Is there a free lunch in food waste?
Est-il un repas gratuit dans les déchets des aliments?

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codigestion et valorisation du biométhane : quels leviers pour développer la filière ?
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Food waste is a big issue
Les déchets alimentaires est un gros problème

- Unavoidable = peelings, rotten
- Avoidable = surplus inventory, misshapes, sell-by
  - If there was less, more people could be fed
- Food waste in landfill = landfill gas
  - leakage = climate change
- Food waste is at least 70% moisture
  - Low net calorific value for incineration
  - More emission volume

- Inévitables = épluchures, pourrie
- Évitable = surplus d'inventaire, déformé, vendent par
  - Si il y avait moins, plus de personnes pourraient être nourries
- Les déchets alimentaires dans les décharges = gaz d'enfouissement
  - fuites = changement climatique
- Les déchets alimentaires est d'au moins 70% d'humidité
  - Faible valeur calorifique nette pour l'incinération
  - Plus de volume d'émission

Feeding pigs
l'alimentation des porcs

- Best environmental footprint but
- 2001 FMD attributed to undercooked swill
- Instead of tightening enforcement (sensors, interlocks, telemetry) Minister banned swill and EU followed suit
- We are where we are
- EC is looking at food waste to animal feed again

- Meilleur empreinte environnementale, mais
- 2001 fièvre aphteuse attribuée à des eaux grasses insuffisamment cuite
- Au lieu de resserrer l'application (capteurs, verrouillages, télémétrie) ministre interdits eaux grasses et l'UE ont emboîté
- Nous sommes là où nous sommes
- CE se penche sur les déchets alimentaires à l'alimentation animale à nouveau

AD
digestion anaérobique

- Sewage sludge AD for more than 100 years
  - 85% of UK sludge treated by AD
  - Best to harness this existing infrastructure and expertise
  - Co-digestion yields more biogas than separate digestion
  - Co-located with treatment for dewatering liquor
- Plethora of market distorting subsidies for biogas in the UK
  - Cheaper to AD than to "repurpose" to hungry people
  - Farm rents increased because AD maize
- Better to replace subsidies with a tax on emissions from fossil C

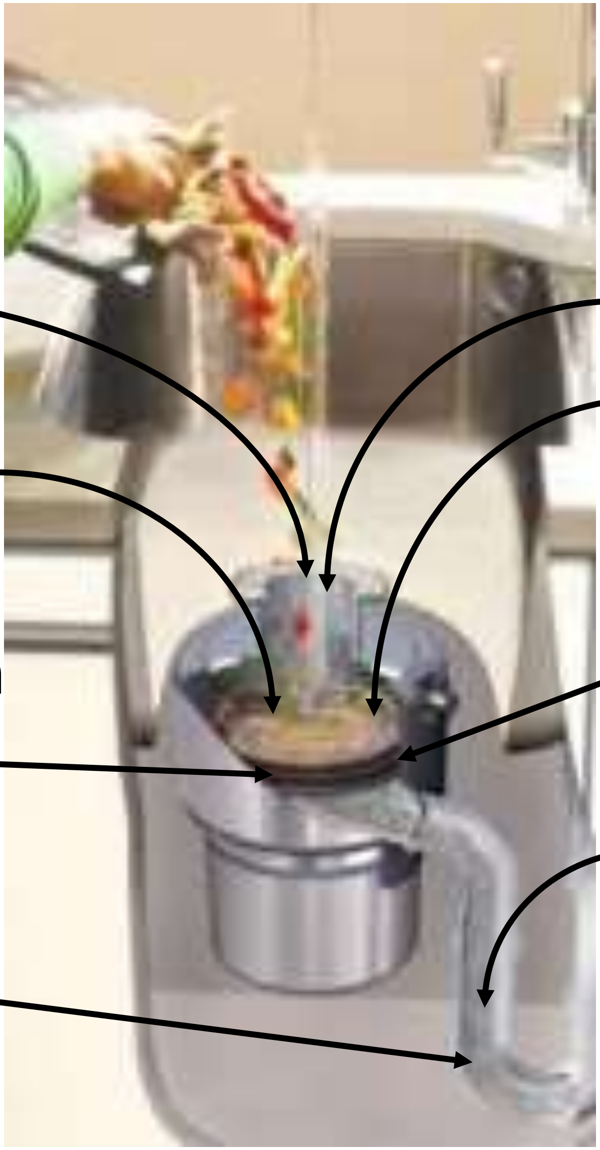
- Les boues d'épuration DA pour plus de 100 ans
  - 85% du Royaume-Uni boues traitées par DA
  - Le mieux est de tirer parti de cette infrastructure et l'expertise existante
  - Co-digestion donne plus de biogaz que la digestion séparée
  - Co-localisé avec le traitement pour l' eau de déshydratation
- Pléthore de distorsion du marché des subventions pour biogaz au Royaume-Uni
  - Moins cher à DA que de «Réutilisation» à des personnes souffrant de la faim
  - Fermages augmenté parce DA maïs
- Mieux vaut remplacer les subventions par une taxe sur les émissions de fossiles C

- Digested sludge used under Sludge Regulations
  - Willing seller : Willing buyer ☺
- Treated waste used under exemption (area ≤50ha)
  - Bureaucracy + Registration fee + Delay & no appeal ☹
- EoW = Digestate Quality Protocol (DQP) but sludge is a prohibited input for DQP
  ∴ co-digestate = waste ☹
- Industry builds new mono-digestion but
  - Quantity of food waste collected less than forecast – effect of Love Food Hate Waste?
  - Difficulty and cost of separating physical contaminants unresolved technology – can be 10% of receipts
  - Built and planned capacity > feedstock
  - Gate-fees falling
  - Some will fail financially

- Les boues digérées utilisé en vertu du Règlement de boues
  - Je vendeur: acheteur consentant ☺
- Déchets traités utilisée sous exemption (zone ≤50ha)
  - Bureaucratie + Frais d'inscription + Delay & sans appel ☹
- EOW = digestat Protocole de qualité (DQP) mais boues est une entrée interdite pour DQP
  - ∴ co-digestat = déchets ☹
- Industrie construit nouveau mono-digestion, mais
  - Quantité de déchets alimentaires recueilli moins que prévu - effet de l'amour alimentaire haine déchets?
  - Difficulté et le coût de la séparation des contaminants physiques technologie suspens - peuvent être de 10% des recettes
  - Construit et capacité prévue> matières premières
  - Frais de réception décroissants
  - Certains vont échouer financièrement

Food Waste to Sewer
Déchets alimentaires à l'égout

- Under sink food waste disposer (grinder) FWD
- Sink outlet
- Spinning plate with swinging lugs; no knives
- Grind chamber with perforated walls
- Small particles to drain



- Sous l'évier de déchets alimentaires (grinder) FWD
- Sortie évier
- Spinning plaque avec pattes battantes; pas de couteaux
- Chambre de broyage à parois perforées
- Les petites particules à de canalisation

Food Waste to Sewer
Déchets alimentaires à l'égout

- Under sink food waste grinder
  - Diverts food waste without physical contaminants to AD ☺
  - It has come down sewer so it is sewage and digestate is sludge ☺
  - Beijing, Boston, Goteborg, Milwaukee, Philadelphia, Shanghai, Stockholm, Tacoma are encouraging FWD
  - Evidence shows using FWD doesn’t block sewers, doesn’t increase load on treatment, does increase biogas, does have good public participation
  - some people do not want to hear the evidence

- Sous l'évier déchets alimentaires meuleuse (FWD)
  - Détourne les déchets alimentaires sans contaminants physiques à DA ☺
  - Il est venu dans les égouts de sorte qu'il est des eaux usées et des boues digestat est ☺
  - Pékin, Boston, Goteborg, Milwaukee, Philadelphie, Shanghai, Stockholm, Tacoma sont encourageants FWD
  - L'expérience montre en utilisant FWD ne bloque pas les égouts, ne pas augmenter la charge sur le traitement, ne augmente biogaz, fait avoir une bonne participation du public
  - certaines personnes ne veulent pas entendre la preuve

Are FWDs allowed?
FWDs sont permis?

- EN 12056-1:2000 *Gravity drainage systems inside buildings. General and performance requirements* allows for FWDs
- Most countries allow FWDs
- Austria, Belgium, France, Luxembourg, Netherlands, Poland and Portugal appear to ban FWDs but do not enforce their regulations and FWDs are sold in all these countries.
  – 100000 are used in NL and ban might be rescinded

- EN 12056-1: 2000 *Systèmes de drainage gravitaire à l'intérieur des bâtiments. Prescriptions générales et de performance* permet pour FWDs
- La plupart des pays permettent FWDs
- Autriche, Belgique, France, Luxembourg, Pays-Bas, la Pologne et le Portugal semblent interdire FWDs mais ne font pas respecter leurs règlements et FWDS sont vendus dans tous ces pays.
  – 100000 sont utilisés dans Pays-Bas et l'interdiction pourrait être annulée

We can design wonderful policies but will citizens participate?

Nous pouvons définir des politiques merveilleuses, mais les citoyens vont participer?

- Kerbside collection plateaus at less than 75% of people (Islington, London only 30%) and there is contamination with plastic, metal, glass, etc.
- FWD have high user satisfaction/participation
  - Nilsson et al. (1990) found 96% satisfaction (Sweden)
  - Karlberg & Norin (1999) 96% (Sweden)
  - NILIM (2005) 80% of people in trial would continue to use FWD (Japan)
  - UBA (2012) less that half the people in Germany use a biowaste bin
  - LGA (2014) >90% user satisfaction (Shrewsbury, UK)

- Plateaux de collecte en bordure de route à moins de 75% des personnes (Islington, Londres 30% seulement) et il ya une contamination avec du plastique, métal, verre, etc.
- FWD ont une grande satisfaction de l'utilisateur / participation
  - Nilsson et al. (1990) ont trouvé 96% de satisfaction (Suède)
  - Karlberg et Norin (1999) à 96% (Suède)
  - NILIM (2005) 80% des personnes en procès continuer à utiliser FWD (Japon)
  - UBA (2012) à moins que la moitié des gens en Allemagne utilisent un bac de biodéchets
  - LGA (2014)> satisfaction des utilisateurs de 90% (Shrewsbury, Royaume-Uni)

Unique case study - 0% to 50% FWD installation in 12 years
Étude de cas unique - 0% à 50% de l'installation FWD en 12 ans
Surahammar, Suède

- Haga wastewater treatment works
  - –primary, activated sludge, AD

- Haga travaux de traitement des eaux usées
  - –primaire, boues activées, DA

Unique case study - 0% to 50% FWD installation in 12 years
Étude de cas unique - 0% à 50% de l'installation FWD en 12 ans

- In 1997 Surahammar commune offered:
  - Home compost € 0
  - lease FWD for 8-years € 37/year
  - Biowaste collection € 285/year
- 1996 10,293 pop 0% FWD
- 2008 9,272 pop 50% FWD
- 4-weekly 24-h composite influent samples
  - Haga WwTW is conventional

- En 1997 Surahammar commune offert:
  - Accueil compost € 0
  - louer FWD pendant 8 ans 37 € / an
  - Collecte des biodéchets € 285 / an
- 1996 10293 pop 0% FWD
- 2008 9272 pop 50% FWD
- 4-hebdomadaires de 24 h échantillons composites influents
  - Haga WwTW est classique

Flow and load did not change but biogas increased 46% Écoulement et la charge ne changent pas? Mais biogaz ont augmenté de 46%

	Flow m^3/d	$kgBOD_7/d$	kgCOD/d	kgN/d	$kgNH_4/d$	kgP/d	$BOD_7:N$	m^3 biogas/d
Mean 0% FWD 120 weeks 11/01/95-30/04/97	4706	408	1084	113.6	74.0	18.0	3.50	331
Mean 50% FWD 120 weeks 13/12/06-01/04/09	4678	331	892	107	71	13.3	3.11	484
Difference (late post$_{120}$ - pre)	-0.59%	-19.0%	-17.7%	-6.1%	-3.9%	-26.1%	-11.1%	+46%
P (1-tail T-test)	0.50	0.06	0.09	0.18	0.28	0.002	0.11	0.01

- Karlberg & Norin found electricity to activated sludge did not change when 30% used FWD
- Karlberg et Norin trouvé l'électricité à boues activées n'a pas changé lorsque 30% utilisé FWD

- 46% more biogas when 50% use FWD
- 46% plus de biogaz lorsque 50% l'utilisation FWD

Lab estimates of loads exiting FWDs
Lab estimations de charges sortant FWDS

	COD	BOD	N_{tot}	NH_4-N	P_{tot}	SS
	g/cap.day					
Bolzonella et al. (2003) [1]	75		2.5		0.25	50
de Koning and van der Graaf (1996) [2]	76	52	1.6			48
de Koning (2004) [whole wastewater] [3]	95	66	2.1		0.3	60
NILIM (2005) [4]		11.3	0.73		0.11	8.2
Rosenwinkel and Wendler (2001) [5]	27	10.5	1.5		0.19	34
Thomas (2011) [6]	35.8	16.5		0.03	0.11	14.1
Tidåker et al. (2005) [5]	48	17.2	0.81	0.09	0.14	33.4
Wainberg et al (2000) [5]	52.6		1.0		0.2	19.0
mean	**58.5**	**28.9**	**1.5**	**0.1**	**0.2**	**33.3**
median	52.6	16.9	1.5	0.1	0.2	33.7
standard deviation	24.4	23.9	0.7	0.0	0.1	18.6

Footnotes

1. Cafeteria waste both food prep waste and plate waste and 2 different FWD
2. calculated from $C_{445}H_{736}O_{221}N_{27}S$
3. Additional loads of pollutants due to the use of FWD estimated from other studies [Nilsson et al. 1990, van Nieuwehuijzen 2002, de Koning 2003]
4. Based on an assumed 99g food waste /person.day, which was derived from FWD installed in 301 domestic properties and one hotel.
5. Averages of a summary of the literature and the authors' own laboratory data
6. Based on 142g food waste which was the average collected by each volunteer

Per capita load and biogas at Haga WwTW calculated from influent monitoring, literature values for FWD output and population data

La charge et biogaz à Haga WwTW calculées à partir de la surveillance de l'influent habitant, valeurs de la littérature pour la sortie de FWD et les données de la population

	BOD_7	COD	N	NH_4-N	P	Biogas	$Flow_{median}$
	kg/d	kg/d	kg/d	kg/d	kg/d	m^3/d	m^3/d
Mean pre FWD	408	1084	114	74	18	331	4020
Mean 50% FWD	331	892	107	71	13.3	484	3575
Using population data for Surahammar + Ramnäs (and +Virsbo for biogas) at the mid dates of monitoring periods							
	g/cap.d	g/cap.d	g/cap.d	g/cap.d	g/cap.d	L/cap.d	L/cap.d
Mean pre FWD	47.9	127.3	13.3	8.7	2.1	32.2	472
Mean 50% FWD	42.9	115.6	13.9	9.2	1.7	52.2	463
Literature mean input from FWD	14.45	29.25	0.75	0.05	0.1		
∴ expected if sewers were inert	62.4	156.5	14.1	8.7	2.2		
∴ in-sewer biotransformation	-19	-41	-0.2	0.5	-0.5		
	-31%	-26%	-2%	5%	-22%		

62% increase but only ½ pop using FWD

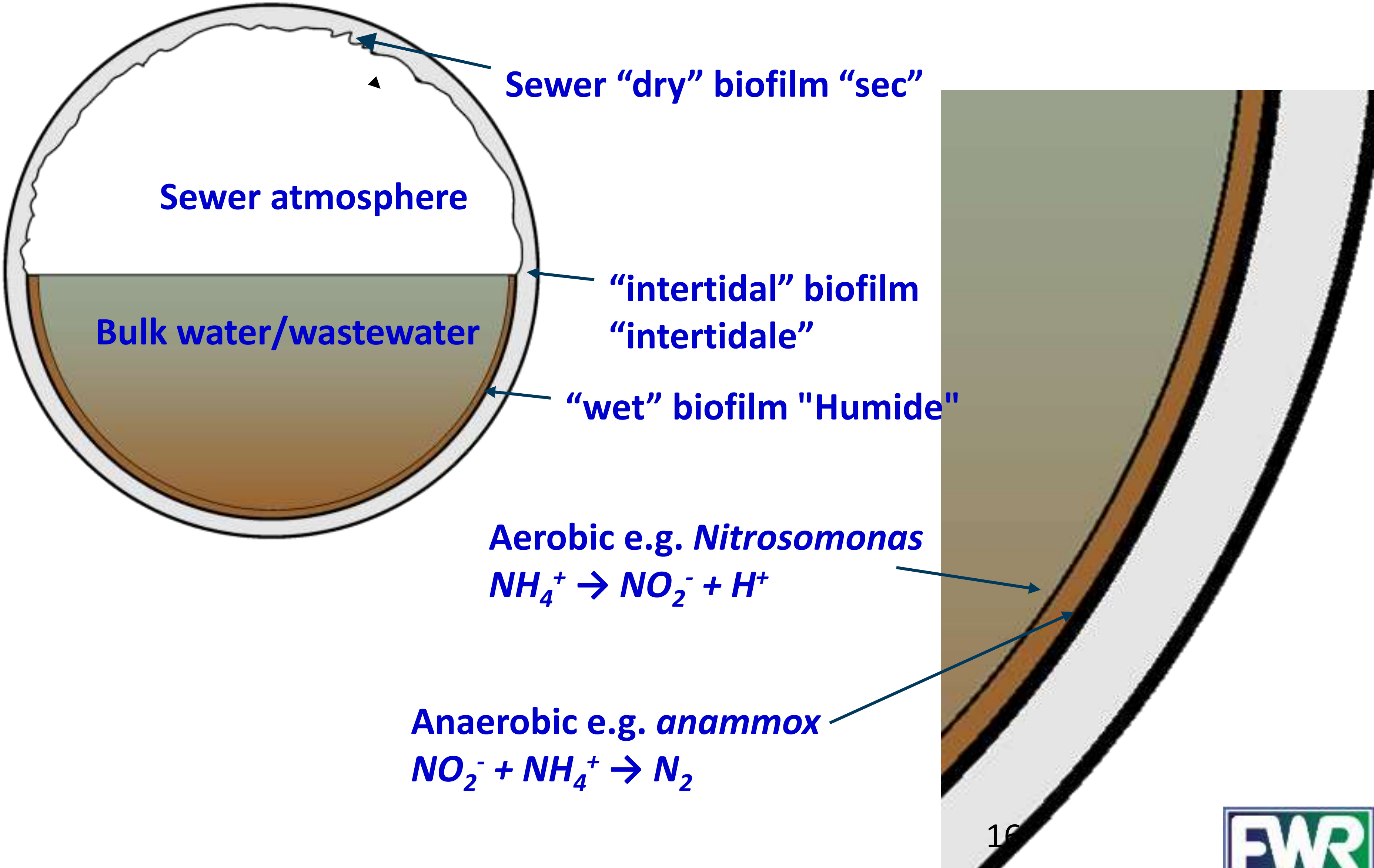
62% d'augmentation, mais seulement la population ½ utilisant FWD

Food waste is not deposited in sewers
Les déchets alimentaires ne se dépose pas dans les égouts

- Several video surveys of sewers – none found FWD effect deposits
- Mattsson et al. (2014) videoed 180 locations totalling 10 km of sewers
  - Scored sewer deposits by the WRc system
  - Sewer deposits and sewer condition not correlated with density of FWDs upstream
- 98% of FWD output <2mm (Kegebein et al., 2001)
- Specific Gravity of FWD output similar to or less than faecal solids so if sewer self-cleanses with faecal solids it will self-cleanse with FWD

- Plusieurs enquêtes vidéo d'égouts - aucune enquête a révélé des dépôts à effet de FWD
- Mattsson et al. (2014) filmé 180 sites totalisant 10 km des égouts
  - Dépôts d'égout marqués par le système WRc
  - Dépôts d'égout et de l'état d'égout pas corrélées avec la densité de FWDS amont
- 98% de FWD sortie <2 mm (Kegebein et al., 2001)
- Densité de la production de FWD similaire à ou moins que les solides fécaux si égouts auto-nettoie avec des solides fécaux il sera auto-nettoyer avec FWD

Sewers are both conveyance systems and ecosystems. Treatment starts in sewers
Égouts sont deux systèmes de transport et les écosystèmes. Le traitement commence dans les égouts



Conclusions

- Co-digesting food waste with sludge is environmentally sensible
  - **But** unlikely to be financially worthwhile because of market-distorting subsidies and regulations and because of competition for feedstock.
- The evidence shows WwTW can enjoy a free lunch from in- sink food waste diverters delivering ground food waste to sewers.
- Ground food waste relieves the carbon : nutrient restriction in “normal” domestic wastewater.
- FWDs do not impose additional flow or load on wastewater collection or treatment
- FWDs do not affect deposition in sewers adversely
- Sewers that self-cleanse with faecal solids will self-cleanse FWD output
- Choice makes it easier to do the right thing

- Déchets alimentaires co-digestion des boues est judicieux de l'environnement
  - Mais peu de chances d'être financièrement intéressant en raison des subventions et des règlements qui faussent le marché et en raison de la concurrence pour les matières premières.
- La preuve démontre WwTW peut profiter d'un repas gratuit du broyage des déchets alimentaires dans les égouts
- Déchets alimentaires broyé améliore l'équilibre du carbone: les éléments nutritifs dans les eaux usées domestiques "normal".
- FWDS ne pas imposer débit ou une charge supplémentaire sur la collecte ou traitement des eaux usées
- FWDS ne affectent négativement le dépôt dans les égouts
- Égouts que l'auto-nettoyer avec de solides fécaux sera sortie d'auto-nettoyage FWD
- Choix rend plus facile de faire la bonne chose

IS THERE A FREE LUNCH IN FOOD WASTE?

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Abstract

Food waste is a big issue. Some food waste might be avoidable (post-harvest waste, over-buying, expired sell-by dates, etc.) but some food waste is unavoidable (peelings, etc.). Landfilling is undesirable because of climate change emissions and leachate. The net calorific value of food waste is small because of the high moisture content so incineration is a poor option. Kerbside collection (for composting or anaerobic digestion) has the issues of participation rates, physical contaminants and competition between treatment facilities, which drives down gate fees perhaps to the point of non-viability. Using food waste as a free lunch for pigs (after proper cooking) has a good carbon footprint but it is largely forbidden in the EU. Under-sink food waste disposers (FWD) have high participation rates and improve the carbon to nutrients ratios in the wastewater and deliver contaminant-free biogas substrate to wastewater treatment works. The biogas yield per household using a FWD is approximately twice that per household without FWD. The data show the volume of wastewater does not increase and neither does the load because of the power of in-sewer bio-transformations. It is a free lunch for WwTWs (and it does not affect sewers adversely), which is the reason that advanced thinking cities in the USA and Europe are encouraging citizens to use their FWDs. The paper presents the data.

Keywords biofilms; biogas; CCTV; food waste; in-sewer-process; load; regulations; sewers; subsidies

Introduction

Food waste (both domestic and industrial) is a big issue. Some is unavoidable (peelings, etc.) but some is avoidable (surplus inventory, misshapes, etc.). If there was less avoidable food waste, more people could be fed, but there is the question of distribution. If food waste is dumped in landfill it generates climate changing landfill gas. It has low net calorific value because it is at least 70% moisture, so there is no benefit from incineration. Based on analysis by Quested and Johnson (2009) and the UK Office of National Statistics, each year local authorities in UK collect 233 kg food waste per household and it is mainly as residual waste.

Food waste collection for feeding to pigs was practised for centuries but was banned in the UK and then in the whole EU following an outbreak in 2001 of foot and mouth disease after the original infection had been attributed to infected meat that had not been cooked in the legally required manner. It might have been better to tighten enforcement of the cooking requirements, which would be easy with modern sensors and telemetry, but we are where we are. The European Commission is reassessing how more food waste could be used as animal feed safely.

Anaerobic digestion (AD) has been used to treat sewage sludge for around 100 years. The UK water industry treats about 85% of its sewage sludge by AD. Biogas from AD is renewable energy and as such its use qualifies for subsidies in many countries. In the UK there is now a plethora of incentives banded according to the feedstock. The subsidy for renewable energy from AD of sewage sludge is only one-quarter of the subsidy for energy from other AD. These market-distorting subsidies have led to it being financially advantageous to feed food nearing its use-by date to AD rather than to redistribute it to hungry people; they have also pushed up the price of agricultural land for growing crops to feed AD.

The objective of promoting renewable energy is to decarbonise; this might be accomplished better by taxing emissions from fossil carbon rather than the plethora of market-distorting subsidies with their unintended consequences. But again, we are where we are.

Objectively it would seem desirable to harness the existing AD and biosolids recycling infrastructure at wastewater treatment works (WwTWs) to treat food waste rather than build new infrastructure. The capacities of existing AD could be trebled by retrofitting thermal hydrolysis, which would more than satisfy the requirements of the Animal By-Products Regulations. WwTW also have the advantage that they are able to treat dewatering liquor so the digestate can be recycled as cake whereas most stand-alone food waste AD facilities have to recycle their digestate as liquid with more than 5-times the number of truck movements. However this logic is confounded by the subsidies and also by the regulations regarding land application.

In the UK, sewage sludge can be land applied under the Sludge (use in agriculture) Regulations (Anon, 1989 and DoE, 1996). The situation between the water company and farmer is "willing seller: willing buyer"; both parties are obliged to keep records but there is no registration bureaucracy or fees. Anything that comes down the sewers is sewage and the sludge derived from it is sewage sludge.

In the EU, food waste is categorised as "waste" and even after it has been treated it is still "waste" until it has satisfied some "end of waste" criteria. It is unlikely that there will be EU EoW criteria for biologically treated wastes because it has not been possible to find a compromise acceptable to all Member States. Regrettably, some "experts" regard sewage sludge prejudicially compared with other biologically treated wastes though the soil and plants do not make any distinction. The evidence does not support the prejudice (e.g. Evans and Smith, 2012). Some Member States have their own national EoW criteria. In France the Norm NF U44-051 embodies the EoW criteria. In the UK there is the Quality Protocol for Digestate but this does not permit sewage sludge as an input. Thus co-digesting sewage sludge with trucked in food waste takes it out of the Sludge Regulations and puts it in the waste management permitting regimen, which entails registering the land in parcels not exceeding 50 ha, paying a fee and waiting 6 weeks or more for authorisation.

Unsurprisingly, people build new infrastructure in the expectation of earning top rate subsidies and being able to recycle the digestate under the QP EoW exemption but it looks as if some sites will fail financially. There is downward pressure on gate fees for AD as sites compete to attract long-term contracts for feedstock. Analysts are saying that with the existing facilities and those that are in construction and planned, there is going to be excess capacity. The quantities of food waste collected are less than forecast because campaigns to reduce the amount of food waste are being successful and because householders are not participating as much as expected. An unresolved issue for the majority of domestic food waste, especially, is separation of physical contaminants before AD. If plastic film (whether biodegradable or not) is not removed it floats to the surface forming a mat that has to be removed from inside the digester. "Heavy" contaminants (glass, metal, grit) accumulate in the bottom of digesters and also have to be removed. Even after washing, physical contaminants can amount to 10% of the mass of waste taken into a site; it has to be disposed of to landfill or incinerated at substantial cost.

Co-digestion is still a good idea in principle (Evans et al., 2002 and CIWEM, 2011a) but it is inhibited in the EU by legislation (as discussed above) and in the UK it looks as if the water companies have missed the boat because so much mono-digestion has been built already (or planned), long-term contracts have been snapped up, gate-fees are falling and there would be the additional burden of working outside the sludge regulations.

Food Waste to Sewer

In sink food waste disposers (more correctly diverters) are means by which water companies can capture some of the food waste for AD without the burden of physical contaminants, competition from other AD sites or regulatory complications. Beijing, Boston, Goteborg, Milwaukee, Philadelphia, Shanghai, Stockholm, Tacoma and other cities are all realising this potential.

In theory FWDs appear not to be permitted in Austria, Belgium, France, Luxembourg, Netherlands, Poland or Portugal but in practice none of these countries enforces the regulation and indeed FWDs are sold in all these countries. The government in the Netherlands estimates 100000 FWDs are used in NL and it is considering rescinding the ban because exclusive reliance on kerbside collection and bio-bins has not proved to be effective at achieving food waste diversion from the residual waste.

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Environment Agency (UBA) In Germany reported that 56% of the population does not use bio-bins either because they are not provided or because the people choose not to use them (BMU & UBA, 2012).

The following section will explore the issues. CIWEM and Water UK hold very different positions but whereas CIWEM's is fully referenced (CIWEM, 2011b) Water UK has refused to debate [or even read] the science.

The food waste diverter (FWD) was invented in 1927 by architect John W. Hammes of Racine, Wisconsin, USA to be a convenience for his wife. After 11 years of development his company started manufacturing and selling FWD in 1938. Some cities in USA mandated FWD for all new build residential properties. FWD fit the standard drain outlet hole of kitchen sinks and there are adaptors for other sizes. A FWD comprises a 'grind chamber' which has perforated walls; the floor is a disc with lugs driven by an electric motor that spins the food scraps against the wall by centrifugal force. There are no knives in a FWD so it cannot cut plastic or fingers. FWDs operate with a stream of water (which could be the vegetable washing water); this conveys the ground food waste through the drains. Particles cannot escape the grind chamber until they are small enough to pass the outlet screen. The grind effectiveness does not deteriorate with time. When FWDs wear out it is because the bearings have failed: life is typically 12 years. FWDs are 95% recyclable at end of life (Insinkerator, private communication, 2010).

Field trials have found that user satisfaction with FWDs is high, e.g. Nilsson et al. (1990) found 96% satisfaction; Karlberg and Norin (1999) also reported 96% satisfaction in the trial before launching FWD as an option; NILIM (2005) found 80% of users would use FWD after their trial. A trial for the LGA in Shrewsbury, UK has also found very high user satisfaction (Philippa Roberts, Low & behold, private communication, 2014); this contrasts with kerbside collection that plateaus at less than 75% participation.

Today approximately 50% of households in the USA have a FWD; in some cities more than 90% have them. Atwater (1947) reported that initially sewerage engineers in the USA were apprehensive that the output of FWDs might their affect sewers and/or wastewater treatment adversely [just like Water UK] but after reviewing the experiences of about 300 municipalities he concluded their fears were unfounded. New Zealand and Australia also have high rates of installation at more than 30% and more than 20% respectively.

Surahammar in Sweden is an interesting case study because it has witnessed a rapid increase in FWD installation (from 0% to 50% of households in 12 years) and the wastewater is treated at a "conventional" WwTW that monitors the influent with 24-hour composite samples taken every fourth week.

In 1997, after a pilot study, Surahammar chose to offer its citizens differential charges for waste collection plus a bring system for cardboard, glass, metal and plastic (i.e. drop-off locations to which residents take these materials). The policy has been effective in that the tonnage of waste to landfill from the municipality decreased from 3600 tonnes/year in 1996 to 1400 tonnes/year in 2007.

Surahammars KommunalTeknik AB (SKT) operates the solid waste, water supply, wastewater, wood-fired electricity generation and district heating in Surahammar Kommune; it is a company wholly owned by the municipality. Householders who purchased, used and maintained their own authorised compost bins paid nothing for food waste collection because, in effect, they made no demand on SKT. The highest charge was for households that chose kerbside weekly collection (twice a week in hot weather) of source-segregated biodegradable municipal waste. The third option was an 8-year contract to lease a FWD from SKT. SKT installs the FWD and repairs any faults. After 8 years the FWD becomes the property of the householder, whose waste collection charge reverts to that of a home composter; alternatively the householder can have a new FWD and start another 8-year contract. The approximate annual costs to householders are leasing 37 euros and kerbside collection 285 euros. Unsurprisingly take-up of FWD leasing was rapid.

SKT says they have not had to put any additional water into supply, they have not had to do any additional sewer cleaning or maintenance, the H_2S has not changed and their rodent control contractor says there has been no impact on rats apart from ones associated with the occasional compost bin.

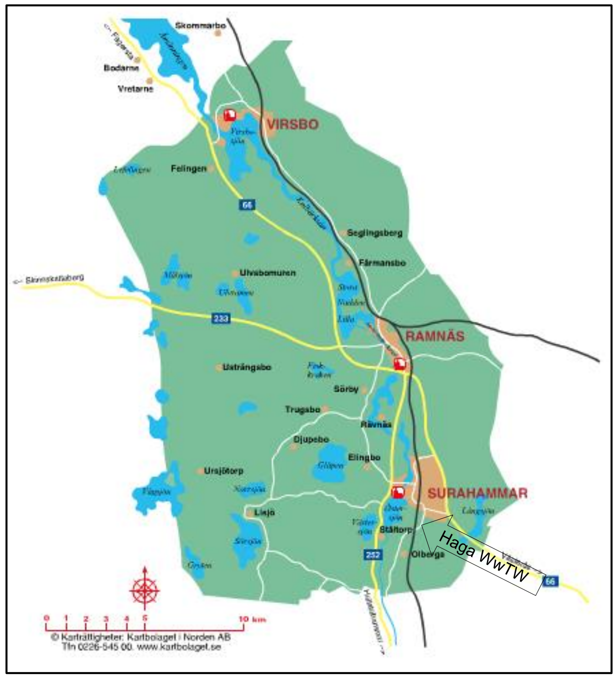

Figure 1 Map of Surahammar municipality and its "localities"

Surahammar Municipality comprises three "localities" (urban areas with more than 200 inhabitants) totalling about 9000-10000 people plus smaller settlements totalling about 800 people (Figure 1 and Table 1). Haga WwTW is just south of Surahammar. Ramnäs' sewer network is connected to the Surahammar sewer network by a rising main. Virsbo has its own WwTW and only its sludge is tankered to Haga WwTW.

Haga WwTW has a "conventional design" comprising preliminary screening (3mm), grit settlement, primary clarification, diffused air activated sludge, chemical precipitation of phosphorus and mesophilic anaerobic digestion. Sanitary sewers are laid at a gradient of 0.004 to 0.005. Surface water sewers are separate but with interconnections for times of surcharge. Aeration of the activated sludge is controlled by dissolved oxygen probes. The discharge consent is 15 $mgBOD_7/L$ and 0.5 mgP/L; there is no nitrogen limit. The digested sludge is composted/dried/phytoconditioned with miscanthus grass after thickening in former drying beds. The resultant soil-like biosolids are trucked to a local topsoil manufacturer. The analytical suite comprised BOD_7, COD, N_{tot}, NH_4-N and P but not suspended solids. Haga measures biogas production but does not quantify its digested sludge production. Haulage off site to soil manufacture in Vasteras is sporadic so unrelated to digestate production. Since food waste is more than 70% moisture and 90% volatile solids and since it undergoes 90% volatile solids reduction in digestion, the contribution to digested sludge production would only be about 50 kgDS per tonne food waste. All analyses were performed using Swedish Standards Institute methods.

Census data (Table 1) show that the population has been declining gradually since 1990. The waste management initiative that included home composting, kerbside collection or FWD for food waste started in May 1997.

Table 1 Population data published for Surahammar and interpolations for the mid-dates of the statistically analysed WwTW loads

Name	Status	Census data 31/12/1990	31/12/1995	31/12/2000	31/12/2005	31/12/2010	Interpolated 06/03/1996	06/02/2008
Surahammar	Municipality	11,381	11,107	10,340	10,196	9,949	11,079	10,092
Ramnäs	Locality	1,585	1,622	1,552	1,489	1,465	1619	1479
Surahammar	Locality	7,083	6,919	6,350	6,276	6,179	6898	6235
Virsbo	Locality	1,905	1,782	1,629	1,587	1,517	1776	1558
Total of localities		10,573	10,323	9,531	9,352	9,161	10,293	9,272
difference from Municipality		808	784	809	844	788	786	820
Surahammar + Ramnäs							8,517	7,714

Source: http://www.citypopulation.de/php/sweden-vastmanland.php
"localities" are defined as urban areas with 200 inhabitants or more

Evans et al. (2010) compared the influent monitoring data from Haga (24 hour composite samples taken 4 weekly) collected before FWD installation (11/01/95 to 30/04/97, 120 weeks) with 120 weeks when approximately 50% of households were using FWD (13/12/06 to 01/04/09) shown in Table 2. The mid dates of these two periods are 06/03/96 and 06/02/08 respectively. Table 1 shows the populations at these mid dates estimated by interpolating from the census data.

Table 2 Statistical summary of the influent flow and load and the biogas data at Haga WwTW from 11th January 1995 to 30th April 1997 compared with 13th December 2006 to 1st April 2009 (from Evans et al. 2010)

	Flow m^3/d	$kgBOD_7/d$	kgCOD/d	kgN/d	$kgNH_4/d$	kgP/d	BOD_7:N	m^3 biogas/d
Mean 0% FWD 120 weeks 11/01/95-30/04/97	4706	408	1084	113.6	74.0	18.0	3.50	331
Variance	3034123	46620	394192	979	405	49.9	1.695	1036
Mean 50% FWD 120 weeks 13/12/06-01/04/09	4678	331	892	107	71	13.3	3.11	484
Variance	5675190	17138	167426	548	282	12.7	1.191	3147
Difference (late $post_{120}$ - pre)	-0.59%	-19.0%	-17.7%	-6.1%	-3.9%	-26.1%	-11.1%	+46%
P (1-tail T-test)	0.50	0.06	0.09	0.18	0.28	**0.002**	0.11	**0.01**

Table 3 summarises the published *de novo* estimates (i.e. from original measurements) of the *per capita* contributions from FWDs into wastewater collection systems.

Table 3 Published estimates of the contributions made by FWD to wastewater composition based on laboratory studies (from Evans et al., 2013)

	COD	BOD	N_{tot}	NH_4-N	P_{tot}	SS
	g/cap.day					
Bolzonella et al. (2003) [1]	75		2.5		0.25	50
de Koning and van der Graaf (1996) [2]	76	52	1.6			48
de Koning (2004) [whole wastewater] [3]	95	66	2.1		0.3	60
NILIM (2005) [4]		11.3	0.73		0.11	8.2
Rosenwinkel and Wendler (2001) [5]	27	10.5	1.5		0.19	34
Thomas (2011) [6]	35.8	16.5		0.03	0.11	14.1
Tidåker et al. (2005) [5]	48	17.2	0.81	0.09	0.14	33.4
Wainberg et al (2000) [5]	52.6		1.0		0.2	19.0
mean	58.5	28.9	1.5	0.1	0.2	33.3
median	52.6	16.9	1.5	0.1	0.2	33.7
standard deviation	24.4	23.9	0.7	0.0	0.1	18.6

Footnotes

1. Cafeteria waste both food prep waste and plate waste and 2 different FWD
2. calculated from $C_{445}H_{736}O_{221}N_{27}S$
3. Additional loads of pollutants due to the use of FWD estimated from other studies [Nilsson et al. 1990, van Nieuwehuijzen 2002, de Koning 2003]
4. Based on an assumed 99g food waste /person.day, which was derived from FWD installed in 301 domestic properties and one hotel.
5. Averages of a summary of the literature and the authors' own laboratory data
6. Based on 142g food waste which was the average collected by each volunteer

Table 4 shows the influent *per capita* loads calculated from Table 2 and the populations interpolated from the census data to the mid-dates of the period before FWDs were installed to the period when 50% of households used FWDs (Table 1). In the cases of BOD, COD, total Kjeldahl nitrogen, ammoniacal nitrogen and phosphorus, the populations of Surahammar plus Ramnäs were used because this is the catchment sewered directly to Haga. In the case of biogas, the population of Virsbo was also included because the sludge from its WwTW is tankered to Haga for digestion. The median flow has been used rather than the mean flow because median flow takes out anomalously high readings associated with extreme weather (rain and snow melt).

Table 4 *Per capita* load and biogas at Haga WwTW calculated from influent monitoring, literature values for FWD output and population data

	BOD_7	COD	N	NH_4-N	P	Biogas	$Flow_{median}$
	kg/d	kg/d	kg/d	kg/d	kg/d	m^3/d	m^3/d
Mean pre FWD	408	1084	114	74	18	331	4020
Mean 50% FWD	331	892	107	71	13.3	484	3575
Using population data for Surahammar + Ramnäs (and +Virsbo for biogas) at the mid dates of monitoring periods							
	g/cap.d	g/cap.d	g/cap.d	g/cap.d	g/cap.d	L/cap.d	L/cap.d
Mean pre FWD	47.9	127.3	13.3	8.7	2.1	32.2	472
Mean 50% FWD	42.9	115.6	13.9	9.2	1.7	52.2	463
Expected mean input from FWD	14.45	29.25	0.75	0.05	0.1		
Expected if sewers were inert	62.4	156.5	14.1	8.7	2.2		
Therefore in-sewer biotransformation	-19	-41	-0.2	0.5	-0.5		
	-31%	-26%	-2%	5%	-22%		

It is reasonable to assume for Surahammar that the *per capita* inputs in the pre-FWD period in Table 4 are representative of the baseline non-FWD contribution to the influent composition at Haga; there is no reason to suppose they changed between 1996 and 2008. If there were no bio-transformations in the sewers, the load in the influent when 50% of households were using FWD should be approximately the baseline load plus the contributions from the FWDs allowing for the fact that only half the contributing population were using FWDs (half of the mean contributions in Table 3). Table 4 shows that the *per capita* loads of BOD, COD and P monitored at Haga were less when 50% of households used FWDs than during the baseline period. However, the *per capita* biogas production (for Surahammar plus Ramnäs plus Virsbo) increased from 32 to 52 litres/capita.day, which is a 62% increase across the whole population.

Even after allowing for the decrease in population, there is the same apparently anomalous conclusion as Evans et al. (2010) that whilst BOD and COD did not increase, biogas substrate from the FWDs must have been getting through to Haga WwTW because mean daily biogas increased by 46%. It appears that biogas substrate (i.e. primary sludge) increased but secondary sludge (activated sludge from treating BOD) did not increase. The absence of impact on secondary treatment was also observed by Karlberg and Norin (1999) who reported that electricity use by the activated sludge plant had not increased between 0% FWD and 30% FWD.

Extensive CCTV surveying of the sewers confirmed that there has been no significant increase of deposition in the sewers of sediment or FOG (Mattsson et al. 2014) indeed had so much food waste been lying in the sewers, they would have blocked long ago. Mattsson et al. (2014) surveyed 180 locations, totalling more than 10 km of sewers, in the Surahammar catchment and found no correlation between deposits and sewer condition and the intensity of FWD installation upstream of the surveyed reach. The specific gravity of particles output from FWDs and their settling velocities are similar to or less than faecal solids (Kegebein et al., 2001) so sewers designed to self-cleanse when conveying faecal solids will also self-cleanse when conveying FWD output.

The unavoidable conclusion is that BOD_7, COD and probably phosphorus have been bio-transformed during the transit time from the households to the WwTW. Raunkjaer et al. (1995) measured removal of easily degradable organic matter as wastewater flowed through gravity sewers but found that particulate organic matter was not affected. They found that the dissolved oxygen was recharged from the headspace air rapidly after emerging from a surcharged section to a gravity section. Tendaj et al. (2008) cited Cedergren (2007) as showing (with respect to the output of FWD) that it is mostly the organic material that is already in dissolved form that decomposes during transportation in the sewerage system, whereas the particulate portion does not decompose.

Sewer walls are coated with biofilms. These are complex, layered microbial ecosystems. DNA profiling has shown that the species composition within biofilms varies from place to place in sewers and responds to the composition of the wastewater flowing past them. Aerobic organisms inhabit the surface of a biofilm adjacent to aerobic wastewater; the oxygen gradient in biofilms is such that adjacent to the walls the organisms might be anaerobic. Some of the dissolved organic matter will have been converted to CO_2 and some will have been converted into biofilm-biomass[1]. Some of the biofilm sloughs off when it gets too thick to resist the shear forces of passing wastewater and also dead cells slough off; i.e. similar to humus sludge sloughing off filter media. The biomass will incorporate phosphate. Sloughed off biomass will add to the suspended solids and thus the primary sludge.

Conclusions

1. Co-digestion of trucked in food waste with sewage sludge is environmentally sensible but it is unlikely to be financially worthwhile because of market-distorting subsidies and regulations and because of competition for feedstock.
2. The evidence shows that wastewater operators can enjoy a free lunch from in-sink food waste diverters delivering ground food waste to sewers.
3. The ground food waste relieves the carbon : nutrient restriction in "normal" domestic wastewater.
4. FWDs do not impose additional flow or load on wastewater collection or treatment (at least not up to 50% installation and there is no reason to suppose this is a limit).
5. FWDs do not affect deposition in sewers adversely; sewers that self-cleanse with faecal solids will self-cleanse when ground food waste is added.

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