The Value of Sludge

from waste to energy to resource

Arjen van Nieuwenhuijzen

Juni 2019

Content

- Introduction
- Some history
- The value opportunities
- Focus on energy and resources
- The future pathway

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CTO Renewable Energy, Water, Resources

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Amsterdam Institute for Advanced Metropolitan Solutions

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AMS Institute was established in 2014 as an ambitious scientific institute located in Amsterdam. In this institute science, education, government, business partners and social organizations are working tightly together to create solutions for the complex challenges a metropole like Amsterdam is facing. Now and in the future.

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The sludge history

1920th Waste water treatment with activated sludge process upcoming; Agro application of sludge

1950th Activated sludge processes create large amounts of waste sludge; land filled, Agro applications

1970th Increasing concerns about (trace) pollutants in sludge; overloading landfilling; manure overload

1975th Increasing applications of waste sludge reduction processes – digestion, improved digestion, ZimPro

1980th Full focus on digestion for waste minimisation and biogas production

1985th Improvement technologies being studied and developed

1990th More and more Waste2Power applications

2000th Energy Factory Ideas based on Sustainability Goals

2010th Energy an Resource Factories for Circular Economy

The sludge history

The sludge history

stora

postbus 80200, 2508 GE den haag 070-512710 stichting toegepast onderzoek reiniging afvalwater

1985-02_optimalisatie-gistingsgasproduktie

Optimalisatie van de gistingsgasproduktie

STOWA
Stichting Toegepast Onderzoek Waterbeheer
Postbus 8090
3503 RB Utrecht
tel. 030-321199
fax 030-321766

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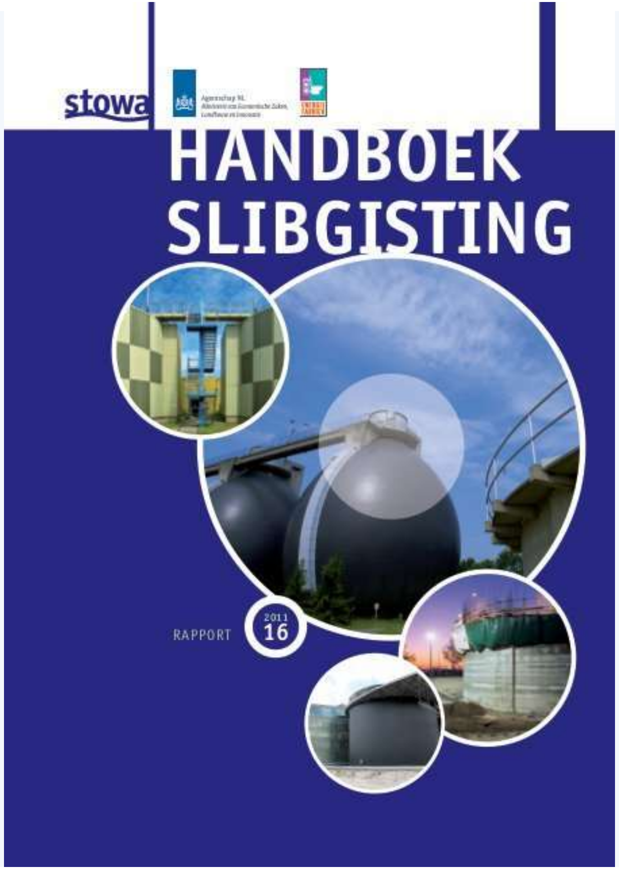


The value of sludge

Waste

Energy

- Organic matter conversion to biogas: electricity and heat, of green gas production
- Organic matter incineration: electricity and heat

Resource materials

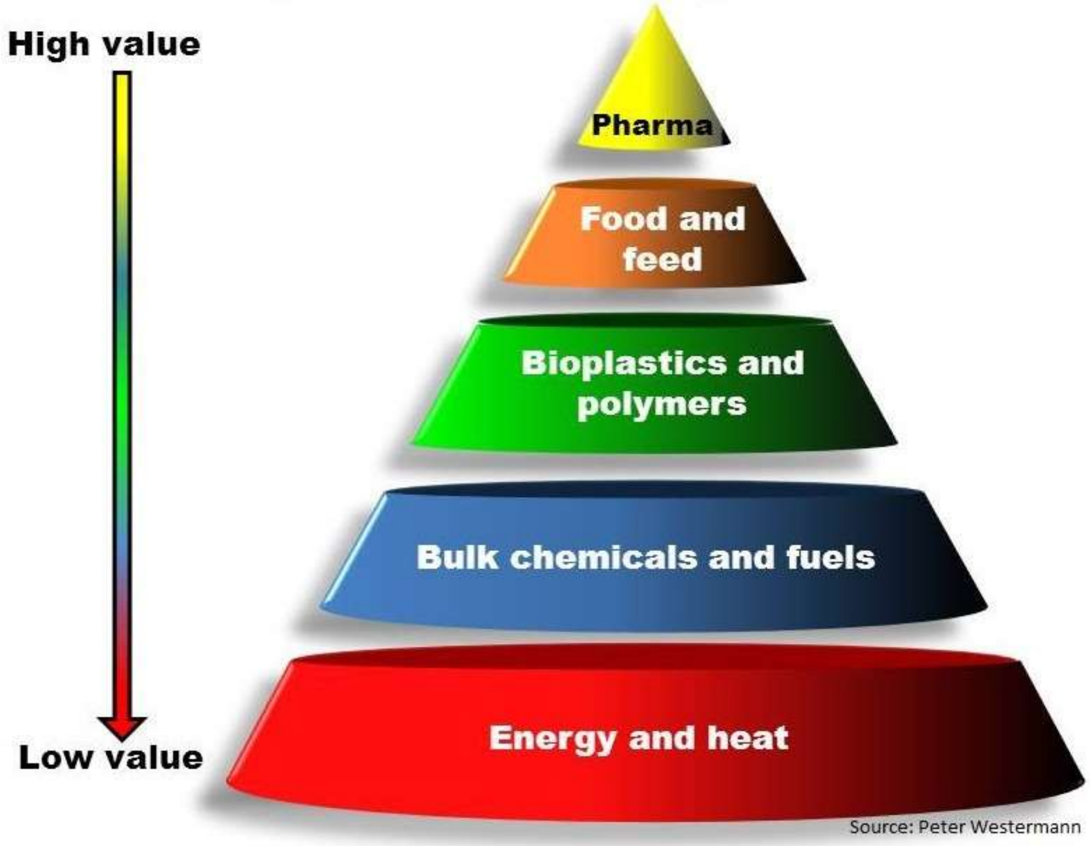
- Organic matter (soil improvement and compost, fatty acids, bio-flocculant, bioplastics),
- Phosphorous (fertilizer), nitrogen (fertilizer),
- Cellulose, lignin (bio-composite)
- Proteins (potential feed stock), (trace) metals,

The value of sludge

Waste

Energy

Resource materials



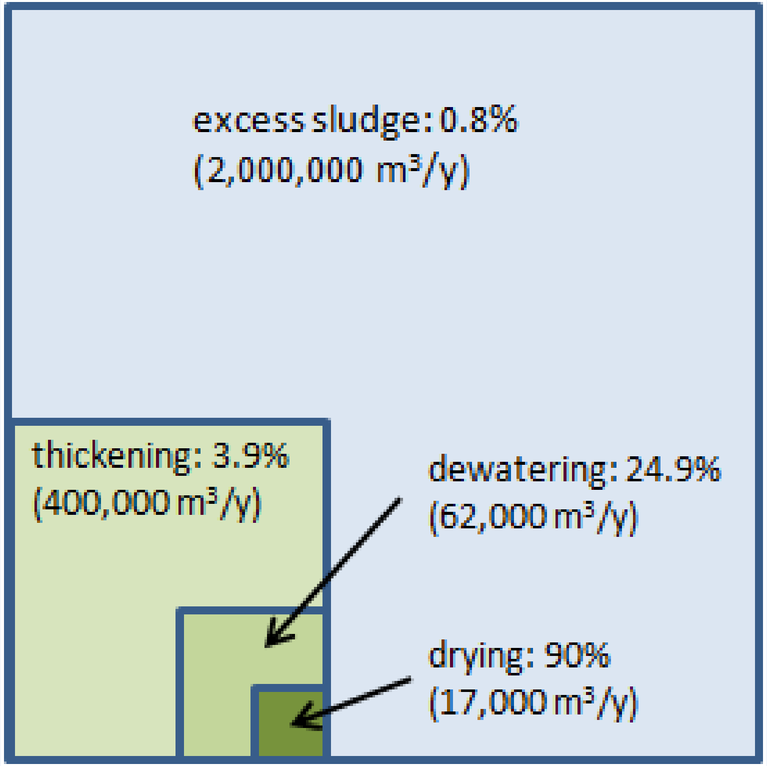
Sludge as a waste

Primary goal of sludge treatment:

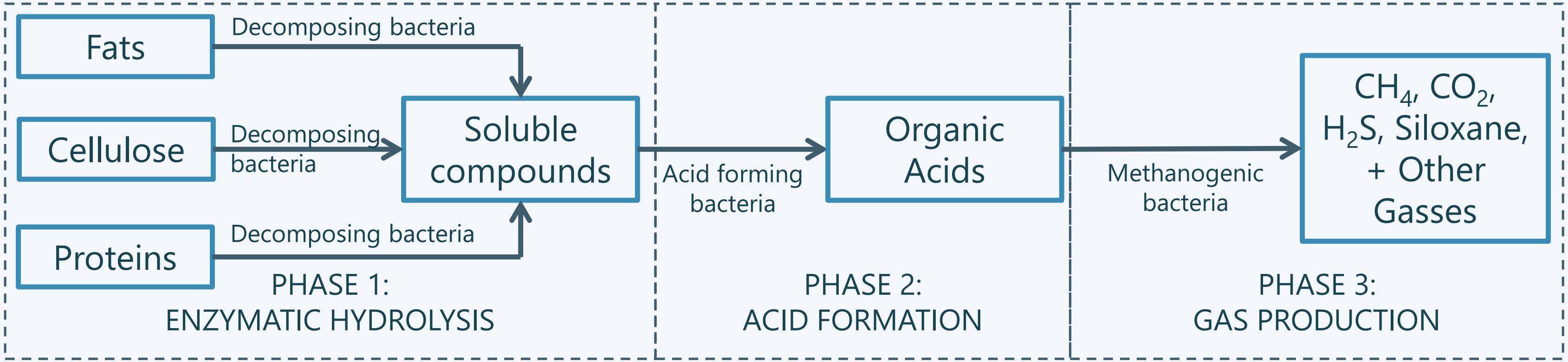
- Decrease of final waste production due organic waste conversion;
- Decrease water content for further handling;
- Sludge stabilisation to prevent uncontrolled decomposing;
- Odour and pathogen reduction for a more hygienic product;
- Generation of power (and heat).

Cost reduction for sludge disposal:

- Mostly reduced by decreasing volume of sludge;
- Reduced amount and volume lowers transportation costs;
- Disposal options reduced by controls on land filling and agricultural use.

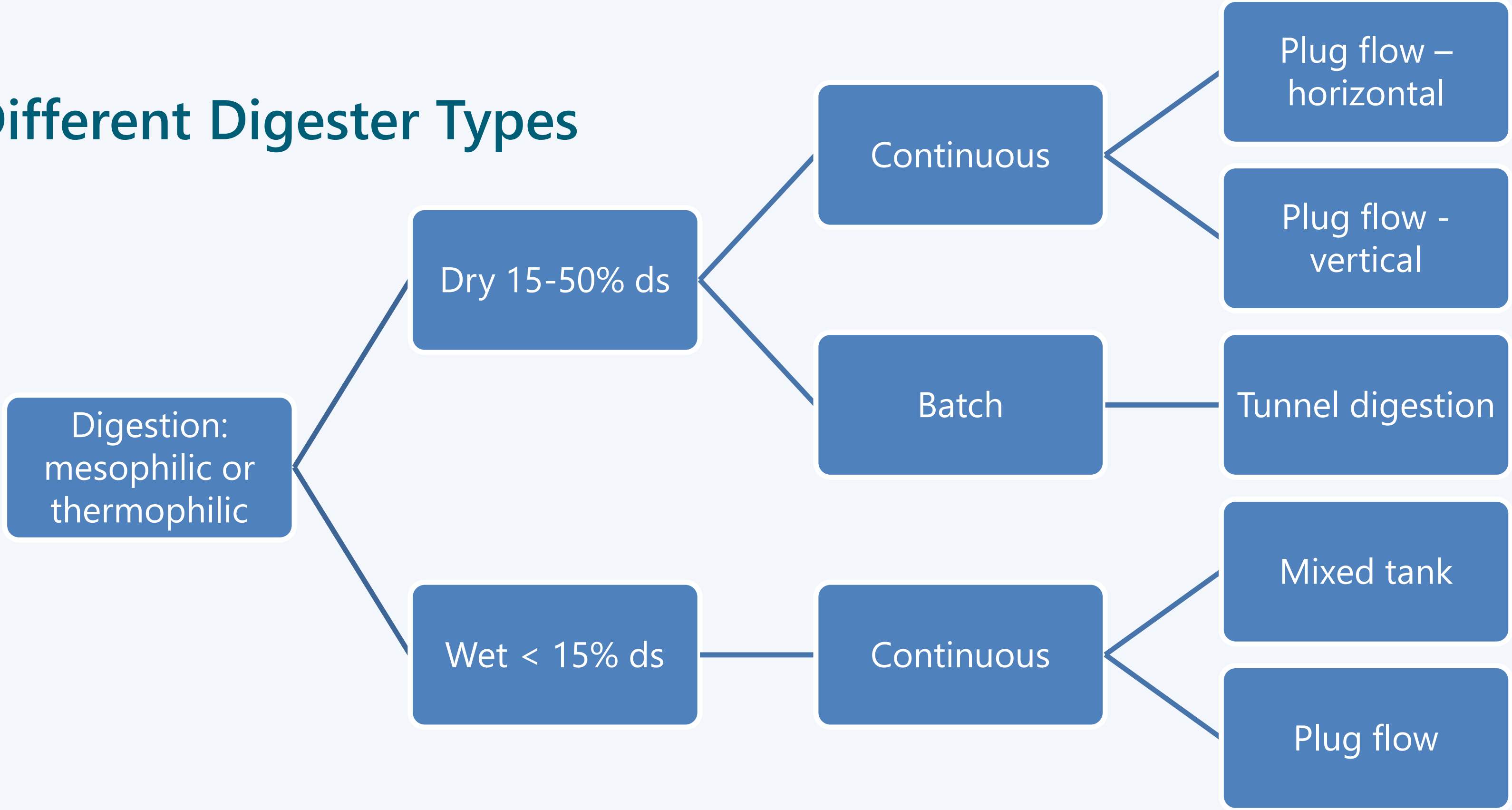


Principle of Digestion



- Phase 1: Bacteria turns larger organic polymers molecules to smaller monomers;
- Phase 2: Acidification creates acetic acid, hydrogen and carbon dioxide. Oxygen is used up and creates anaerobic conditions;
- Phase 3: Methanogenic bacteria ferment acetic acid to form CH_4 and CO_2 in anaerobic conditions. Temperature of the digester affects which methanogenic bacteria form (Mesophilic or Thermophilic).

Different Digester Types



Choice of Digestion Process

- Affects the organic solids degradation and methane generation phase of digestion;
- Mesophilic digestion: 30 – 40 °C, retention time of 20 – 25 days. Stable, but old and inefficient technology;
- Thermophilic digestion: 45 – 55 °C, retention time of 10 – 15 days. Requires more control but greater biogas yield;
- Advanced / assisted digestion: Thermal Pressure Hydrolysis / Chemical Thermal: Pre-treat sludge at high temperature (160°C) and high pressure (6-10 bars), up to 40% more degradation of secondary sludge and biogas.
- Plug flow versus mixed: up to 20 % higher degradation and biogas. Requires more control but greater biogas yield
- Enzymatic enhancement: up to 25 % higher degradation and biogas. Requires more control but greater biogas yield

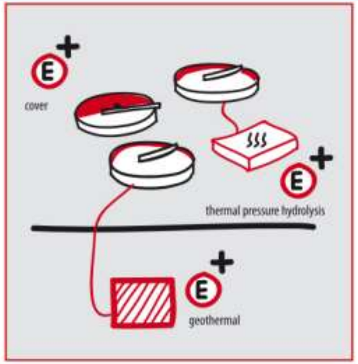
Reference Project - Amsterdam

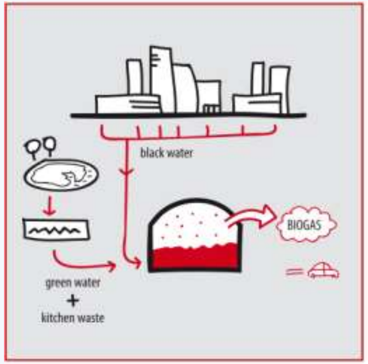
Witteveen + Bos 2005

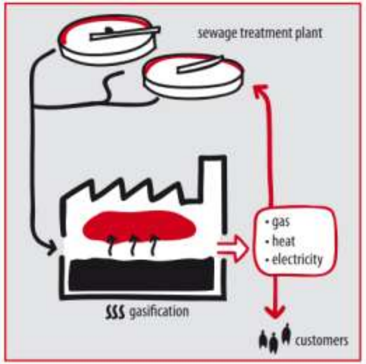
Energy Factory WWTP Amsterdam-West and AEB Amsterdam

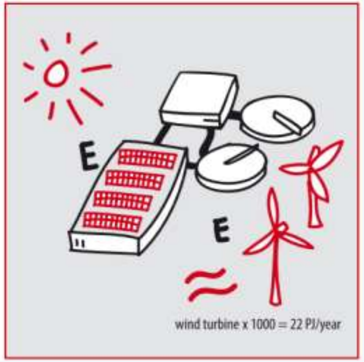
Sludge Waste Electricity Heat

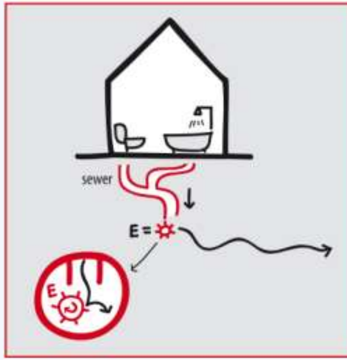
Energy Saving and Recovery











Energy Saving and Recovery – 13-14 Energy Factories

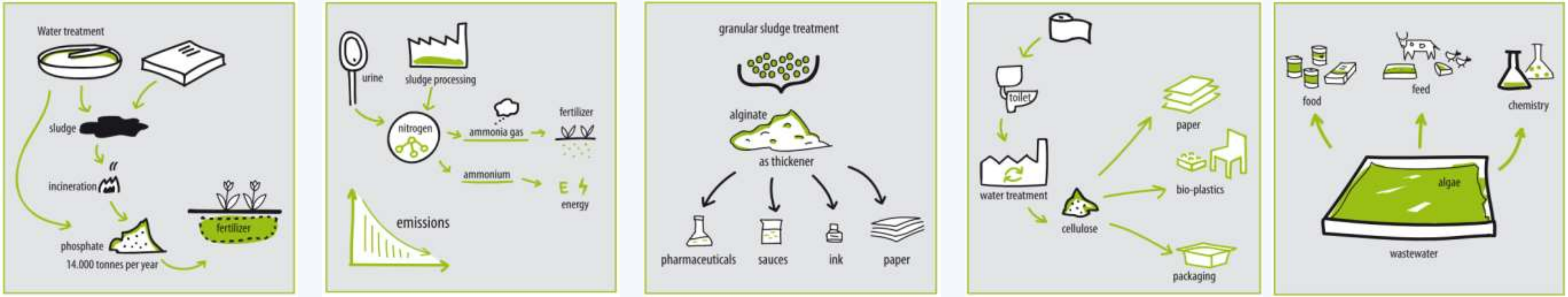
Energy and Resources Factory Apeldoorn

Energy and Resources Factory Tilburg

Energy Factory Hengelo

The future will be different:

From waste water and sludge treatment towards Resource Recovery
(water, P, N, bio fertilizer, cellulose, bioplastics, fatty acids, bio flocculants, …)



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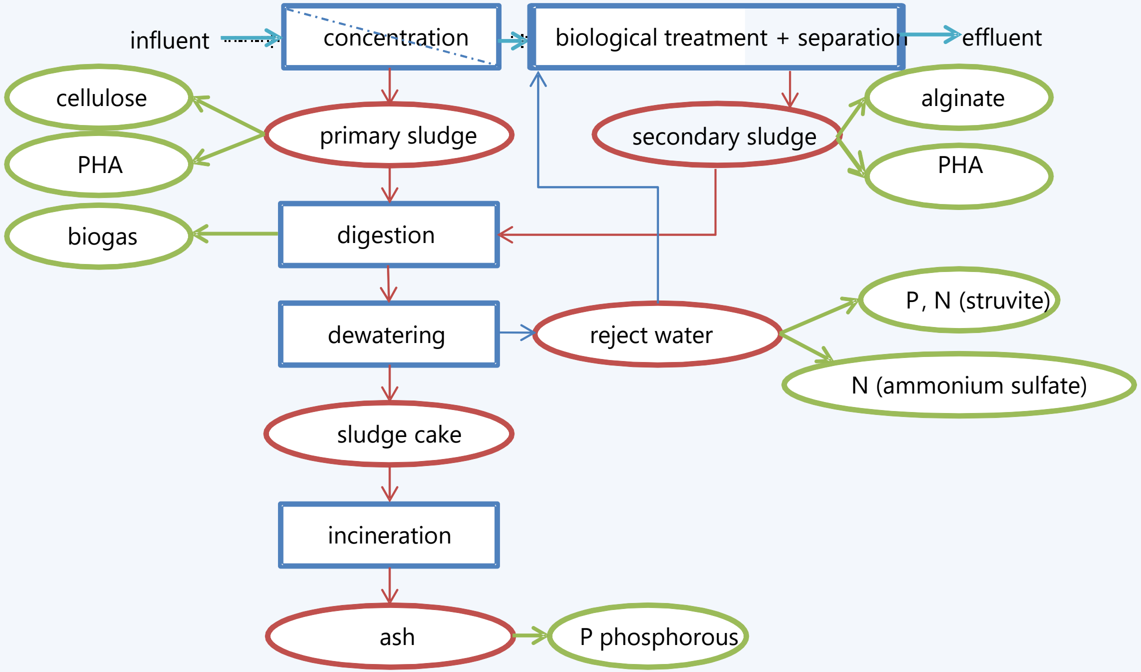
Resource Recovery (P, N, cellulose, bioplastics, fatty acids …)

Integrated Waste Plant AEB Amsterdam

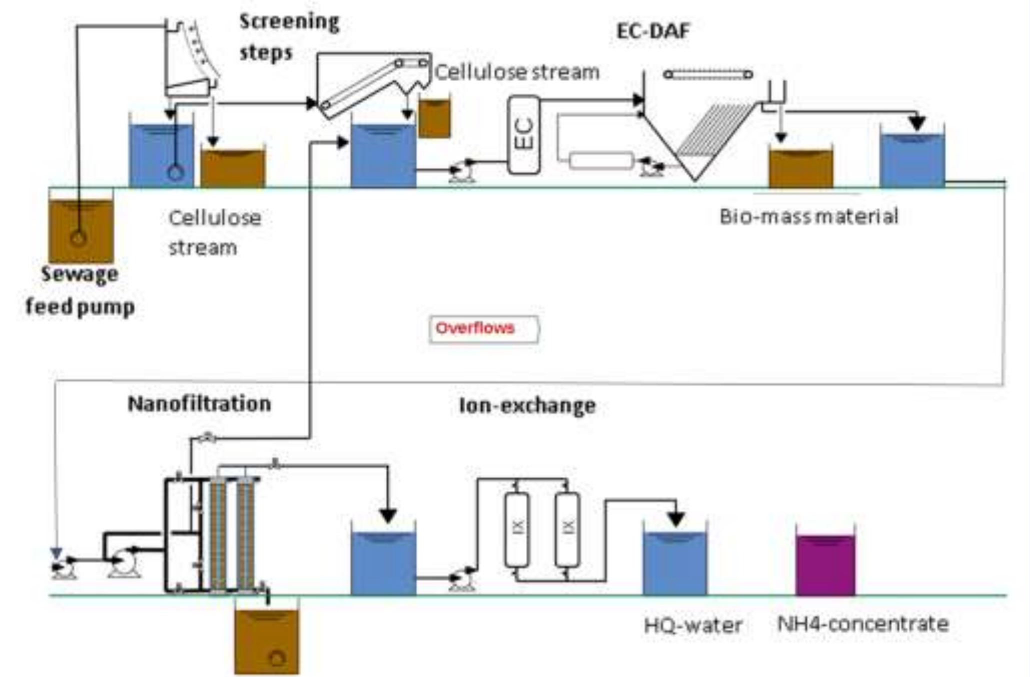
Plastic recycling Facility Twence

Phosphorous (Struvite) Recovery Plants Amsterdam, Apeldoorn, Tilburg

Potential resources recovery versus sustainability



Resource Water Refinery Factory® Wilp concept



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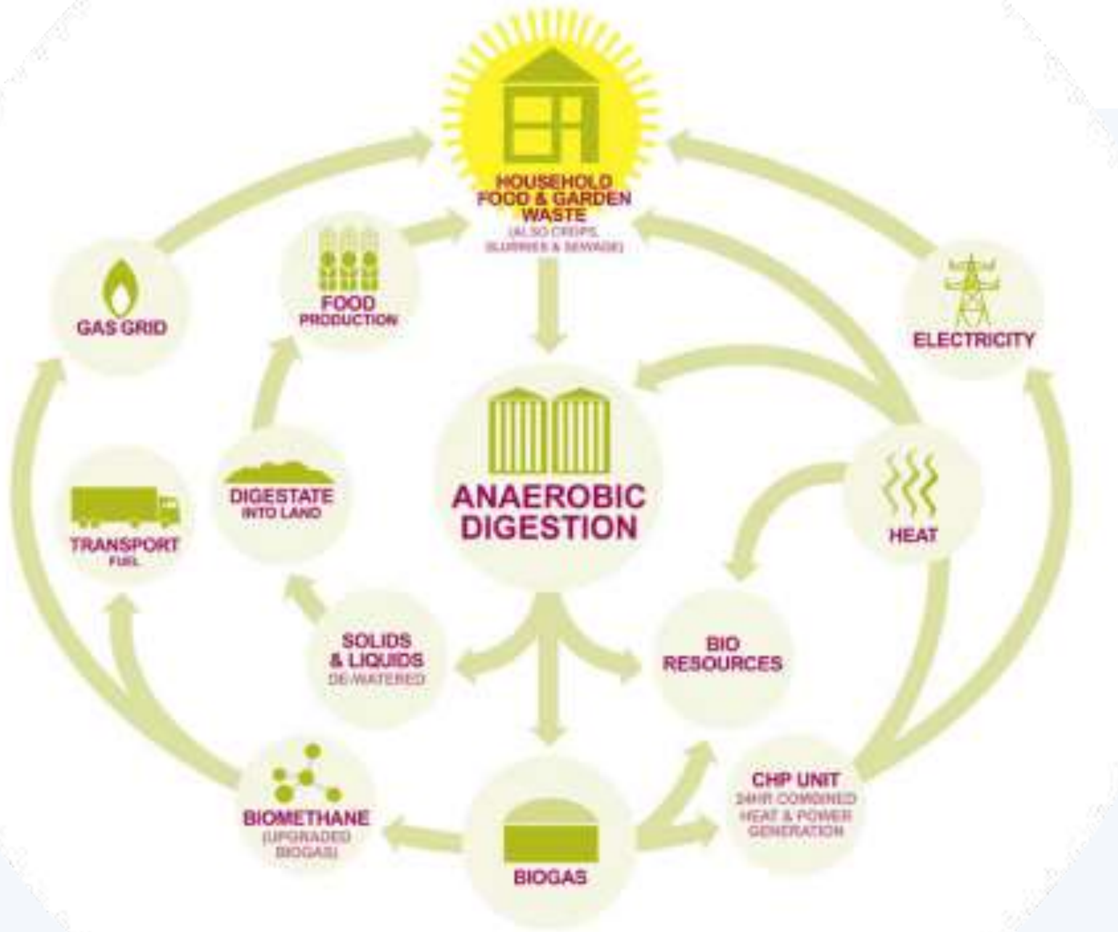
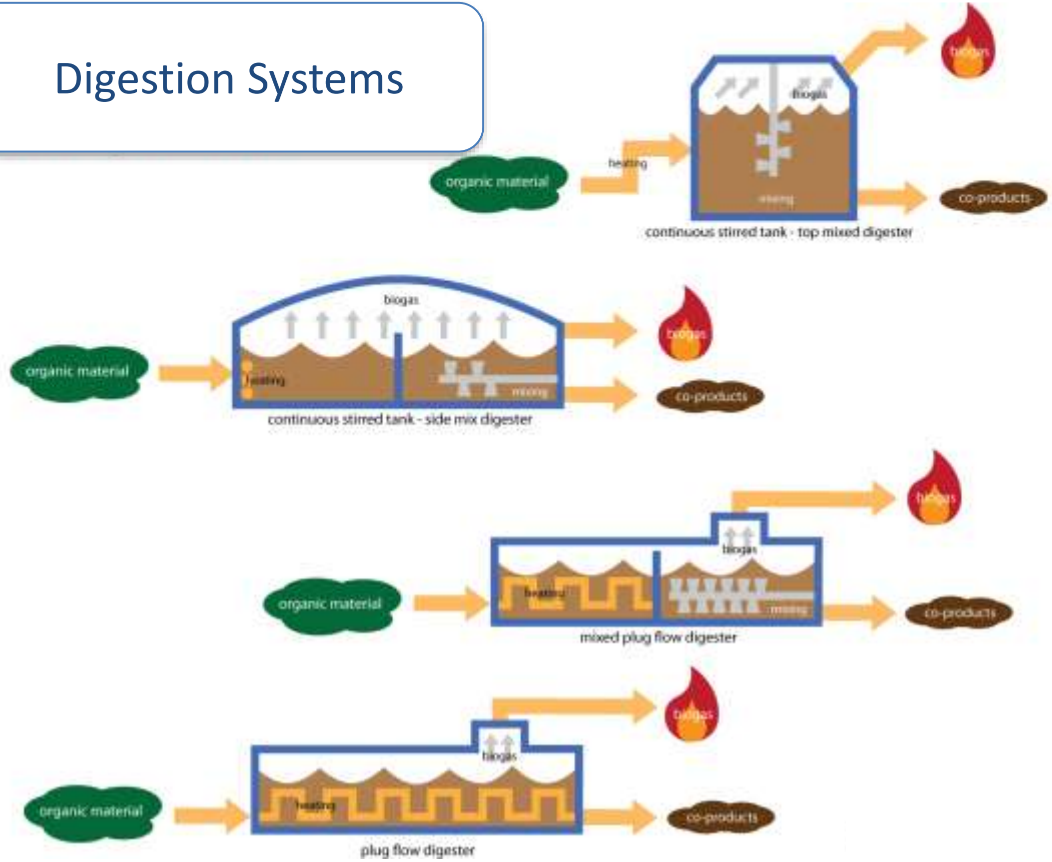
Digestion


HOUSEHOLD FOOD & GARDEN WASTE
(ALSO CROPS, SLURRIES & SEWAGE)
FOOD PRODUCTION
GAS GRID
ELECTRICITY
ANAEROBIC DIGESTION
DIGESTATE INTO LAND
TRANSPORT FUEL
HEAT
SOLIDS & LIQUIDS DE-WATERED
BIO RESOURCES
BIOMETHANE (UPGRADED BIOGAS)
BIOGAS
CHP UNIT
24HR COMBINED HEAT & POWER GENERATION

Digestion Systems



Selection of Digestion Process – Data Collection

- Collection of data from available streams
- Categorisation of waste source: Sewage sludge/ abattoir/ farm waste/ type of animal/ Organic Fraction of Municipal Solid Waste (OFMSW)/ food processing, what type of food?
- Sewage sludge: Where does the sludge come from? Primary settlement/ aeration SAS/ UASB/ SBR/ MBR.
- Volume / tonnage and thickness (dry solids content %DS).
- Organic dry solids content (%ODS).

- Assumptions for missing data based on industry standard values where data is not available, improve model as further information becomes available.

Selection of Digestion Process – Data Analysis

Process of assessment:

- Analyse energy potential from each waste stream: What is worth digesting, what isn't?
- Transportation costs: What is worth transporting, what isn't?
- Pre-treatment: Removal of inert solids/ excess water/ contaminants. Revenue streams from byproducts?
- Combine feeds to a single feed product for calculation model;
- Selection of digestion process: Wet/ dry/ mesophilic/ thermophilic/ thermal hydrolysis;
    - Ratio of Carbon : Nitrogen : Phosphorous;
    - pH of digester is important to prevent toxicity and maintain balance of ammonia/ ammonium.
- Calculation of biogas potential per option: Different feedstocks and processes produce different volumes of biogas with different percentages of methane.

Comparison of Wet and Dry Digesters

Wet Digestion		Dry Digestion	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Inert materials removed before digestion do not take up volume	Extra process steps for washing and dewatering	Fewer process steps	Mixing and pumping issues
Inert materials reusable	Larger digester volume	Ashes after digestate incineration reusable	Risk of incomplete digestion
Easy mixing	Wastewater treatment required	No water treatment required	Risk of toxic concentrations
No damage by inert materials	Inert materials not removed may damage mixing equipment		

Expected Biogas Production (depending on organic fraction)

- Sewage sludge: ~ 15-56 Nm^3/tonne fresh material;
- Organic Fraction of Municipal Solid Waste (OFMSW): ~ 100 Nm^3/tonne fresh material;
- Food waste: ~ 120 Nm^3/tonne fresh material;
- Camel manure: ~ 30 Nm^3/tonne fresh material;
- Cattle manure: ~ 40 Nm^3/tonne fresh material;
- Poultry manure: ~ 100 Nm^3/tonne fresh material;
- Slaughterhouse water: ~ 160 Nm^3/tonne fresh material.

- Biogas content: 55 to 75% methane, plus CO_2, H_2S, siloxane.
- Highly dependant on digestion process, pre-treatment, composition of feed-stock .... Many factors affect biogas.

Selection of Digestion Process – Post Digestion Options

- Regulatory impacts on disposal of products;
- Quality control of pathogens/ heavy metals;
- Recovery of fertiliser (Nitrogen/ Phosphorous) from digestate liquor;
- Transportation and disposal costs.
- Post-treatment options:
  - Dewater to 20-30 %DS;
  - Dry to 90 %DS;
  - Incinerate to 100 %DS inert ash product;
  - Composting.
- Disposal options:
  - Landfill
  - Soil conditioner
  - Soil fertiliser

Thermophilic digestion

- Applicable on primary and secondary sludge & co digestion material
- 50 – 58 °C
- Full reactor; retention 12 – 18 days
- ds% 4 - 10
- Up to 40% extra conversion and biogas production
- pH control; complex process control
- Effect on dewaterability inconclusive

Pre-treatment by Thermal Pressure Hydroloysis

- Applicable on secondary sludge mainly
- Pre-treatment; retention several hours
- 5 – 10 bar
- 120 – 180 °C
- ds% 8 – 16 (pre-dewatering needed)
- Up to 40% extra conversion on secondary sludge + extra biogas production
- pH control; complex process control
- Effect on dewaterability inconclusive

Thermal chemical pretreatment

- Applicable on mainly secundary sludge
- Pretreatment; retention time several hours
- Oxidative additive
- 60 – 80 ^{o}C

- Thermista
- TRL: pilot/demo

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Enzymatic Hydrolysis Pasteurization Digestion (EHPD)

- Applicable on primary and secondary sludge & co digestion material
- 30 – 38 °C
- Full reactor; retention 15 – 25 days
- ds% 4 - 10
- Up to 40% extra conversion and biogas production
- pH control; complex process control
- Effect on dewaterability inconclusive

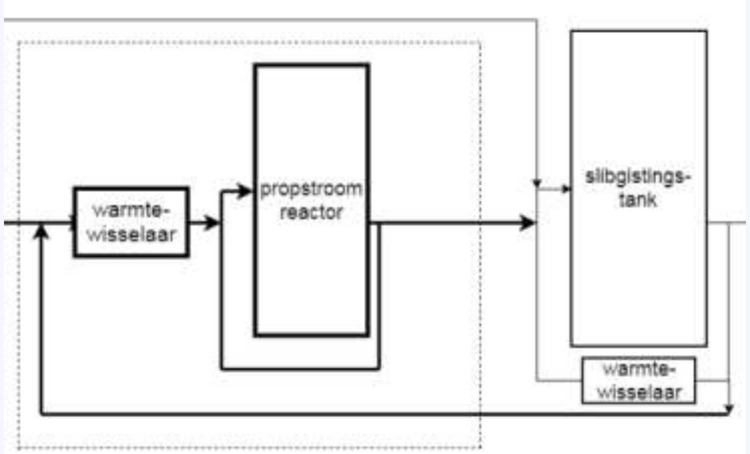
Autogenerative High Pressure Digestion (AHPD)

- Applicable on primary and secondary sludge & co digestion material
- 30 – 58 °C
- Full reactor; retention 10 – 18 days
- ds% 4 - 16
- Up to 45% extra conversion and green gas production (95% CH_4)
- pH control; complex process control
- Effect on dewaterability inconclusive

Plug flow technology

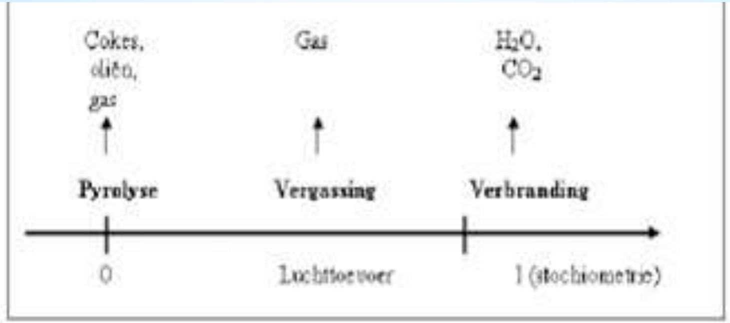
- Plug flow ~ spreading sludge retention time
- Up to 25 % higer convertion
- pH control; complex process control
- Effect on dewaterability inconclusive

- Ephyra – 3 stage digestion
- Thermfilly – 2 stage digestion
- Tanks in Series



Advanced technologies for sludge treatment

- Pyrolyse
- Gasification
- Wet Air Oxidation
- Drying
- Composting
- Advanced incineration



Cost Comparison of Options

- Convert biogas potential to monetary value:
  - Methane content of biogas;
  - Biogas loss through flaring, cleaning, engine efficiency;
  - Can all the electricity generated be used or sold?
  - Price of electricity – reduction of electricity bill on site or sale to outside site?
- Capex and replacement to design horizon;
- Opex: Maintenance, availability, cost of pre and post treatment steps.
- Revenue streams:
  - Electricity generation;
  - Reduction in disposal costs (volume reduction);
  - Beneficial side-streams (Phosphate/ Nitrogen recovery and sale as fertiliser).
- Other benefits: Hygiene of final product affecting disposal routes, reduction in odour complaints
- Compare options on whole-life costing and payback times.

Potential resources recovery and urban development