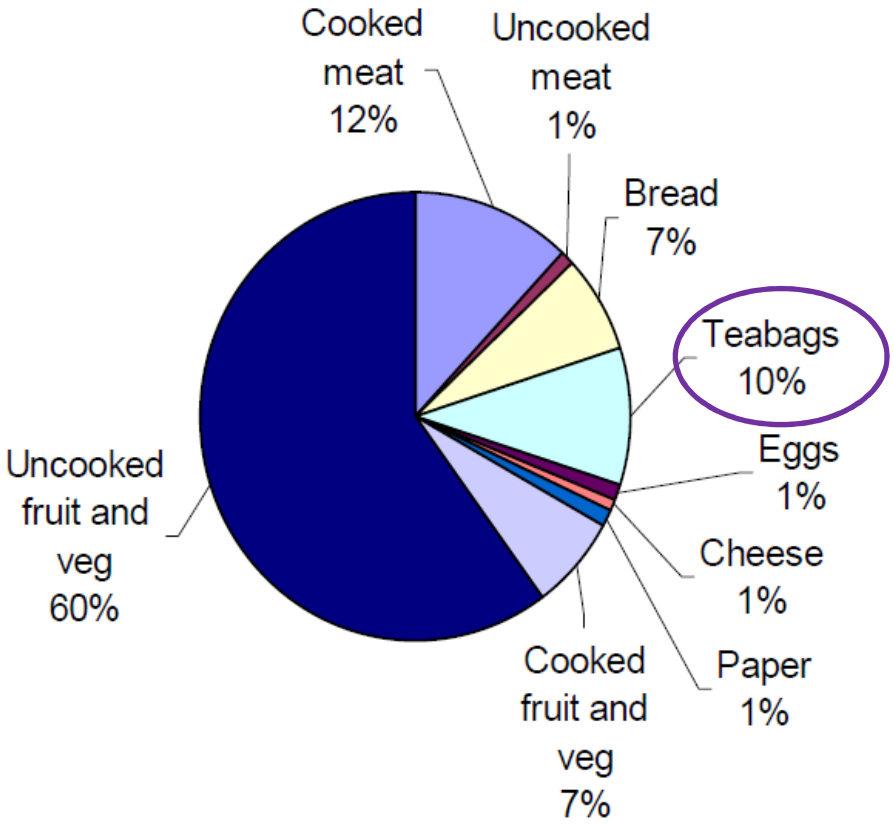
I. Annual AD Research & Development Forum, Bristol, 1-2 November 2011

Source-segregated food waste from household



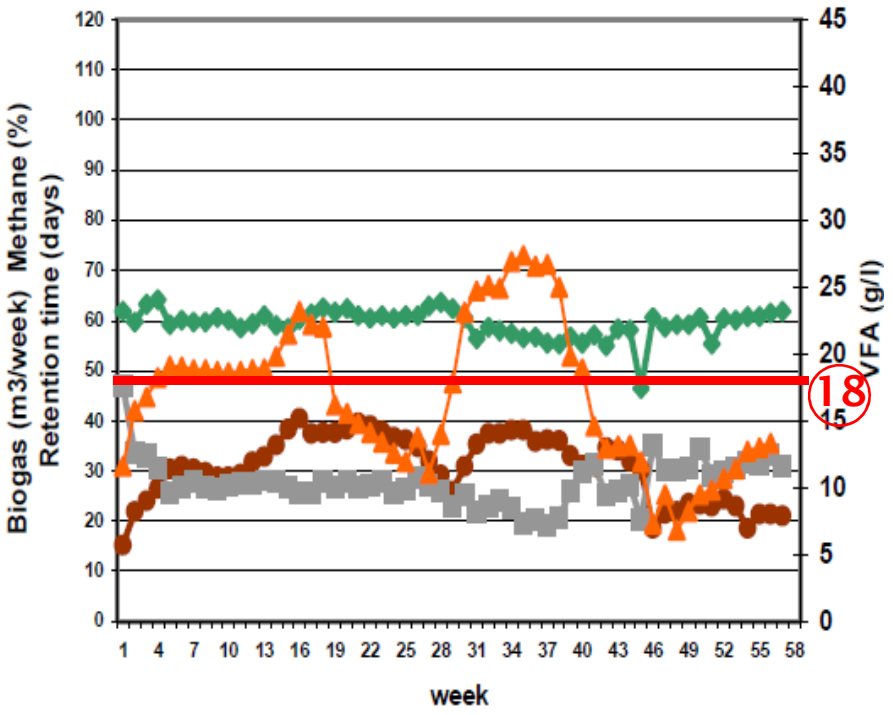
Biffaward
investing in the environment

defra
Department for Environment Food and Rural Affairs

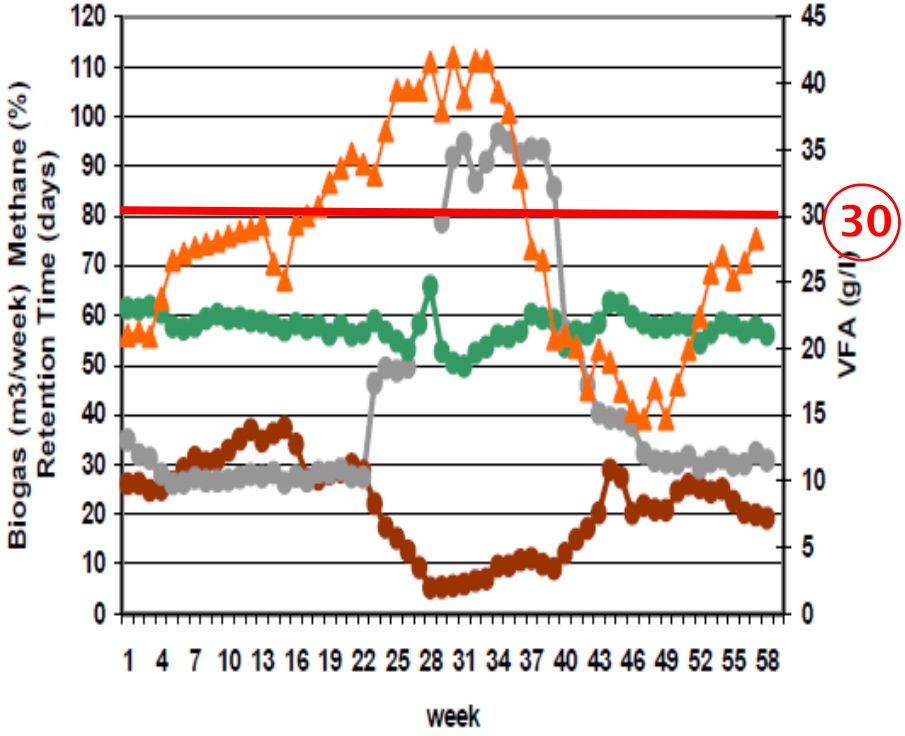
SEVENTH FRAMEWORK PROGRAMME
VALORGAS

Digesters used in the Burford study

Volatile fatty acid (VFA) concentrations



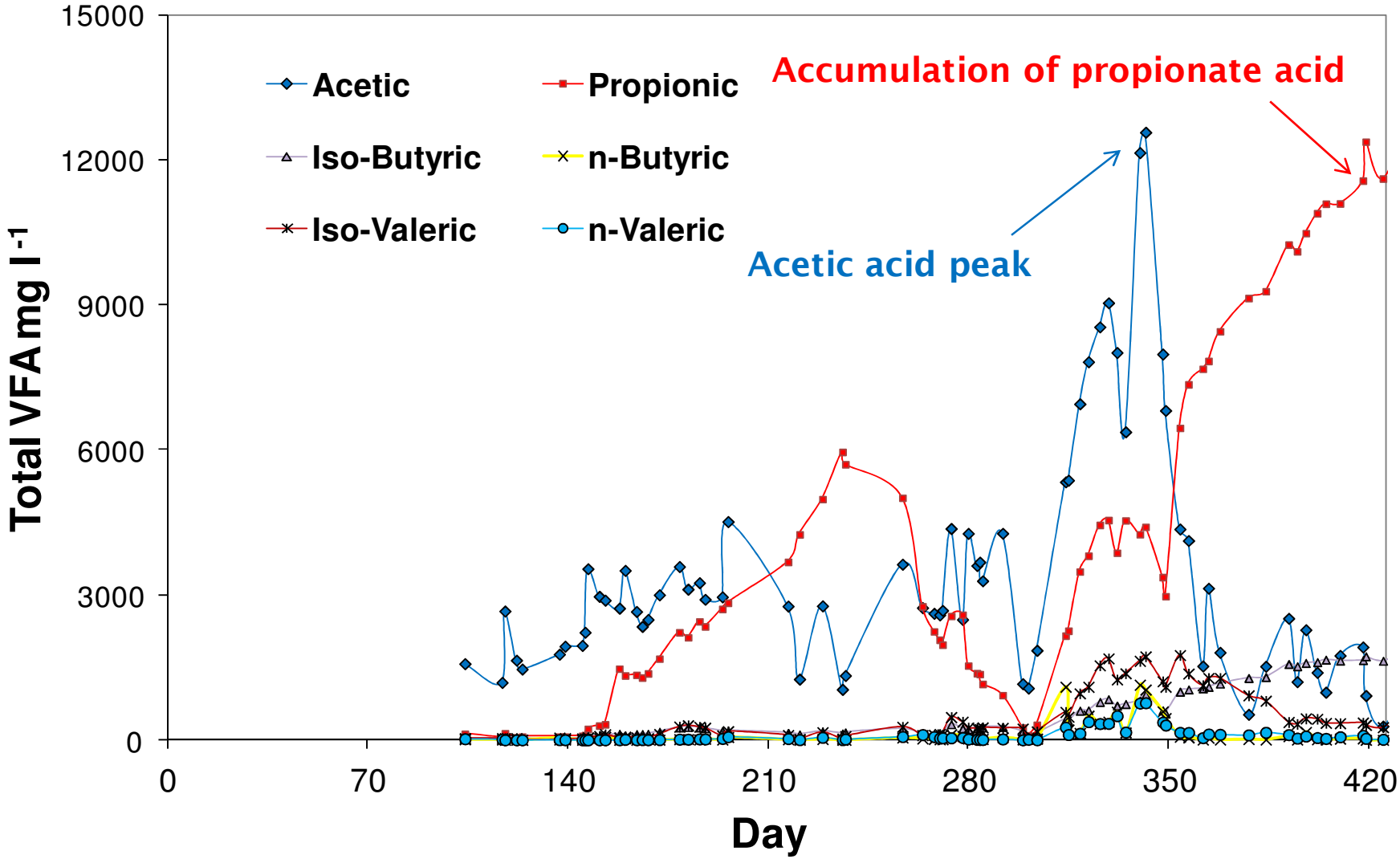
Mesophilic digester



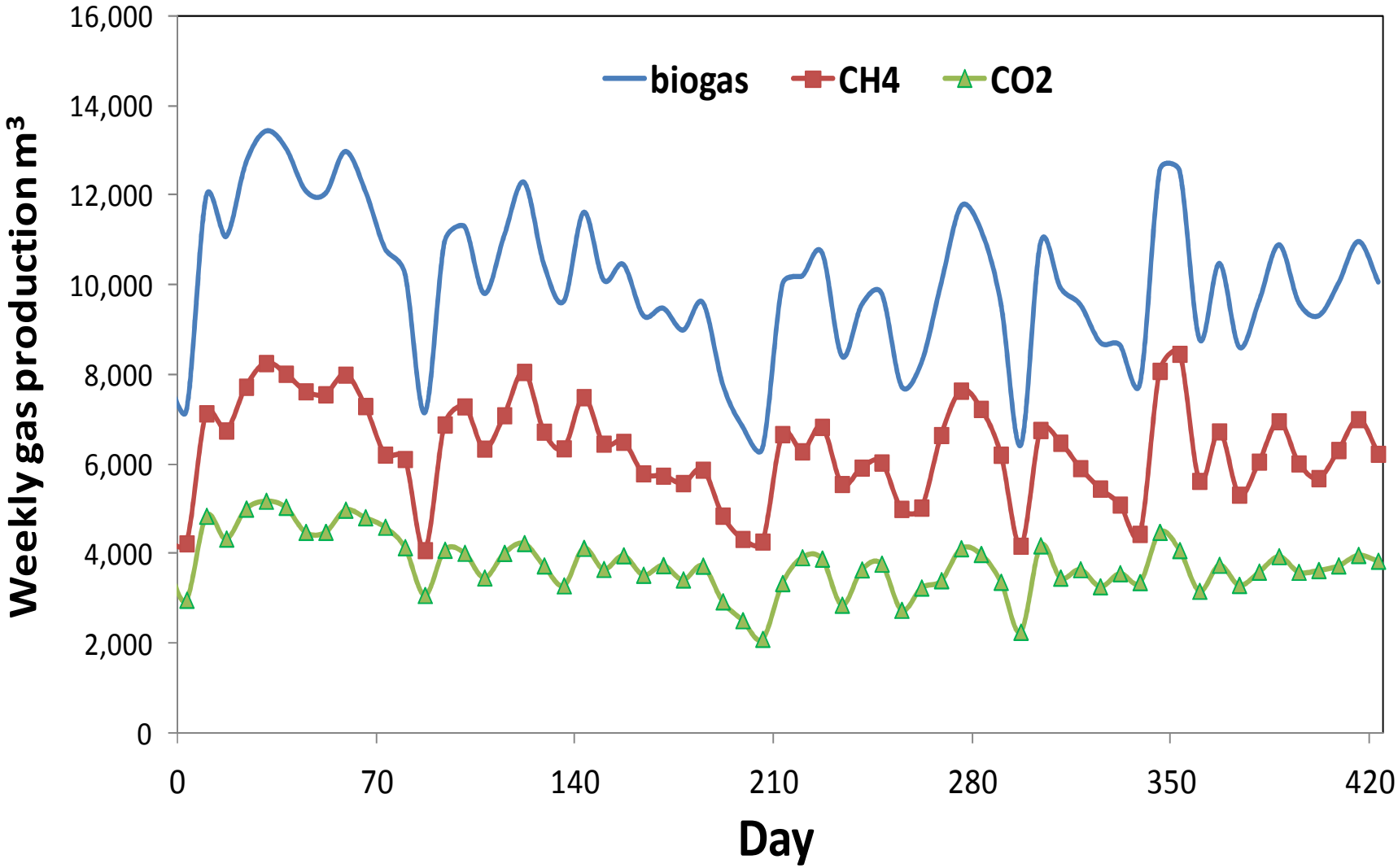
Thermophilic digester

Ludlow demonstration plant

Volatile fatty acid (VFA) concentrations

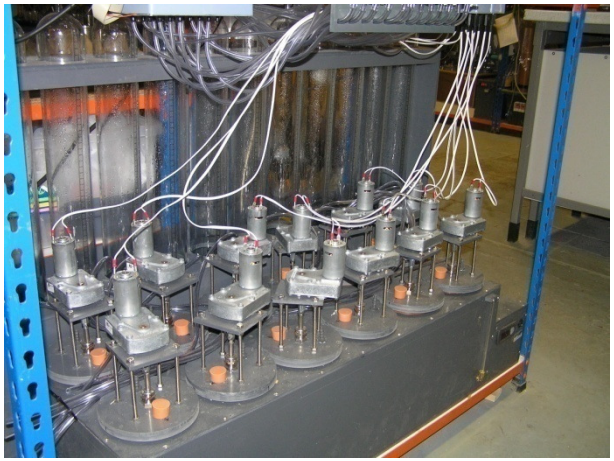


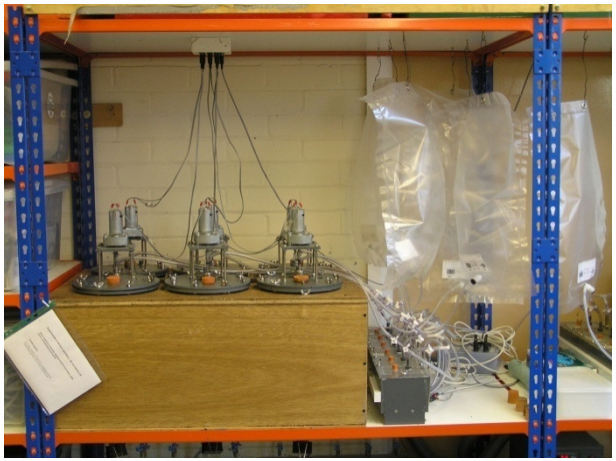
Biogas production



Collected food waste

Laboratory digesters





CSTR-type digesters:

2-litre

5-litre

40-litre

100-litre

Long chain fatty acids (LCFA) accumulation

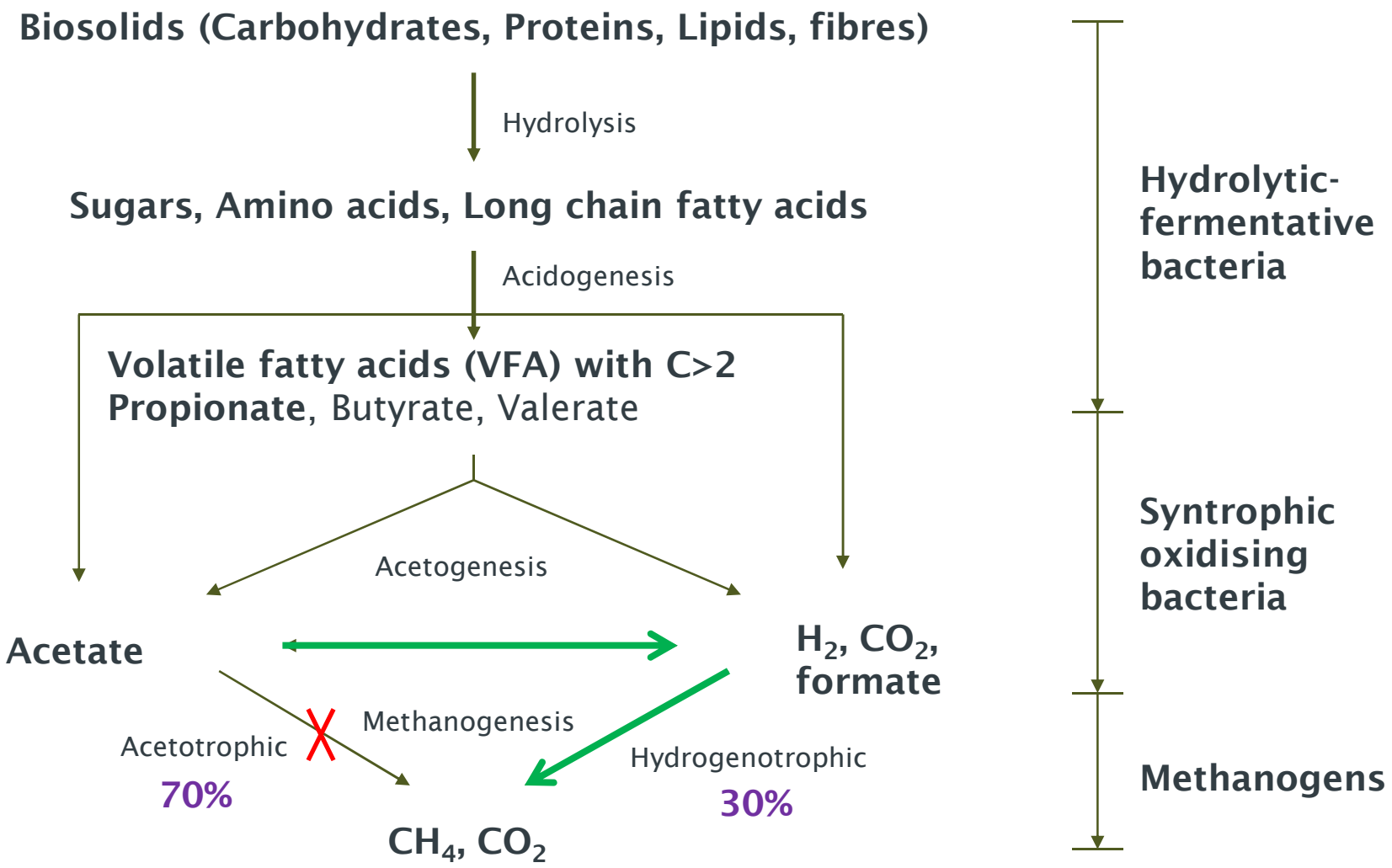
X-ray diffraction analysis

Instability

- **Negative response**
  - accumulation of long chain and volatile fatty acids
- **Loading limit**
  - less than 2 kg VS m^{-3} day^{-1}

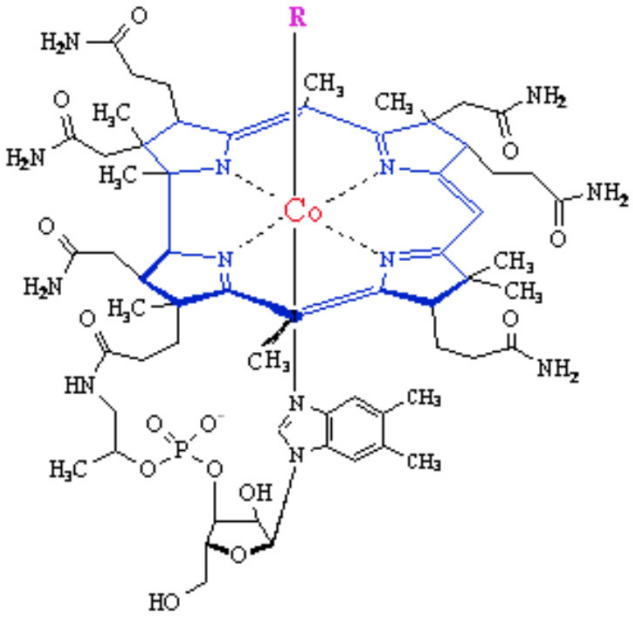
Sub-healthy

Anaerobic conversion of biosolids to methane

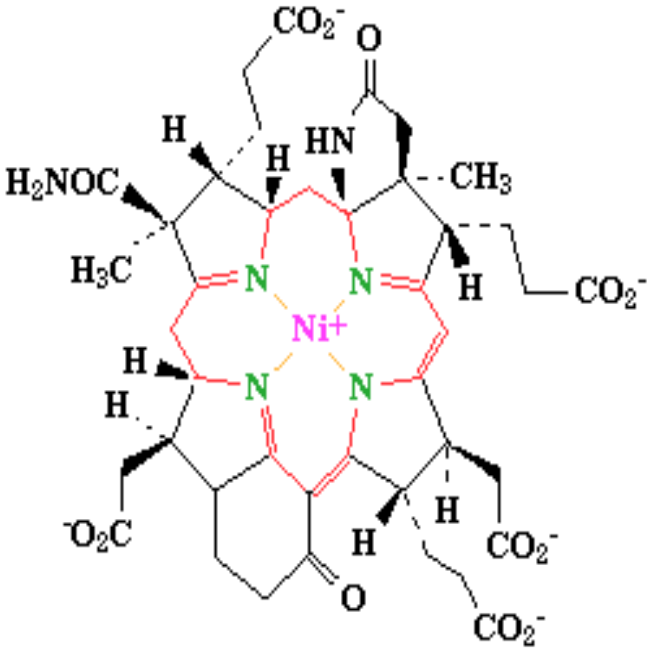


Possible reasons

- **Ammonia toxicity:** 5000~7000 mg N l^{-1}
- **Trace elements deficiency:** Co, Ni, Fe, Se, Mo, W, Zn, Cu, Mn, Al, B



Corrinoid

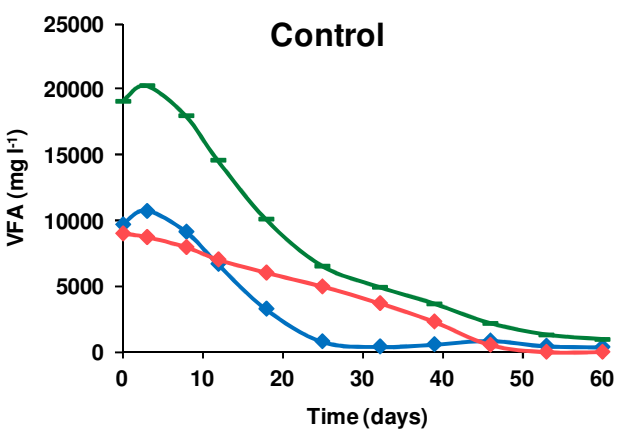


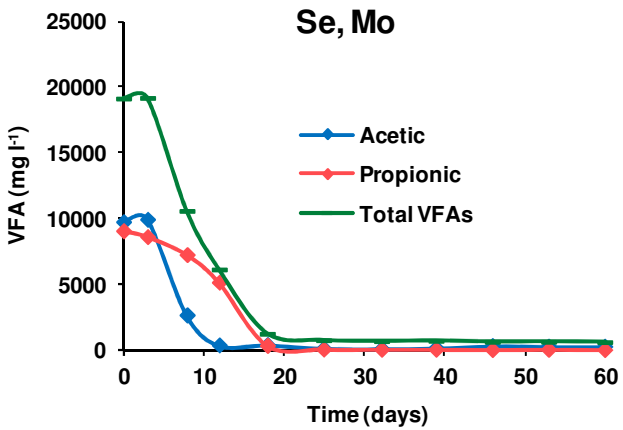
Cofactor F430

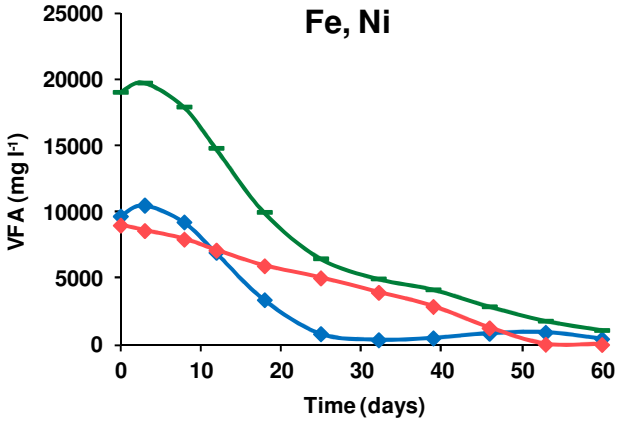
Batch experiments - fractional factorial design

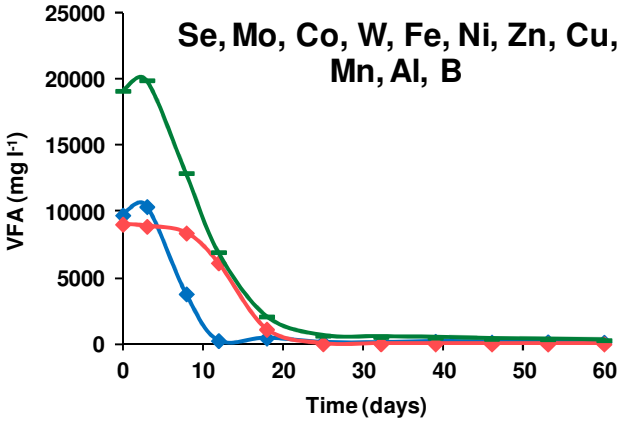
Run	Pattern	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	Al	B
1	−−−−−−−−−−	-	-	-	-	-	-	-	-	-	-	-
2	−−−+++−−−−	-	-	-	Se	Fe	W	-	-	-	-	-
3	−−+−++−−−−	-	-	Mo	-	Fe	W	-	-	-	-	-
4	−−++−−−−−−	-	-	Mo	Se	-	-	-	-	-	-	-
5	−+−−+−−−−−	-	Ni	-	-	Fe	-	-	-	-	-	-
6	−+−+−+−−−−	-	Ni	-	Se	-	W	-	-	-	-	-
7	−++−−+−−−−	-	Ni	Mo	-	-	W	-	-	-	-	-
8	−++++−−−−−	-	Ni	Mo	Se	Fe	-	-	-	-	-	-
9	+−−−+−−−−	Co	-	-	-	-	W	-	-	-	-	-
10	+−−++−−−−−	Co	-	-	Se	Fe	-	-	-	-	-	-
11	+−+−+−−−−−	Co	-	Mo	-	Fe	-	-	-	-	-	-
12	+−++−+−−−−	Co	-	Mo	Se	-	W	-	-	-	-	-
13	++−−++−−−−	Co	Ni	-	-	Fe	W	-	-	-	-	-
14	++−+−−−−−−	Co	Ni	-	Se	-	-	-	-	-	-	-
15	+++−−−−−−−	Co	Ni	Mo	-	-	-	-	-	-	-	-
16	++++++−−−−	Co	Ni	Mo	Se	Fe	W	-	-	-	-	-
17	+++++++−−−	Co	Ni	Mo	Se	Fe	W	Zn	-	-	-	-
18	+++++++++−	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	-	-
19	++++++++++	Co	Ni	Mo	Se	Fe	W	Zn	Cu	Mn	Al	B

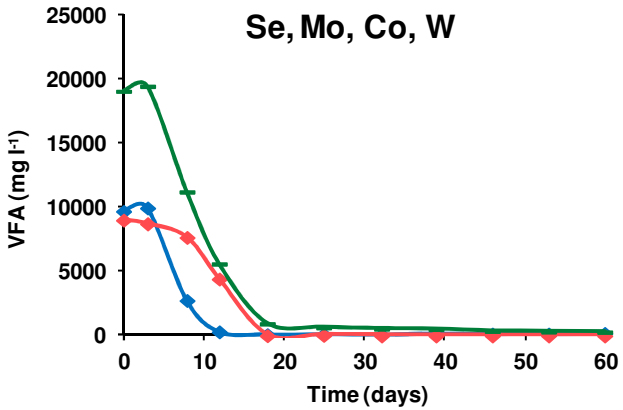
VFA degradation profiles

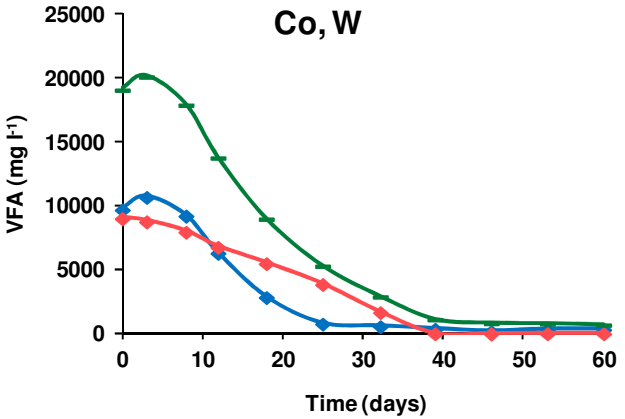






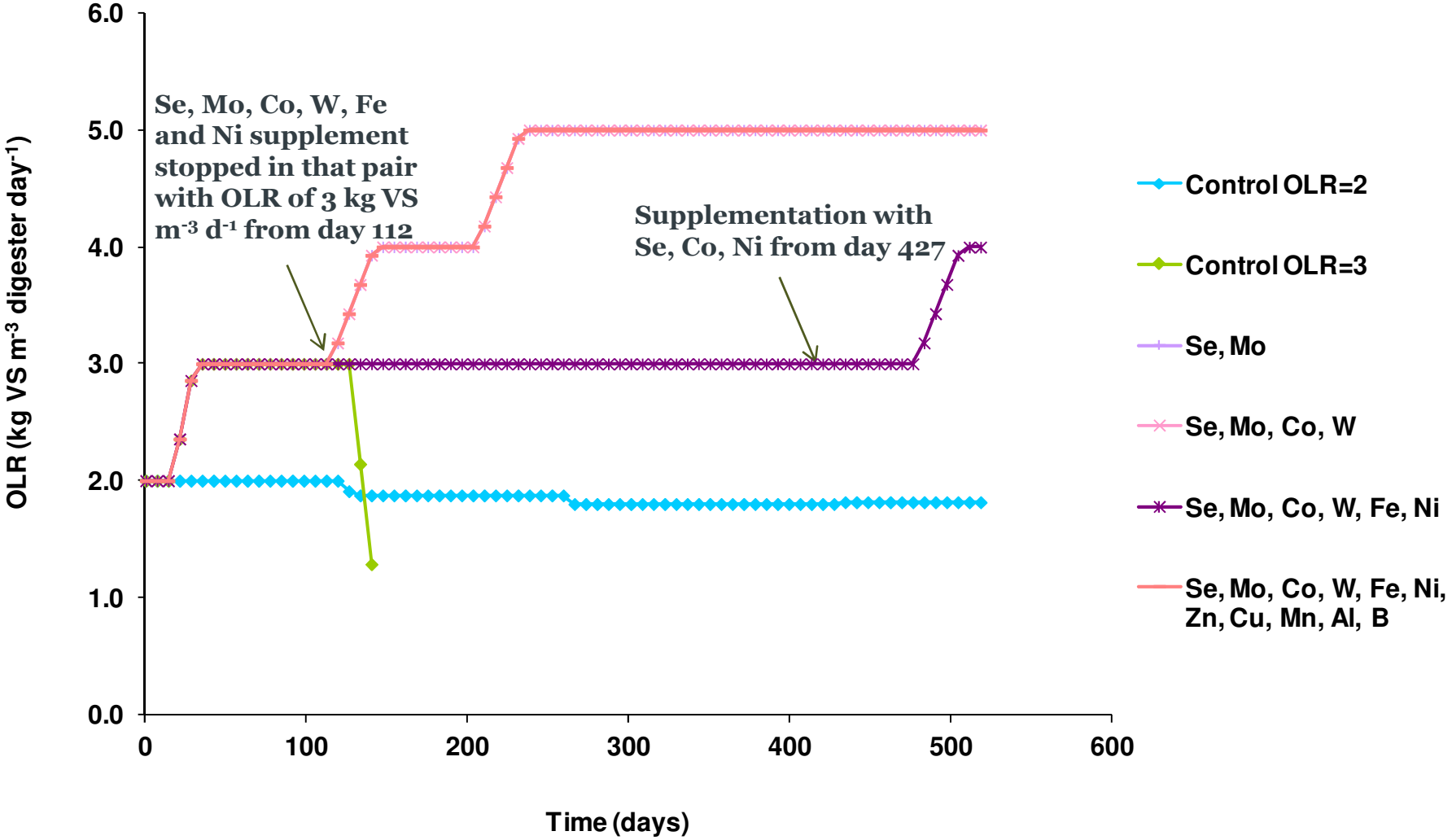




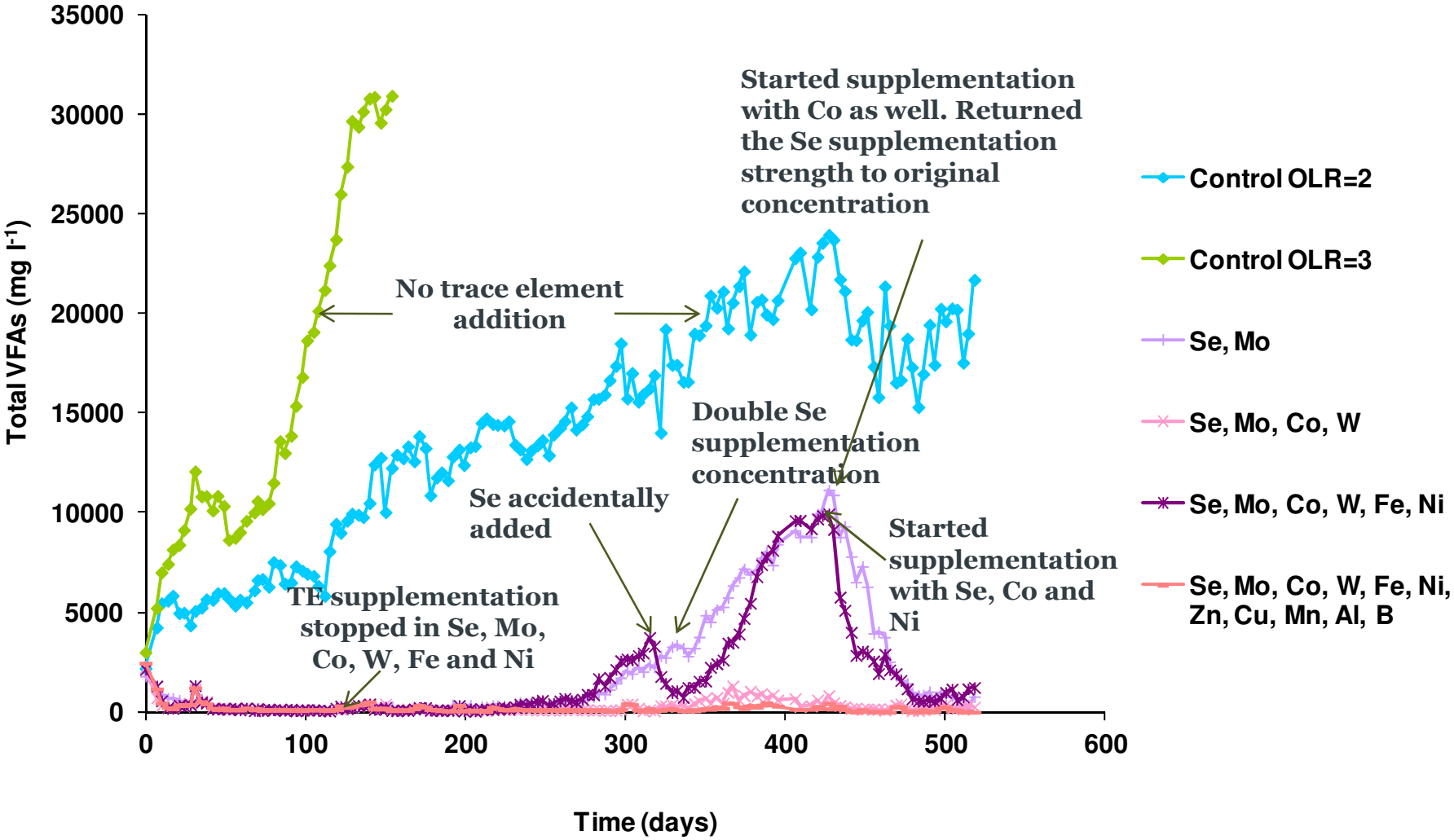


Digester trials

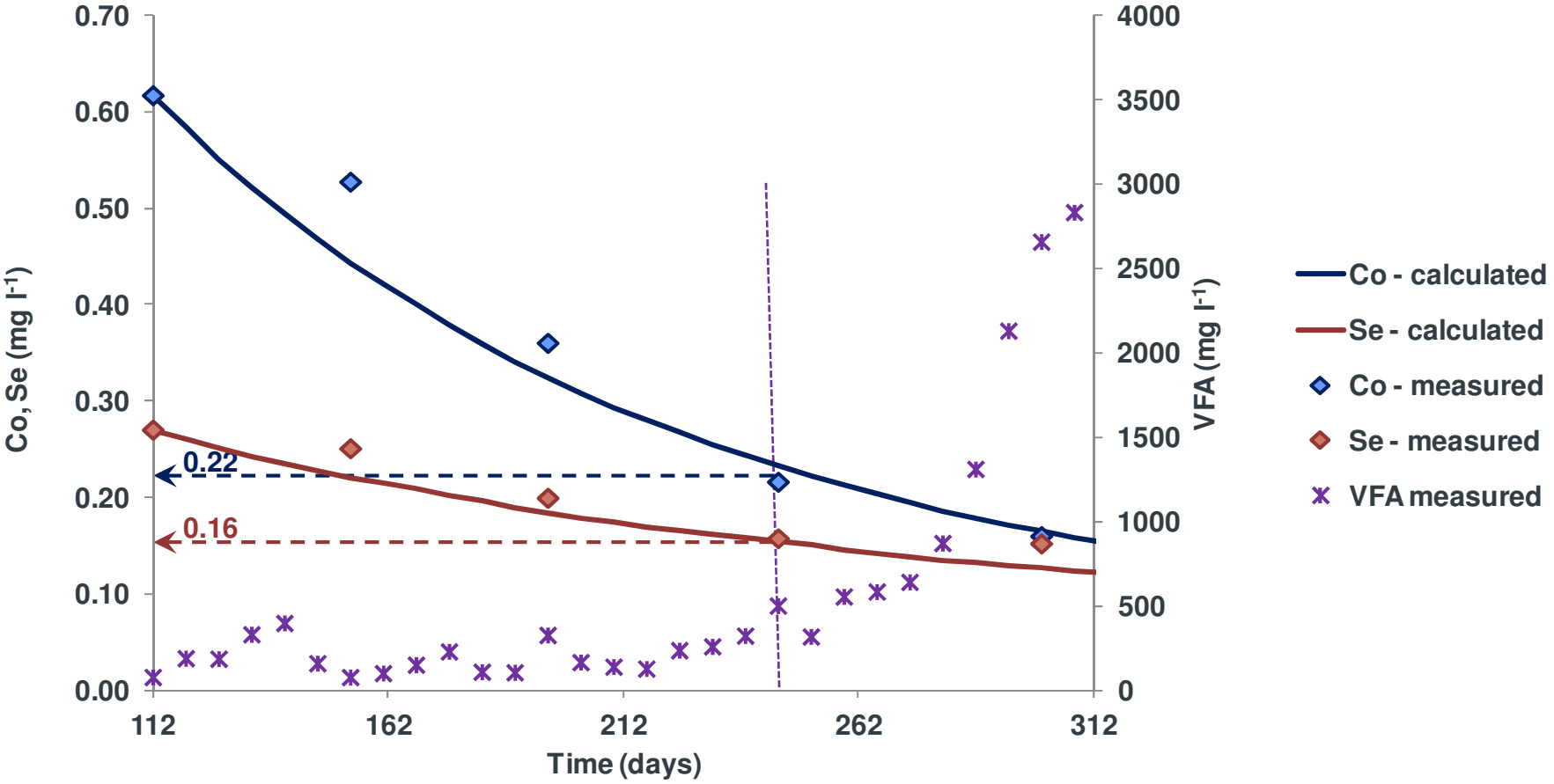
Organic loading rate (OLR)



Volatile fatty acids (VFA) profiles



Co and Se dilute-out curves – VFA profile



Se: 0.16 mg l^{-1} = 0.16 g m^{-3} = 10^{21} Se m^{-3}

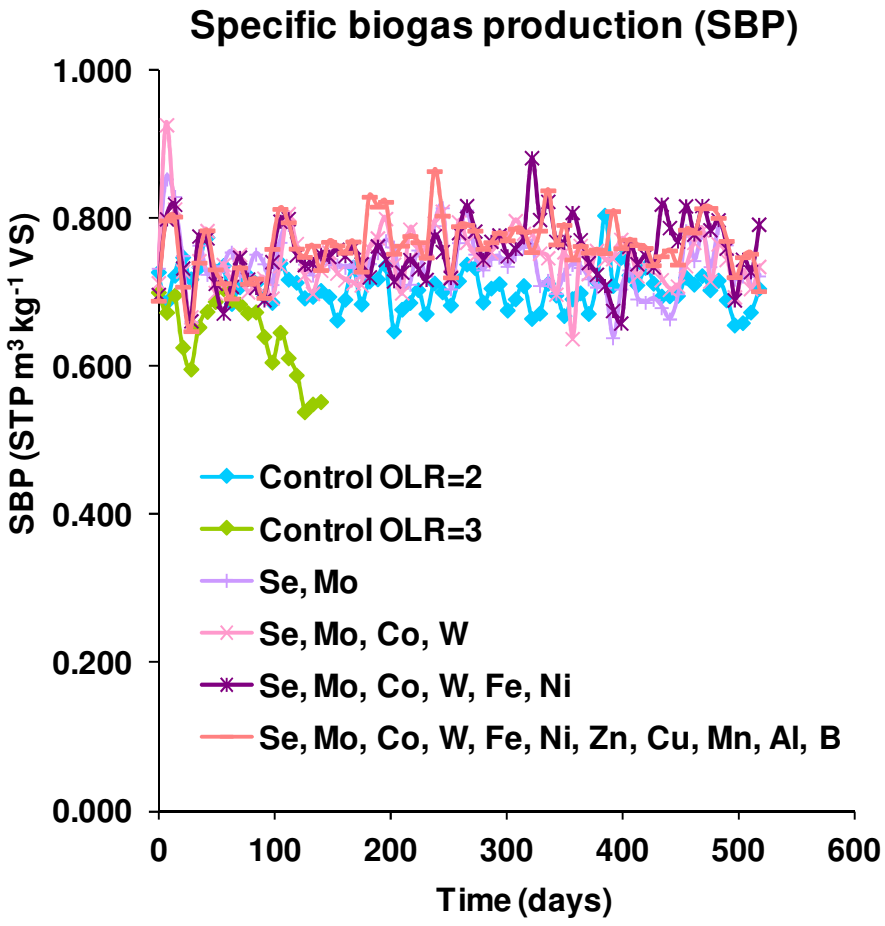
Microorganisms: 10^{16} m^{-3}

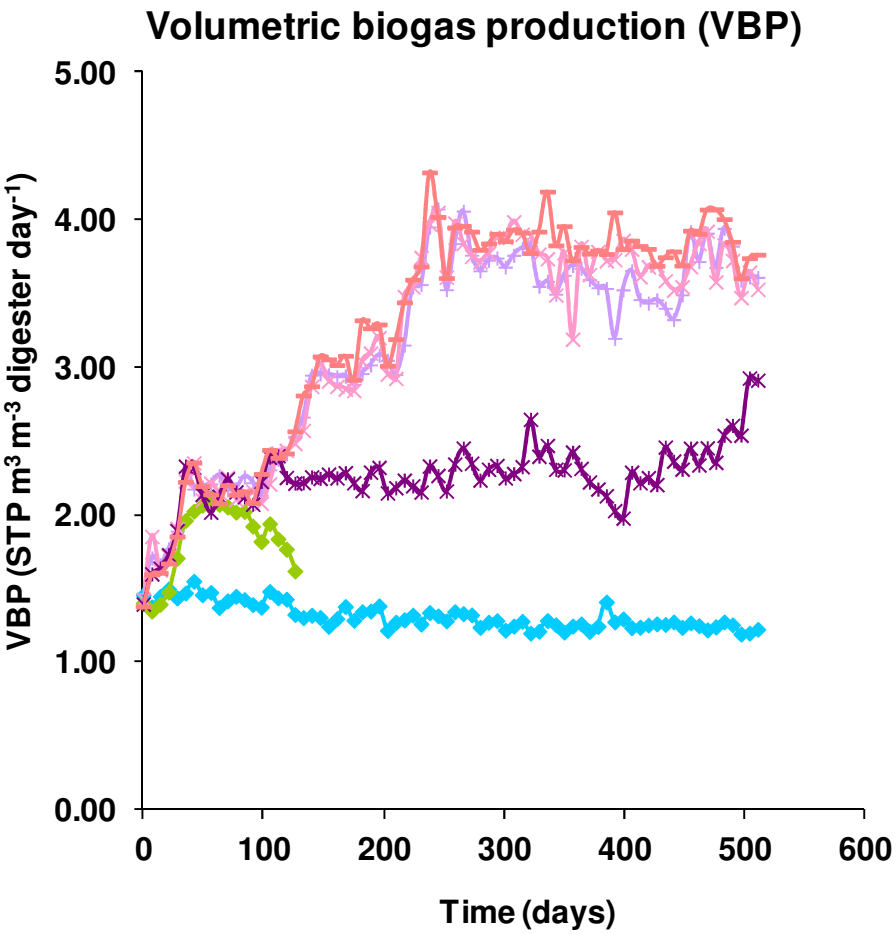
TE required vs TE in the UK food waste

	Minimum requirement at a moderate loading rate	Hackney, London	Eastleigh, Hampshire	Luton, South Bedfordshire	Ludlow, Shropshire
Cobalt (Co)	**0.22**	**0.09** ± 0.05	**0.02** ± 0.01	**0.02** ± 0.00	< **0.06**
Selenium (Se)	**0.16**	**0.10** ± 0.08	**0.03** ± 0.00	**0.28** ± 0.14	< **0.07**
Total Kjeldahl Nitrogen (TKN)		8100	7500	7400	8100

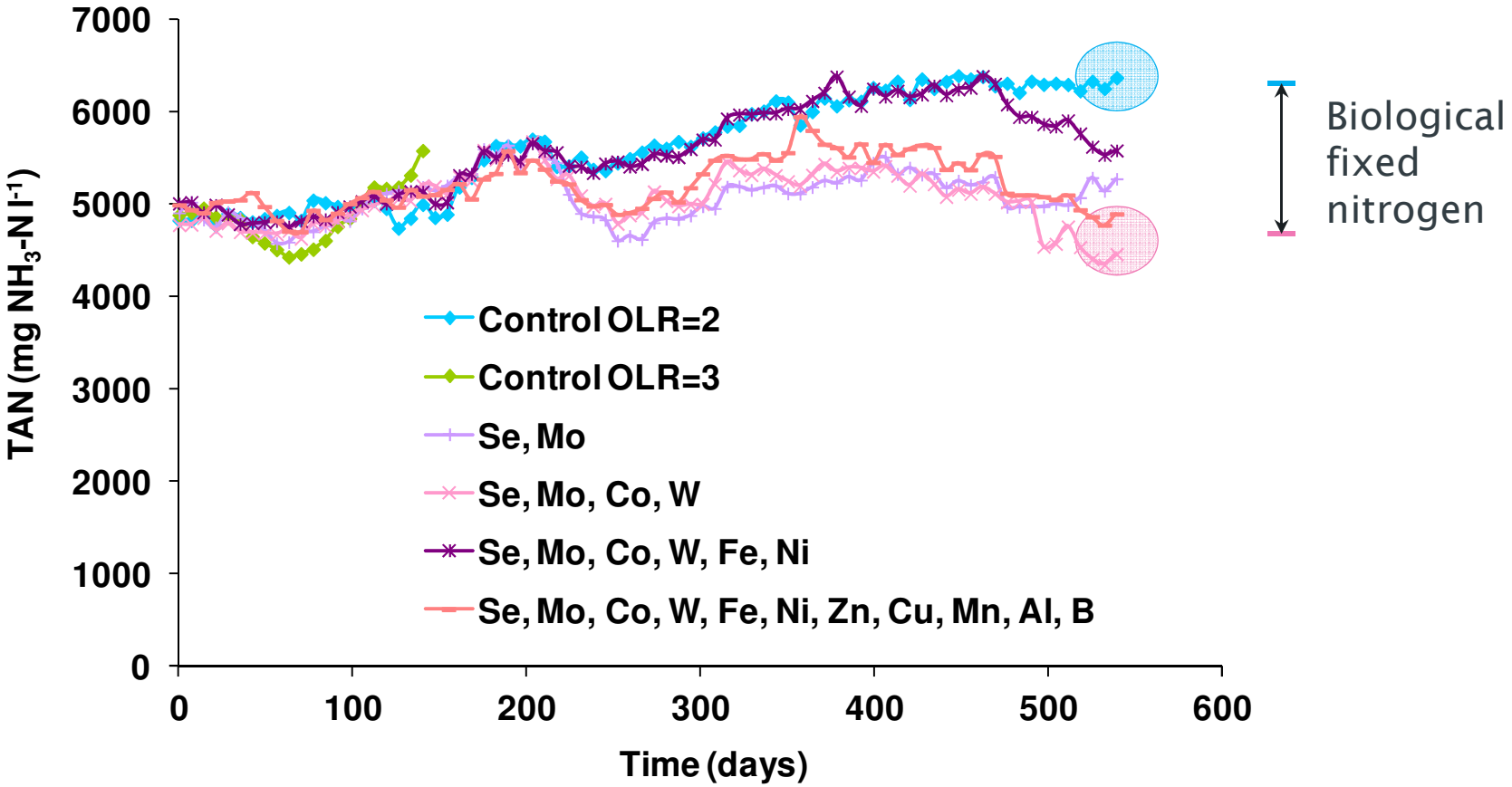
Unit: mg kg^{-1} fresh matter

Digestion efficiency



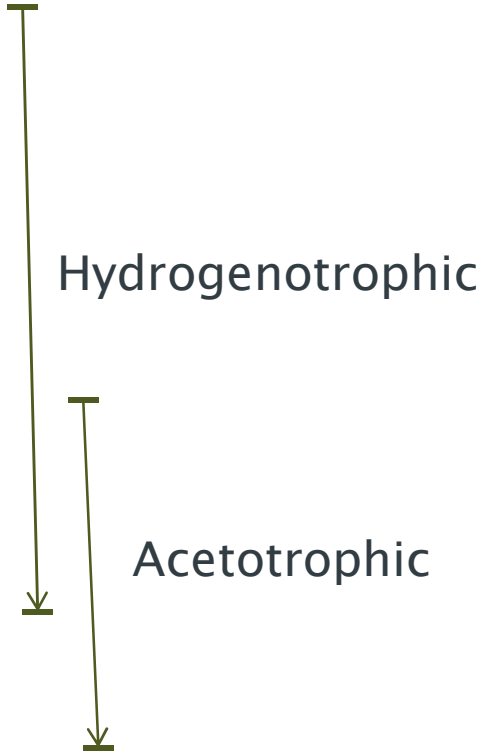


Total ammoniacal nitrogen (TAN)

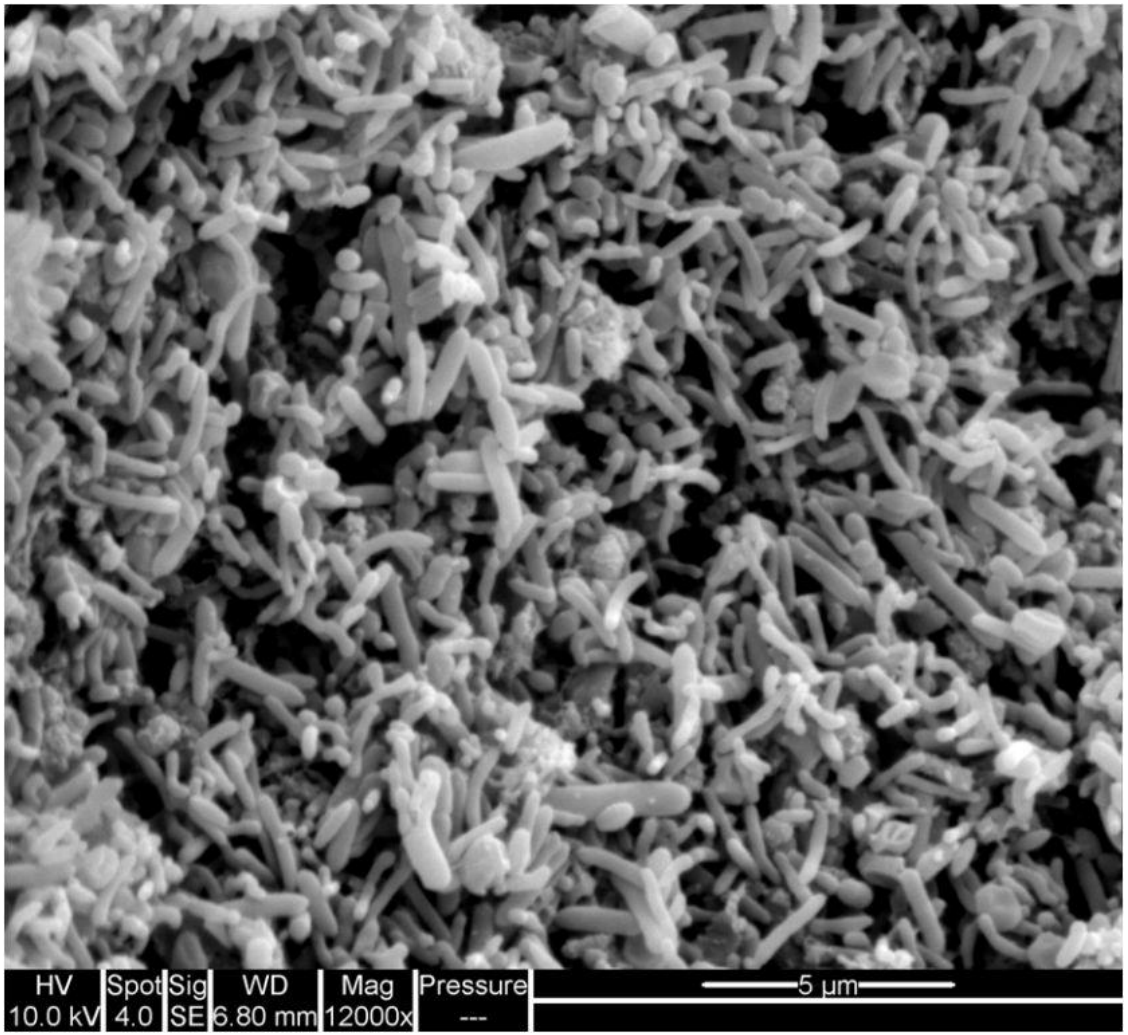


Classification of Methanogen

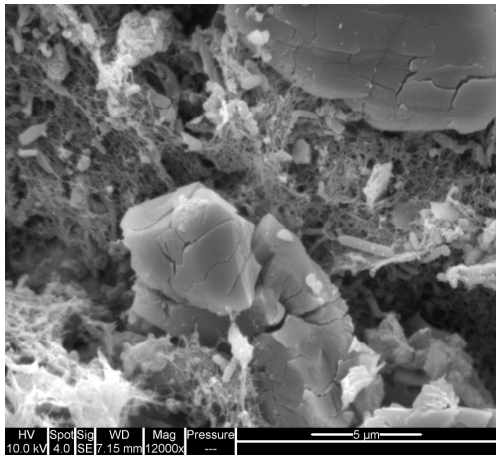
Methanogen	**Carbon source**
Methanobacteriales	CO_2 / formate
Methanococcales	CO_2 / formate
Methanomicrobiales	CO_2 / formate
Methanosarcinales Methanosarcinaceae	CO_2 Acetate
Methanosarcinales Methanosaetaceae	Acetate

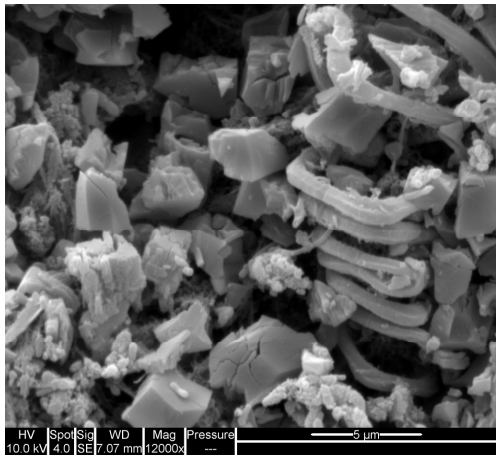


Density gradient centrifugation – SEM images



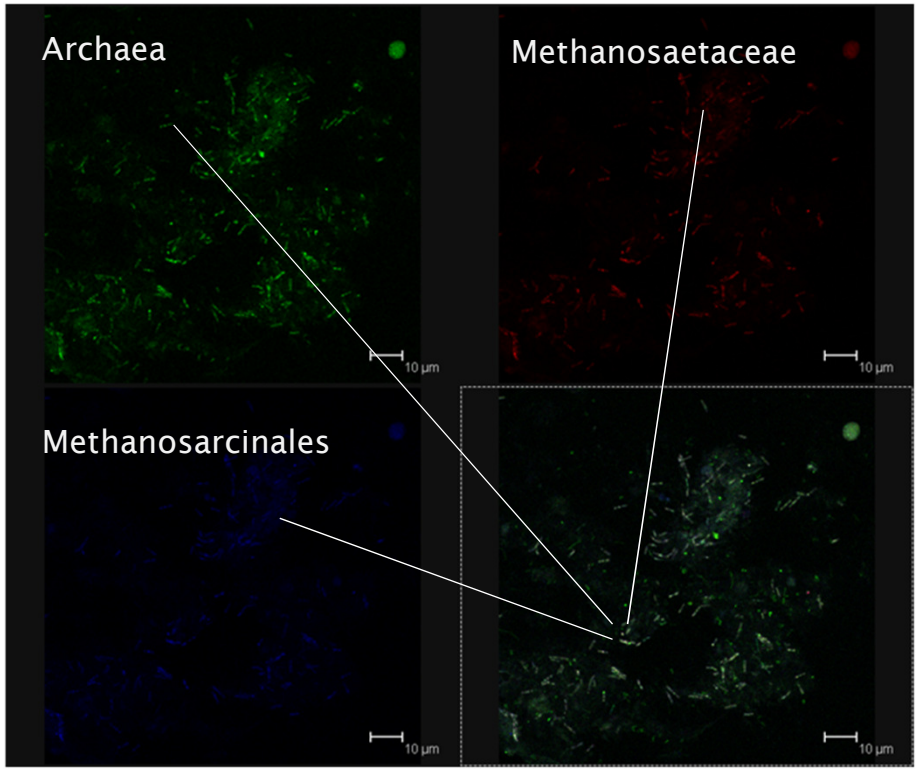
Separated microbial biomass





Food waste residues

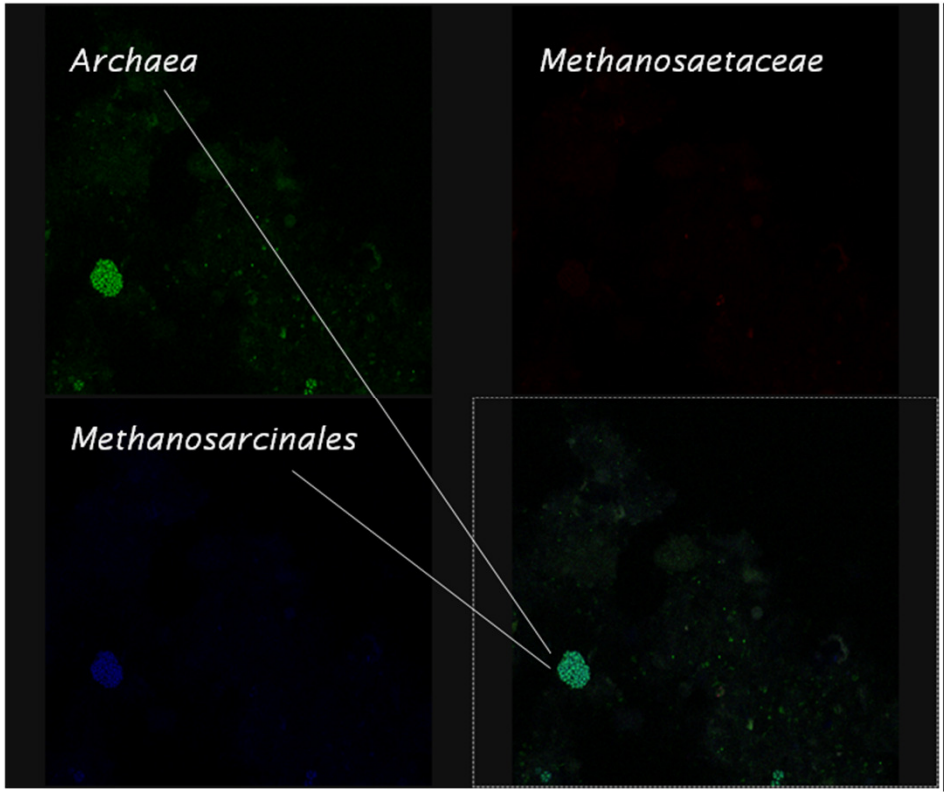
Fluorescence in-situ hybridisation (FISH)



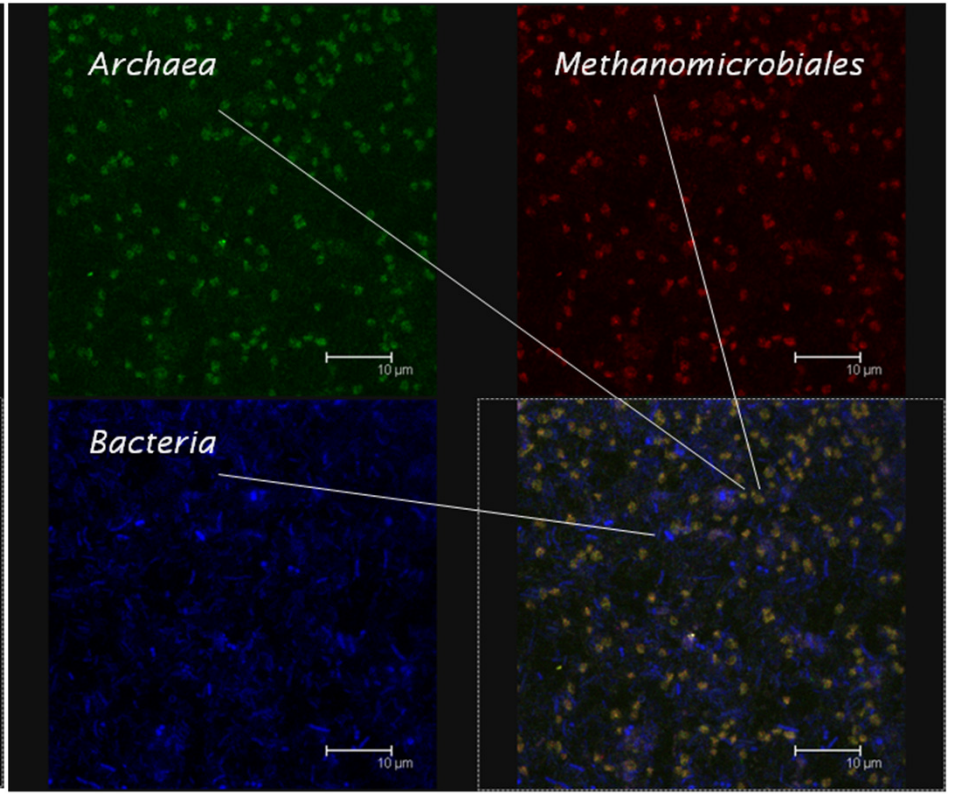
Probe name	Target group	Fluoro-chrome	Formamide (%)
EUB338	*Bacteria (most)*	Cy5	20~50
EUB338+	*Bacteria (remaining)*	Cy5	20~50
ARC915	*Archaea*	6-Fam	20~50
MX825	*Methanosaetaceae*	Cy3	50
MS1414	*Methanosarcinaceae*	Cy3	50
hMS1395	MS1414-helper	-	50
hMS1480	MS1414-helper	-	50
MSMX860	*Methanosarcinales*	Cy5	45
MG1200	*Methanomicrobiales*	Cy3	20
MB1174	*Methanobacteriales*	Cy3	45
MC1109	*Methanococcales*	Cy3	45

Inoculum - *Methanosaetaceae*

Fluorescence in-situ hybridisation (FISH)



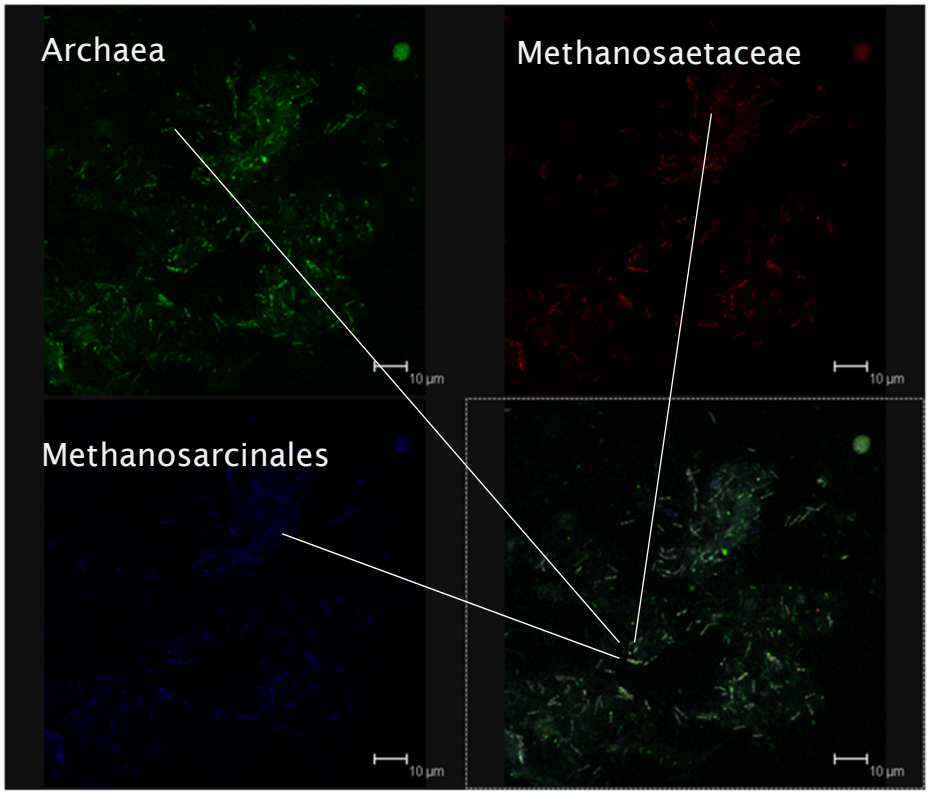
After 3 months - *Methanosarcinaceae*



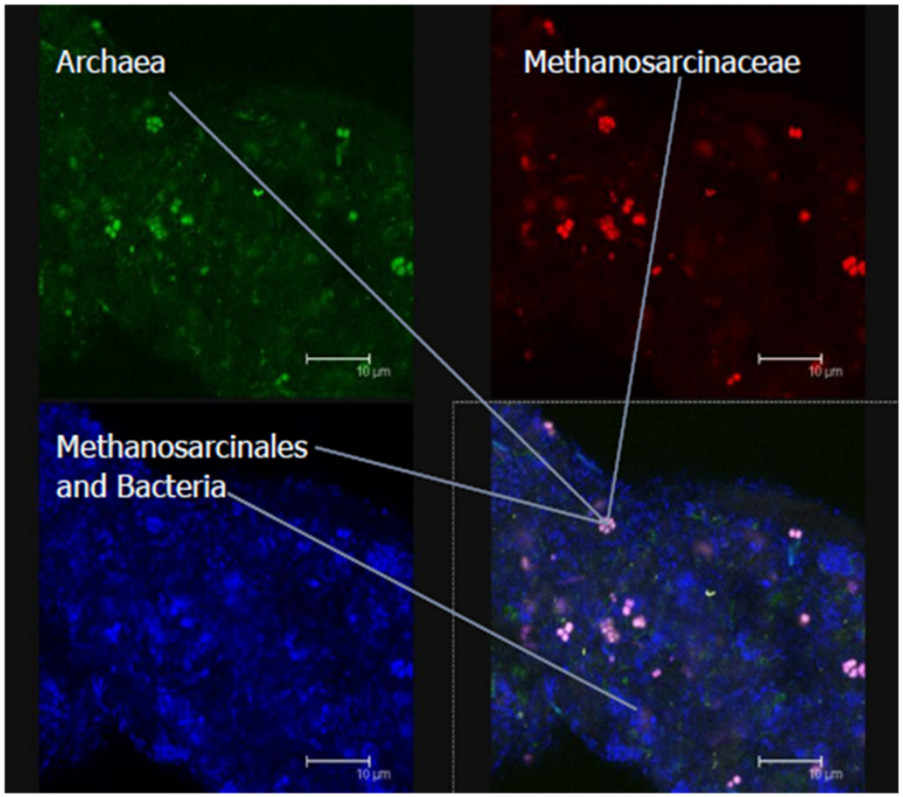
After 1.5 years - *Methanomicrobiales*

After 3 years?

FISH images on another digestate sample



Inoculum



Vegetable waste digestate

Conclusions – trace elements

- Selenium and cobalt are the key trace elements needed for the long-term stability of food waste digesters, but are likely to be lacking in the food waste
- The minimum concentrations recommended in food waste digesters for selenium, cobalt are around 0.16, 0.22 mg l^{-1} respectively, when running at a moderate organic loading rate
- A total selenium concentration greater than 1.5 mg l^{-1} is likely to be toxic to the microbial consortium in the digester
- Food waste is likely to have sufficient Al, B, Cu, Fe, Mn, and Zn. We are still not sure about Ni, Mo and W

Conclusions – digester operation

- Following proper trace element supplementation strategy, food waste digesters can be operated stably with low VFA concentrations at an organic loading rate of 5 kg VS m^{-3} d^{-1} with a volumetric biogas production of 3.8 STP m^3 m^{-3} d^{-1} and specific biogas production of 0.76 STP m^3 kg^{-1} VS

- Prevention of VFA accumulation in the digester by trace element supplementation is necessary, as recovery of a severely VFA-laden digester is not a rapid process even when supplements are added

Application of research finding

Acknowledgements

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Prof Charles Banks, Dr Sonia Heaven, Biogen-Greenfinch

…and to EU FP7 VALORGAS for continuing support to take this work forward