Thermal and catalytic processes for treatment of biomass and waste

Anja Oasmaa, VTT

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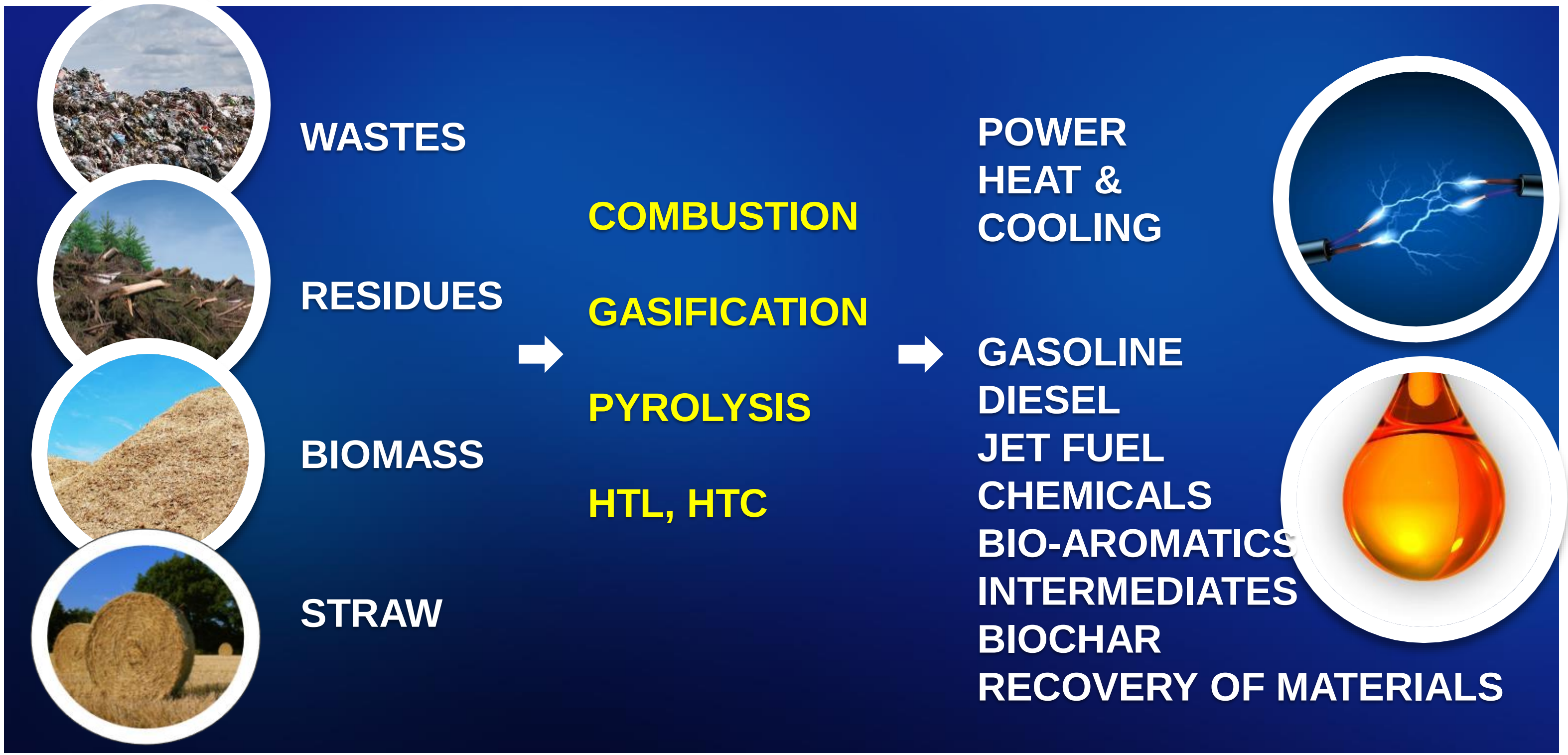
Fast pyrolysis and HTL

Standards and norms

Novel applications in circular economy

Anja Oasmaa has over 35 years expertise in thermal conversion processes, especially in fast pyrolysis and hydrothermal liquefaction and has a wide global network. She has developed analytical methods, norms and standards for bio-oils and been the initiator in EN and ASTM standardisation and REACH work. Presently she is actively involved in circular economy work at VTT and aims to develop conversion processes for waste-derived fuels and chemicals. Latest project is national WasteBusters (2017-18) connected to several company projects the common aim being to clarify business and operational environment for waste thermolysis. Anja has over 139 scientific publications of which 85 scientific peer reviewed publications in international journals and books, H-index of 31, over 3600 citations. She is associate editor in Energy&Fuels. Anja has several patents and invention disclosures. LinkedIN: https://www.linkedin.com/public-profile/settings?trk=prof-edit-edit-public_profile

VTT Thermal conversion platforms



Scaling-up fast pyrolysis technology

IEA BIOENERGY COLLABORATION

UNION FENOSA, SPAIN

FORTUM, PORVOO, FINLAND

ENEL, BASTARDO, ITALY

VALMET, TAMPERE, FINLAND

FORTUM DEMONSTRATION - JOENSUU, FINLAND

1980	1985	1990	1995	2000	2005	2010	2015	2020

BUILDING THE FOUNDATIONS
- Gathering knowledge
- Networking
- Hydrothermal liquefaction
- IEA bioenergy assessments

IPR STRATEGY
- Co-operation with key industrial partners - key patents on fast pyrolysis
- Far-reaching publications
- Participating in piloting

SCALING UP FAST PYROLYSIS
- Consortium for commercialisation
- Demonstration of boiler use
- Norms and standards
- Catalytic fast pyrolysis and HTL for transportation fuels
- Starting CFD modelling

NEW OPENINGS
- Widening feedstock basis
- Widening bio-oil applications
- CIRCULAR ECONOMY - Fast pyrolysis of plastics and other waste for chemicals, materials, and fuels
- Development of HTL

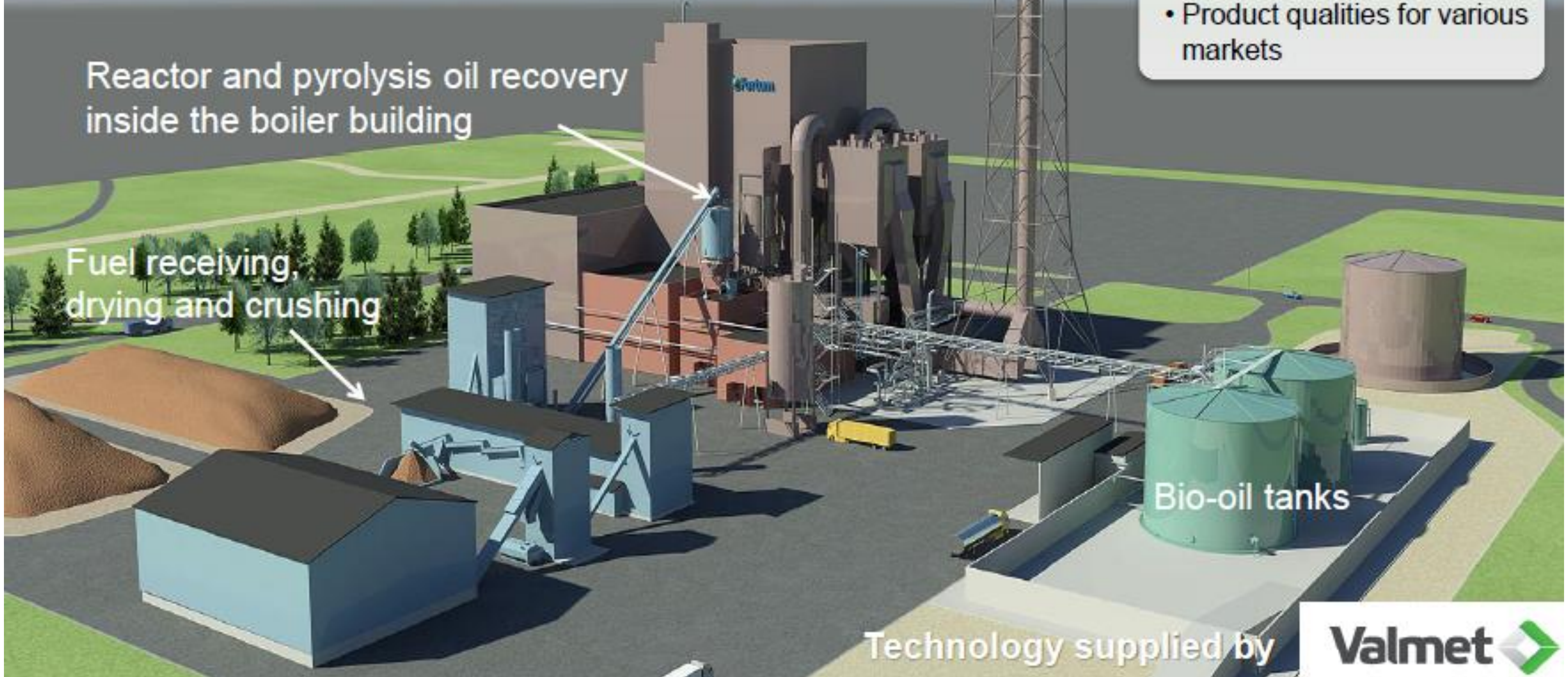
Joensuu: an Integrated Bio-Oil Demonstration Plant

Fortum

- Bio-oil capacity 30 MW
- Annual production 50 000 t, 210 GWh
- Start-up 2013
- Feedstock Forest residues, sawdust

VTT contribution

- The integrated concept, ITP
- Operational skills from pilot to demonstration
- Applications in boilers and engines
- Active role in ASTM & EN standardization
- Product qualities for various markets

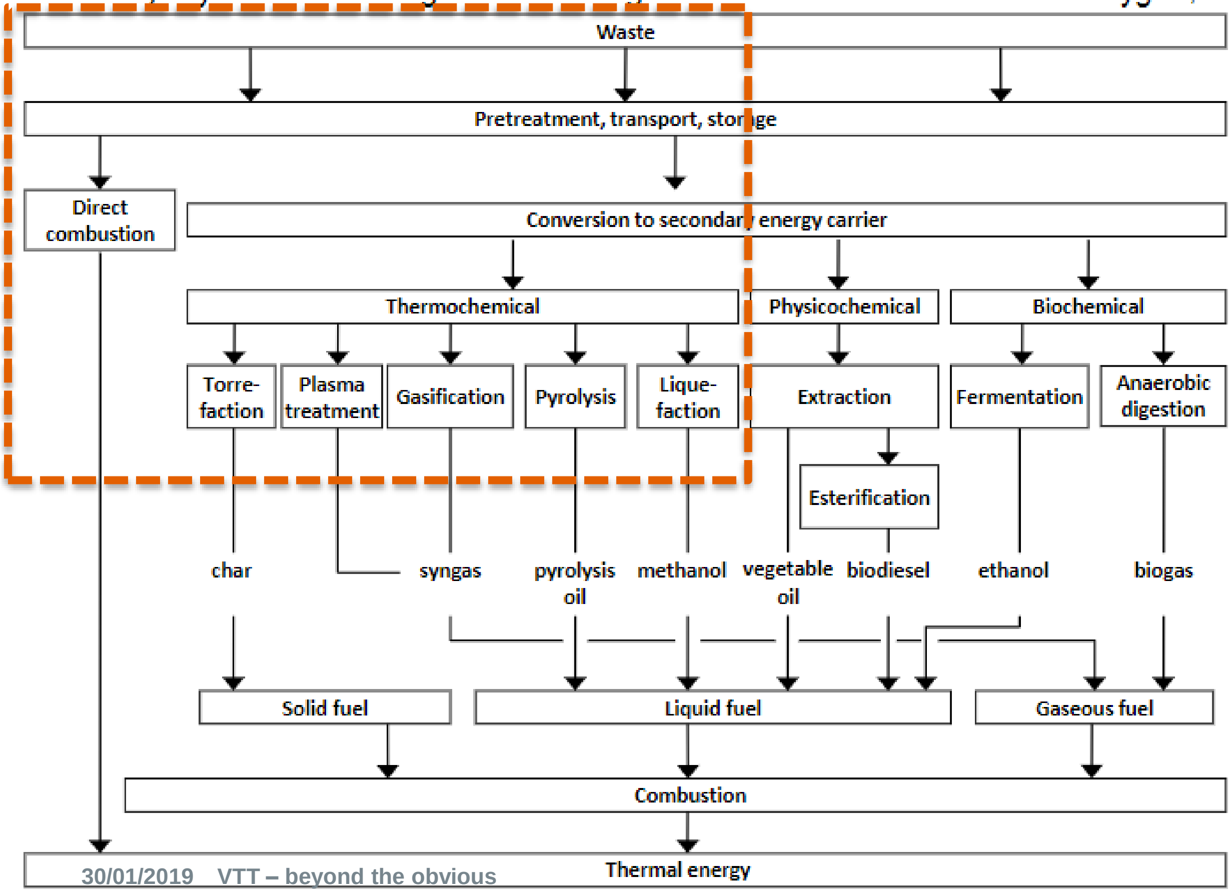


Technology supplied by Valmet

Thermochemical conversion of biomass and waste

Waste to energy conversion technologies

1. Incineration: full oxidative combustion;
2. Gasification: partial oxidation;
3. Pyrolysis: thermal degradation of organic material in the absence of oxygen;



M. Kaltschmitt, G. Reinhardt, Eds. (1997). "Nachwachsende Energieträger - Grundlagen, Verfahren, ökologische Bilanzierung", Braunschweig/Wiesbaden, Vieweg Verlagsgesellschaft.

Main differences – Temperature and time

- **Combustion, incineration (thermal oxidation)** is one common option for managing wastewater solids and other organic residuals http://www.ieabcc.nl/
- **Gasification** is thermal conversion of organic material to combustible gases under reducing conditions with oxygen added in sub-stoichiometric amounts (compared to the amount needed for complete combustion to CO_2 and H_2O). The main product is producer gas (CO + H_2, small amounts of CO_2, H_2O, etc.). After clean-up, syngas is obtained (a mixture of CO and H_2). http://task33.ieabioenergy.com/
- **Fast pyrolysis** occurs at temperatures about 500ºC and residence times about 1s (very high heating rate). It produces 75% of liquid (called bio-oil), and only 12% of char and 13% of gas. http://task34.ieabioenergy.com/
- **Slow pyrolysis** occurs at temperatures about 300-600ºC and residence times about 30 min (slow heating rate). It produces 80% of solid material (charcoal) and 20% of gas. http://www.mobileflip.eu/index.htm
- **Torrefaction** is a mild type of pyrolysis (230-300ºC; about 30 min). It produces torrefied biomass, while the mass loss through devolatilisation is moderate. http://www.mobileflip.eu/index.htm

http://demoplants.bioenergy2020.eu/

Main differences - Air

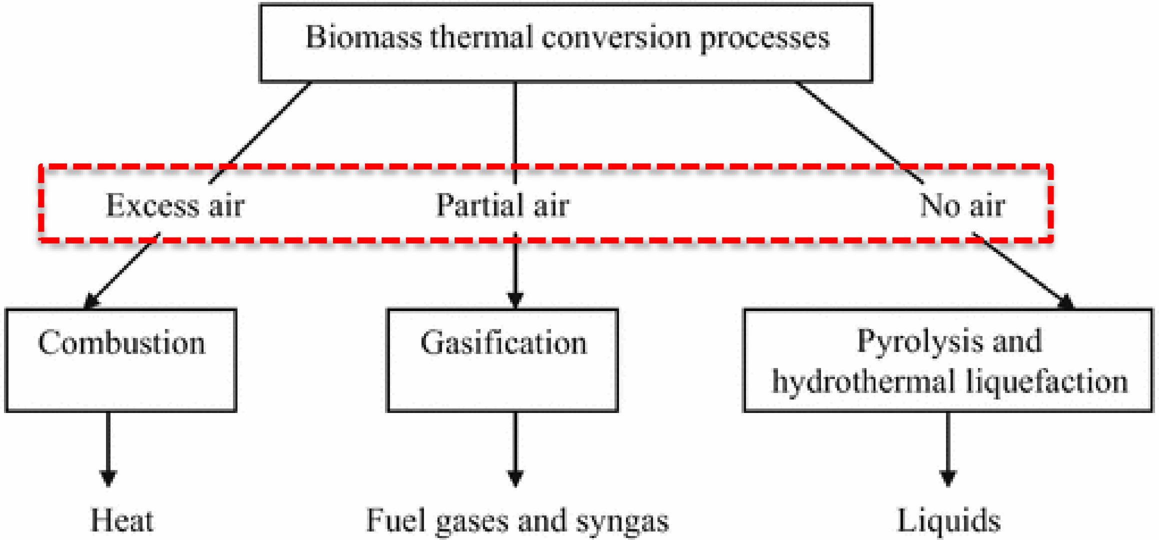


Fig. 6.1 Biomass thermal conversion processes

Thermal decomposition

A. Demirbas, *Biofuels*,
© Springer 2009

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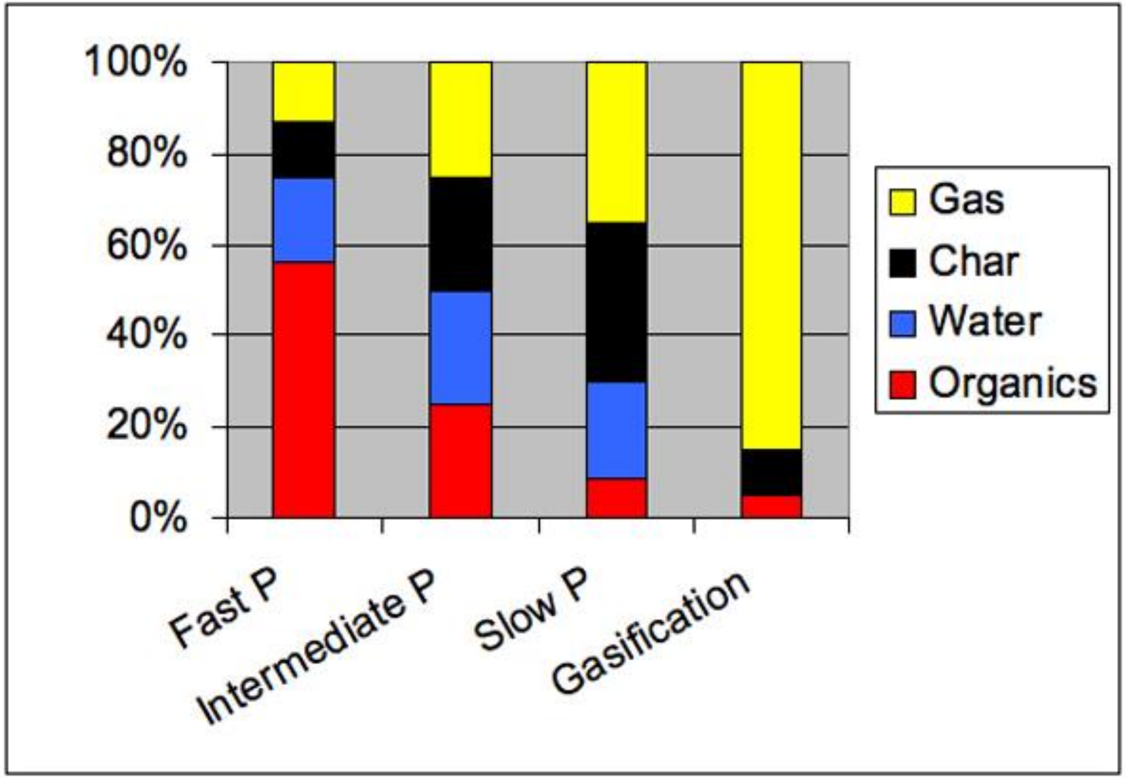
Share of products due to temperature and time



Combustion, incineration

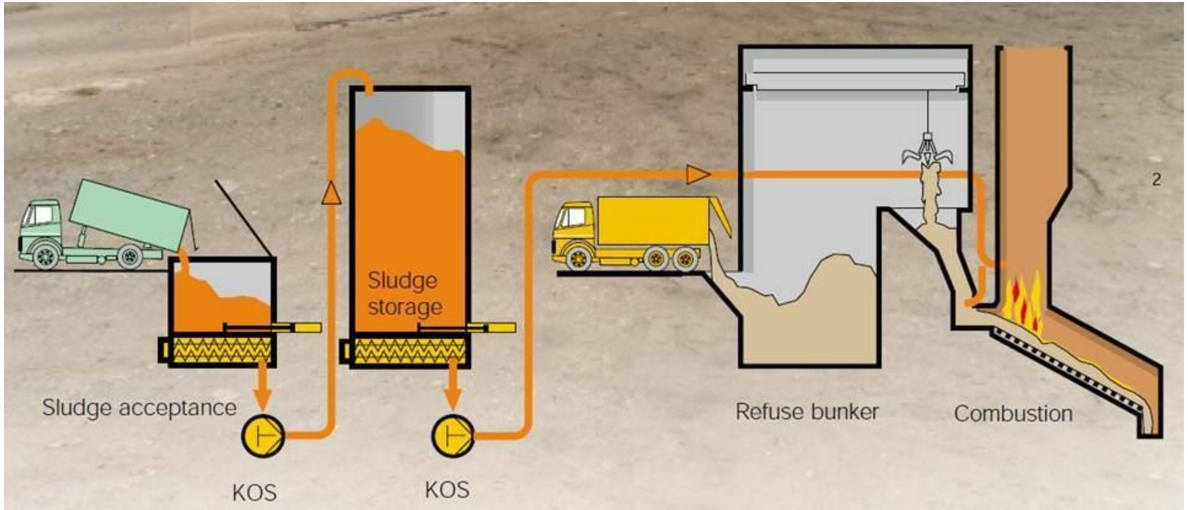
Combustion, incineration

- Incineration (thermal oxidation) is a common option for managing wastewater solids and other organic residuals.
- According to the European Waste Incineration Directive, incineration plants must be designed to ensure that the flue gases reach a temperature of at least 850 °C for 2 seconds in order to ensure proper breakdown of toxic organic substances.
- An incinerator is a device that uses controlled flame combustion to directly "burn" feedstock, and an incineration unit is that part of any facility that processes waste by incineration.
- **A Waste-to-Energy (WtE) facility applies combustion to solid waste-sourced feedstock to maximize and recover thermal energy, or heat**. That heat can then be used directly for process heat, can create useful steam, and/or can drive power generation equipment.

http://www.houstontx.gov/onebinforall/Gasification_vs_Incineration.pdf

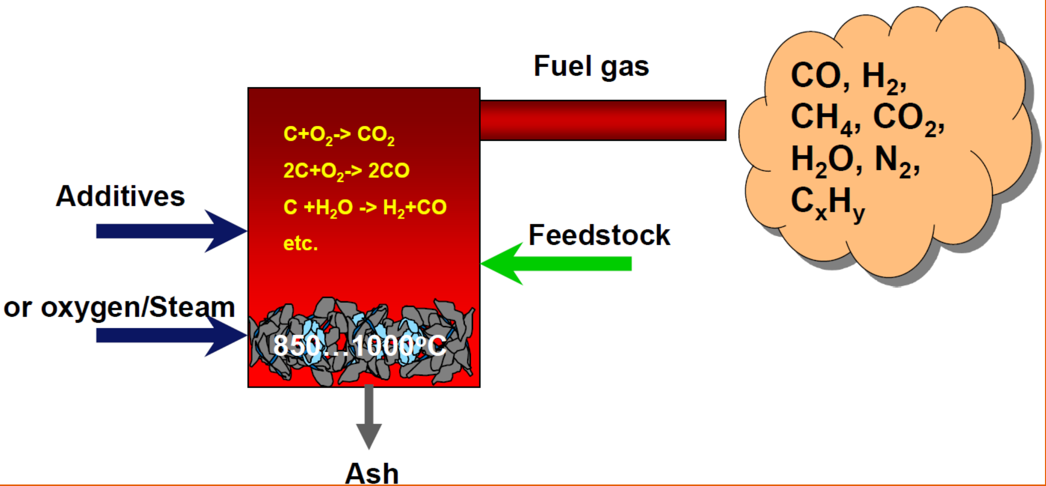
Sludge Incineration

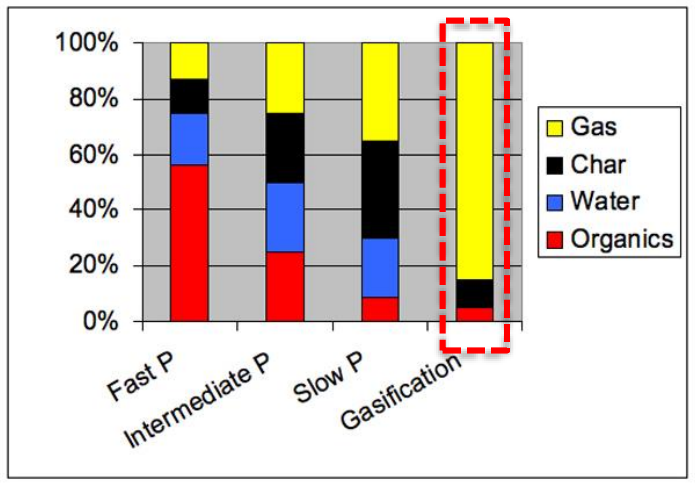
- Incineration of dewatered sludge from wastewater treatment plants reduces the volume of the dry sludge and **produces a sterile non-harmful residue that is free from toxic organic chemicals and pathogens.** It also helps to recover some of the **energy** used in the combustion process especially in large treatment plants whereby there is a huge quantity of sludge generation.
- With the implementation of new technologies, **fertilisers** can be produced out of sewage sludge.



http://www.sswm.info/content/incineration-large-scale

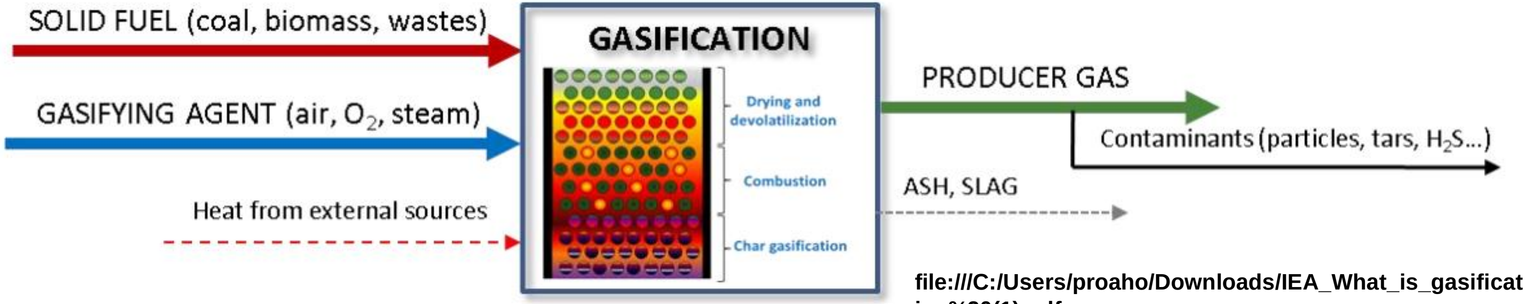
Gasification





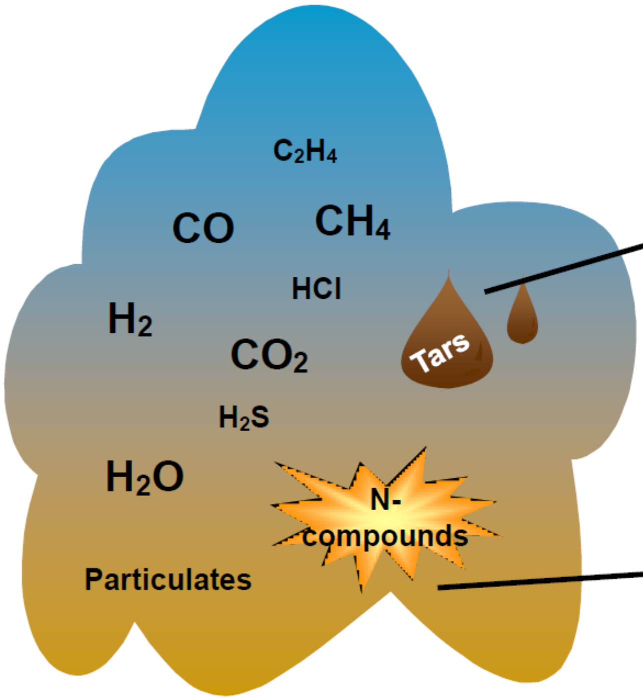
Gasification

- Gasification is a high-temperature process in which a solid fuel (e.g. coal, biomass, wastes) is converted into a combustible gas, called producer gas or syngas. Gasification takes place at high temperatures (700-1500ºC), and heat or small amounts of air or oxygen are added to supply the energy needed for the gasification process.
- **Biomass gasification is mainly used for efficient heat and power production and co-firing at small- and medium-scale plants.**
- **Development is expected to lead to large-scale synthesis of biofuels and chemicals.**



file:///C:/Users/proaho/Downloads/IEA_What_is_gasification%20(1).pdf

Impurities in gas



TARS
- naphthalene, PAH

CLOGGING, SOLID DEPOSITS
- pipes
- filters
- engine ducts

NITROGEN COMPOUNDS
- NH_3, HCN

Will cause NOx-emissions

Gas cleanup steps in advanced gasification applications

Gasification gas cleanup

- Under R&D

PRE-REFORMER → FILTER → DEEP REFORMER →

REMOVAL OF

- ✓ particulates
- ✓ tars and hydrocarbons
- ✓ NH_3 and HCN
- ✓ chlorine
- ✓ alkali metals
- ✓ heavy metals

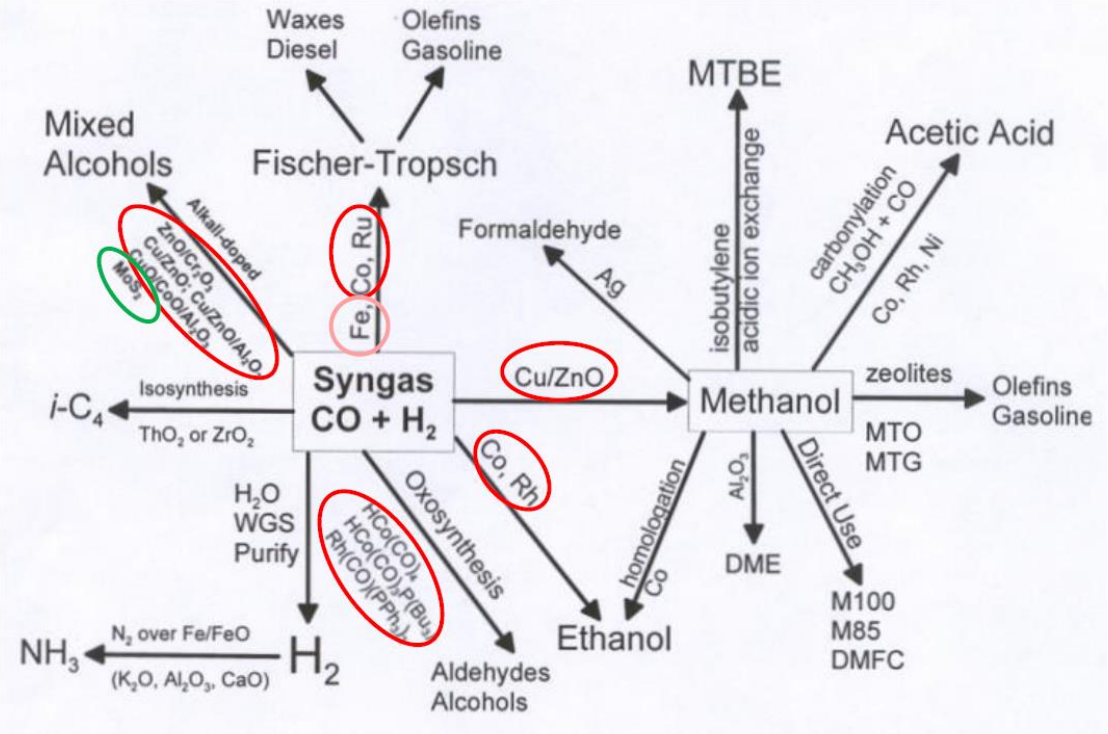
Syngas processing

- Commercial technology

REMOVAL OF

- ✓ Sulphur compounds
- ✓ Residual nitrogen compounds
- ✓ Residual hydrocarbons
- ✓ CO_2
- ✓ H_2O

Products from synthesis gas



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Gasification versus incineration

Sludge Treatment Method	Advantages	Disadvantages
Incineration	• Significant reduction of weight and volume of sludge. • Low sensitivity to sludge composition. • Modern incineration includes the recovery of energy for heat or power consumption. • Sale of energy reduces cost • Bottom ash may be used as a daily cover for landfill. • Salts and acids may be recovered from process water of air pollution controls. • Less need of landfill and landspreading • Some facilities recover and sell metals.	• The use of large quantities of excess air, in order to maximize the conversion of the hydrocarbon-based sludge, increases the production of CO_2. • Operational temperatures do not provide the completed fusion (as slag) of ash and mineral matter. • Costs of air pollution controls may exceed the cost of energy conversion equipment. • In some cases, ash may be dewatered or chemically stabilized to meet land disposal restrictions. • Process water from air pollution controls is eventually discharged to a wastewater treatment plant to not increase costs of treatment equipment.
Gasification	• Significant reduction of weight and volume of sludge. • Less need of landfill and landspreading. • The use of less oxygen results in less emissions. • Syngas produced have many uses (power production, chemicals, methanol, etc.)	• Expensive initial set up • Complex multi-stage process • Syngas must be cleaned/purified • Energy input to start reactions.

Lahti Waste Gasification plant

Highest efficiency for Energy-from-Waste

- World's largest waste (SRF) gasification power plant
- Processes 250 ktpa of Refuse Derived Fuel (SRF) to produce:
  - 50 MW of electricity
  - 90 MW of district heat
  - CHP efficiency of 87,5 %
- Total investment ca. €160m

Lahti Energia, Lahti, Finland

Start-up 2012

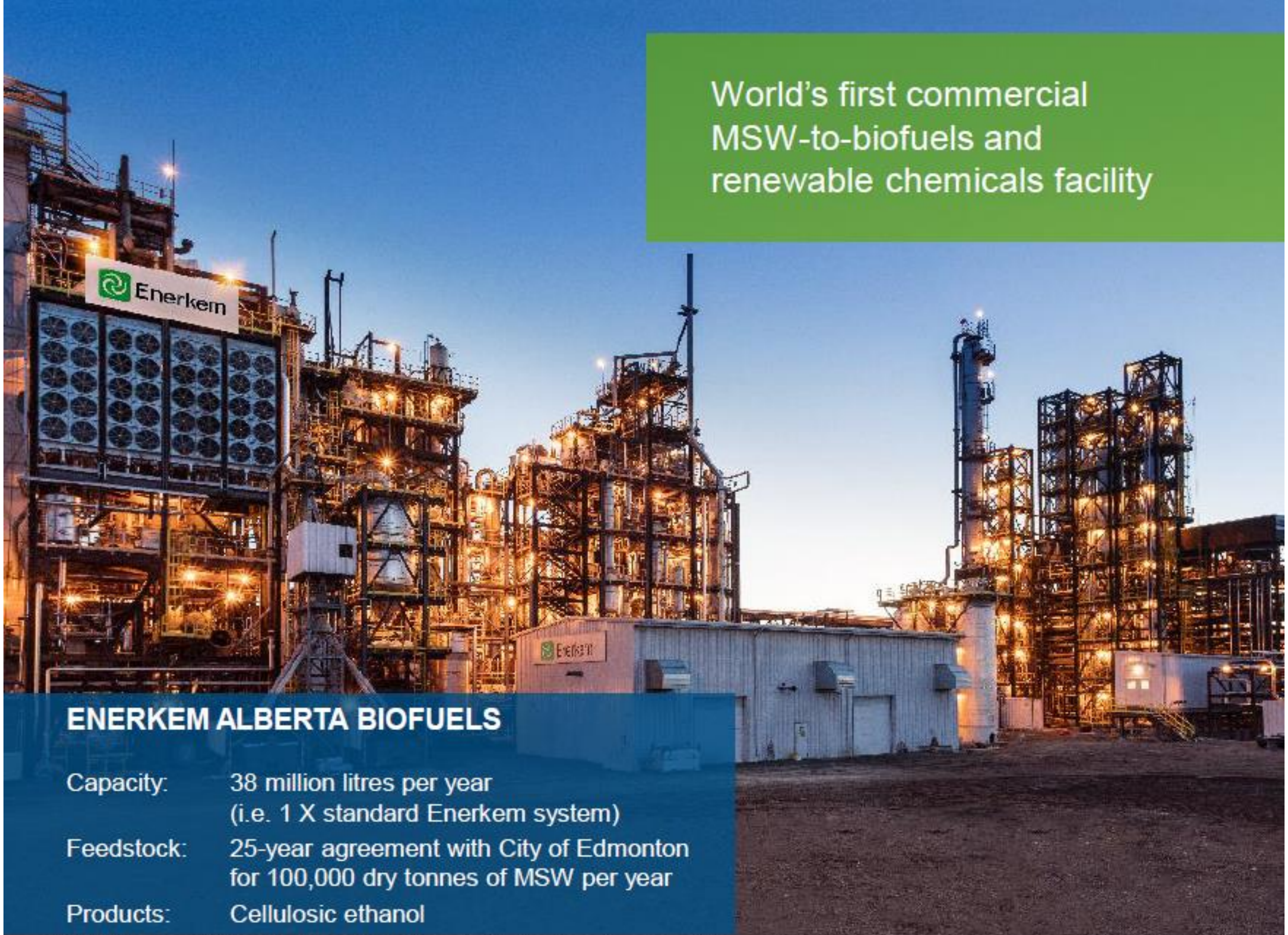
CO_2 emissions reduced up to 50 %

Design fuel

	Design fuel
Fuel	SRF from MSW and C+IW
LHV	18 – 24 MJ/kg,$_{dry}$
Moisture	< 30 w-%
Ash	< 15 w-%,$_{dry}$
Cl	< 0.6 w-%,$_{dry}$
Na + K	< 0.3 w-%,$_{dry}$
Hg	< 0.1 mg/kg,$_{dry}$

Refuse-derived fuel (**RDF**) is a fuel produced from various types of wastes such as Municipal Solid wastes (MSW), industrial wastes or commercial wastes.

Enerkem


World's first commercial MSW-to-biofuels and renewable chemicals facility
Enerkem
ENERKEM ALBERTA BIOFUELS
Capacity: 38 million litres per year (i.e. 1 X standard Enerkem system)
Feedstock: 25-year agreement with City of Edmonton for 100,000 dry tonnes of MSW per year
Products: Cellulosic ethanol

Overview - bringing the model to reality

Rigorous path to commercialization

Enerkem Today

Testing Phase (2002-2008)	Demo Phase (2008-2012)	Commercialization Phase (2012-2016)	Commercial Growth Phase (2017+)

Sherbrooke University (Lab)

Sherbrooke (Pilot)

Westbury Plant (1/10th Full-Scale Plant Size)

Enerkem Alberta Biofuels (Full-scale)

Varennes, Rotterdam, Barcelona, Minneapolis & UK

Lab → Pilot → Demo Syngas → Demo Methanol → Demo Ethanol → Scale-up and Organizational Set-up → Large-Scale Global Rollout

200 kg/hr | 2 metric tonnes / hr | 14.5 metric tonnes / hr

Enerkem

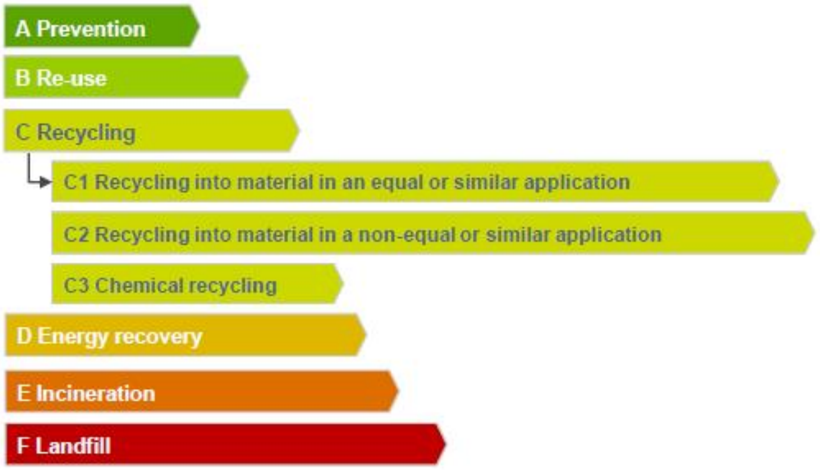
In 2018, Air Liquide, AkzoNobel Specialty Chemicals, Enerkem and the Port of Rotterdam has signed a project development agreement covering initial investments in an advanced waste-to-chemistry facility in Rotterdam. The facility will be the first of its kind in Europe to provide a sustainable alternative solution for non-recyclable wastes, converting waste plastics and other mixed wastes into new raw materials.

Infographic courtesy of Akzo Nobel

Initiated through progressive waste policy…

Incineration tax and recognition of ‘chemical recycling’

- Incineration tax of EUR 13 per tonne to dissuade the combustion of waste
- ‘Chemical recycling’ recognised in Dutch waste legislation



Enerkem

SynGas sewage sludge gasification plant in Mannheim

Throughput	5.000 t/a DS
Gasifiying medium	Air
Gasification temperature	850-900 °C
Firing capacity, sludge	2,2 MWth
Firing capacity, synthesis gas	1,5 MWth
Dryer	Rotary dryer
Plant Footprint	500 m²
Plant Height	25 m

- The sewage sludge gasification plant at the wastewater treatment plant of the municipal wastewater works Mannheim was built in 2010 and commissioned in 2011. The process is largely based on the pilot plant in Balingen, which has been in operation since 2001.
- The plant's capacity of 5,000 t/a DS is more than twice that of Balingen. This is about half of the annual sludge produced by the wastewater treatment plant, which is designed for 725,000 PE and treats approx. 35,000,000 m³ of wastewater per year.
- **After a purification stage, the synthesis gas produced from the gasification process is fed to the furnace of the drum dryer installed at the sewage treatment plant in the neighbouring building for sludge drying.**

Gasification of sludge - Yorkshire Water at Lower Brighouse WWTW

VTT

- The demonstration-scale, proof-of-concept Advanced Thermal Conversion (ATC) gasification plant has (25.10.2017) operated successfully for 10,000 hours and has generated 3.2GWhrs of electricity in that time.

http://events.wwtonline.co.uk/wastewater/gasification-sludge-innovation-action/

- The process uses **dried, pelletised sludge (30%), mixed with pelletised wood (70%), produces syngas, which is used to generate electricity, heat and char.**
- If deployed at a suitable scale, the process has **the potential to generate four times as much renewable electricity as anaerobic digestion (AD),** the most commonly used technology for sludge treatment, while reducing the risks of recycling sludge cake to agriculture.
- Yorkshire Water **plans to recover nutrients** for more efficient, beneficial use
- The gasifier has been developed by Enertecgreen. It uses a proprietary process to produce a consistently high quality gas and avoid the problems of clogging which have hindered previous R&D efforts in the gasifier space.

Plasma gasification

- Plasma gasification is **applicable for wet feedstocks**, thus eliminating the energy intensive drying stage.
- Extremely high temperatures (2,200 to 13,900 °C) in an oxygen-starved environment to completely decompose input waste material into very simple molecules. The heat source is a plasma discharge torch, a device that produces a very high temperature plasma gas.
- Plasma gasification has two variants, depending on whether the plasma torch is within the main waste conversion reactor or external to it.
- Depending of the feed the main products are vitrified slag, syngas and molten metal.
- The most advanced company is currently Kaidi that has taken over the plasma technology developed by Westinghouse Plasma Corporation (WPC), InEnTec and Plasco Energy Group. **Plasma gasification of waste water treatment sludges has TRL 8**. No information on profitability of the plant is available, especially if situated in Europe where operation and business environment is different.

Plasma Gasification Milestones – Commercially Proven

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1983
PLASMA FIRED CUPOLA APPLICATION

General Motors; Defiance, Ohio - commissioned in 1987
Demo – 50 tpd

2002
WORLD'S 1ST COMMERCIAL SCALE PLASMA GASIFIER

Mihama Mikata, Japan - operational in 2002

2012
BIOMASS FACILITY

Kaidi, China – operational Q4 2012

1995
INCINERATOR ASH VITRIFICATION

Kinuura, Japan - commissioned in 1995

2009
SECOND GENERATION ETHANOL FACILITY

Coskata Lighthouse, U.S. -commissioned in Sept. 2009

2016/2017
ENERGY FROM WASTE FACILITIES, Tees Valley, UK – 2,000tpd MSW to combined cycle power Under construction, commissioning dates: TV1 – 2017 and TV2 - 2018

1999
PLASMA GASIFICATION OF MUNICIPAL SOLID WASTE (MSW)

Hitachi Metals; Yoshi, Japan - commissioned in 1999

2008
WORLD'S LARGEST PLASMA HAZARDOUS WASTE FACILITY

Pune, India – operational in 2009

2012
MARC-3 TORCHES

Guanchuan, China – delivery Q1, 2013

1989
INDUSTRY–LEADING TECHNOLOGY

Plasma technology by others such as Alcan – over 500,000 hours of industrial use

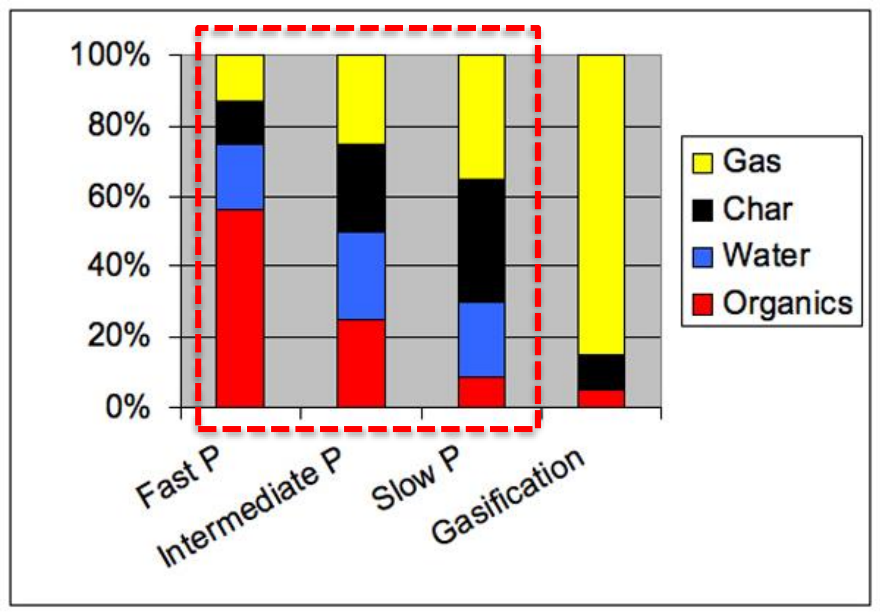
2003
WORLD'S LARGEST PLASMA GASIFIER FOR MUNICIPAL WASTE

Utashinai, Japan - operational in 2003; 200 tpd

2014
DEMONSTRATION FACILITY INTEGRATED WITH EXISTING INCINERATOR

Shanghai, China – operational in Q1, 2014; 30 tpd

Pyrolysis



100%
80%
60%
40%
20%
0%
Fast P
Intermediate P
Slow P
Gasification
Gas
Char
Water
Organics

Pyrolysis processes

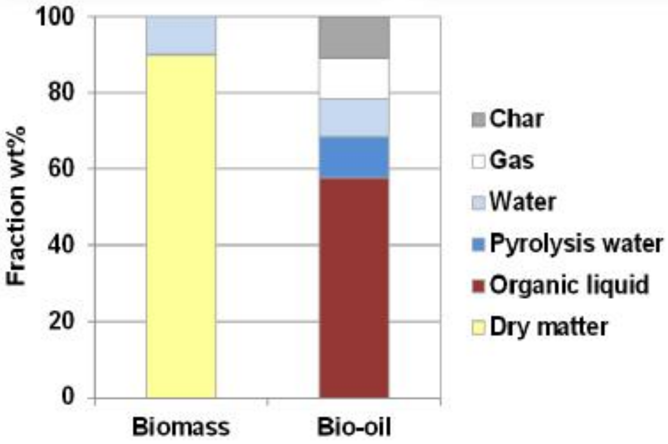
- **Fast pyrolysis** is a thermal treatment of lignocellulosic biomass at short hot vapour residence time (< 5 s) at 450 °C – 600 °C and at near atmospheric pressure, in the absence of oxygen
- The typical yield of bio-oil from woody biomass is 60 –75 wt% on wet basis and 55 - 65 wt% of organic matter. Other products are char and non-condensable gases.
- **Slow pyrolysis** occurs at temperatures about 300-600ºC and residence times about 30 min (slow heating rate). It produces 80% of solid material (charcoal) and 20% of gas.
- **Torrefaction** is a mild type of pyrolysis (230-300ºC; about 30 min). It produces torrefied biomass, while the mass loss through devolatilisation is moderate.

Fast pyrolysis of biomass

Biomass

Bio-oil
Char
Gases

Fuel oils
Transportation fuels
Chemicals



Slow pyrolysis

Newsletter – February 2018

MOBILE FLIP – Mobile and flexible industrial processing of biomass

Europe has a large potential of underexploited agro- and forest biomass side streams, mainly due to their diversity, seasonality and dispersion. The MOBILE FLIP project aims to enhance their usage through flexible and mobile conversion units. By support of three years active research work, several potential technologies are now approaching the demonstration phase.

Pelletizing in an ISO container system, providing an affordable and easily transported upgrading unit for low-density biomass feedstock. In addition, a novel spray nozzle technique has been developed, improving the feedstock versatility and process robustness in ring die pelletizing.

Torrefaction unit for raw materials with up to 50w-% moisture content, composed of a dryer unit, torrefactor and char cooler. Energy for the process is provided by a burner using both wood and torrefaction gas.

Slow pyrolysis demonstrations continue using the second version of the mobile demonstration unit while a bigger capacity unit is under construction aiming at 330 kg/h of raw material input. The cooling and fractionation of the solid product will be done in a separate equipment on a trailer to save space for the carbonization section and to maintain the mobility of the unit.

Hydrothermal treatment for the conversion biomass raw materials into products via saccharification. The goal is to construct a system operating on continual basis at desired temperatures and pressures.

Coordinator
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VTT Technical Research Centre of Finland Ltd, Finland
tel. +358 40 5324962

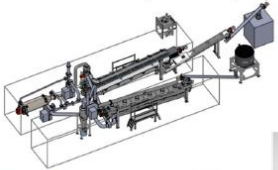
Website
www.mobileflip.eu

Budget
9.7 million €

Resources
716 person months

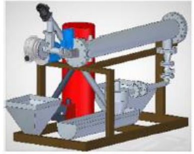
Duration
4 years (2015 – 2018)

Programme
Horizon 2020, SPIRE-02-2014 program



3D plot of torrefaction mobile unit. designed by ETIA.

VTT measurements on Raussi demo.



3D plot of Biogold's hydrothermal pretreatment system operating on continual bases.

SPC pelletizer, mounted in a container system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 637020–MOBILE FLIP.

http://www.mobileflip.eu/pdf/MOBILE_FLIP_newsletter_2018_02_28.pdf

Pyrolysis systems for sludges

- Presently there are only small sewage sludge pyrolysis plants, like Pyreq in Germany
- New Earth closed their plant at Avonmouth in 2015
- There are some planning applications in, like Energy10 at Huntingdon but no information is available
- **The reported reasons for closing include fluctuation of feedstock price, lack of long-term binding agreements with feedstock suppliers, technical problems, and legislative challenges.** It is clear that all legislative issues of the whole value chain should be well known.

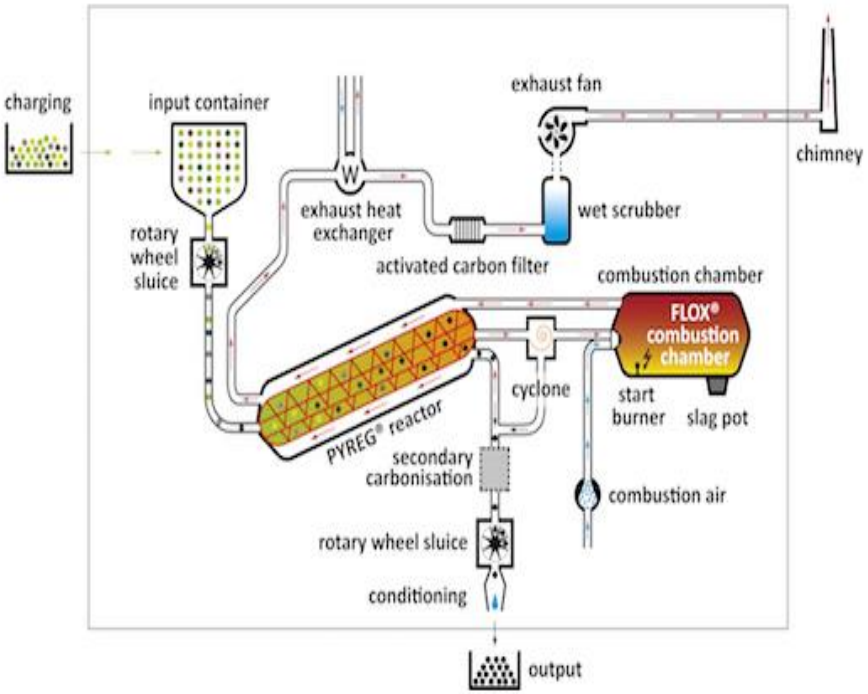
At the WWTP of Linz-Unkel (Germany), ELIQUO has constructed a unique decentralised sludge processing plant. The design, is based on the PYREG® technology, where the sludge is converted into a valuable phosphate rich ash. Currently these ashes are utilised in Germany at part of the production of various fertiliser products.

- The first PYREG-plant for sewage sludge utilization is in operation at the municipal waste water treatment plant Linz-Unkel near Bonn (Germany).

The Linz-Unkel WWTP is treating the sewage from 30.000 inhabitants. Sludge from WWTP Linz-Unkel and sludge from neighbouring WWTP's is digested. The digested sludge is dewatered and dried using an ELODRY™ low temperature dryer. This sludge dryer has been developed in-house based on market leading technology and is produced at the own ELIQUO factories. After drying the sludge to approx. 90% ds, the PYREG® module converts it into a phosphate rich ash utilising a patented two-stage combustion process. The heat which is recovered from the PYREG® system is used together with the waste heat from the works CHP system to provide all the necessary thermal energy for the ELODRY™ process. To further optimize the process waste heat which is recovered from the ELODRY™ process is utilised for heating the WWTP's digesters.

This unique and integrated ELODRY™-PRO concept converts a waste product into valuable phosphate rich ash by utilising the benefits of an entirely closed heat loop. As all of the digested sludge is converted to a valuable ash there is no remaining sludge for disposal and therefore transport and disposal costs are reduced to zero.

Schematic presentation of the PYREG process



http://www.pyreg.de/company-en/news-en.html

- Fuel capacity 500 kW and fuel flow rate up to 180 kg/h (original substance, OS), appr. 1300 t/year (OS).
- Dry substance content (DS) of at least 50% needed and the input is 2000 t p.a. OS with 50% DS.
- The sludge is dewatered in a screw compactor up to 31% dry content and dried to a dry material content in excess of 85% by a low-temperature belt dryer without intermediate storage.
- The biochar satisfies the highest quality standards certified by the standard of European Biochar Certificate (EBC). The phosphate in the sludge remains available to plants as opposed to the conventional practice of complete incineration
- **A unique feature of the process is ThermoSystem solar drying unit, which dries the wet digested sludge to a solid content of 70-85% over 2-8 weeks depending on weather conditions. This makes the energy and operating cost requirements compared to other processes using fossil fuel for drying substantially lower, and reduces the carbon footprint. (EPA/600/R-12/540, June 2012)**

BEST RECYCLING PLANT OF THE YEAR IN SWEDEN

23 February 2018 Biochar, Carbonization, Climate Protection, Company, Event, Media, PYREG plant

We congratulate Stockholm Vatten och Avfall! The biochar project of Sweden's largest water and waste management company is decorated with another award. It was appointed as the best recycling plant of the year by the Swedish recycling industry. With the PYREG technology, the municipal company is refining urban green waste into biochar since 2016, which is then reused in parks, private gardens and green spaces as a soil substrate.

"Working at Stockholm Vatten och Avfall is contributing in many different ways to make Stockholm one of the world's most sustainable cities. The award is an acknowledgement from the sustainable industry in Sweden that they value and appreciate what we are doing which feels amazing", says Jonas Dahllöf (left), head of department at Stockholm Vatten och Avfall. Together with Mattias Gustafsson (left) and Helena Liljestrand (middle) he received the award.

The award for the best recycling plant was awarded at the Swedish Recycling Gala 2018. The annual competition honors innovations, product improvements, investments and extraordinarily achievements.

http://www.pyreg.de/en/

Pyrolysis was pilot tested for six years at the Los Angeles County Sanitation Districts Joint Water Pollution Control Plant

HIGHLIGHTS

- Fully-integrated system processing biosolids
- Over 10,000 wet tons processed
- Provided design basis for commercial scale-up

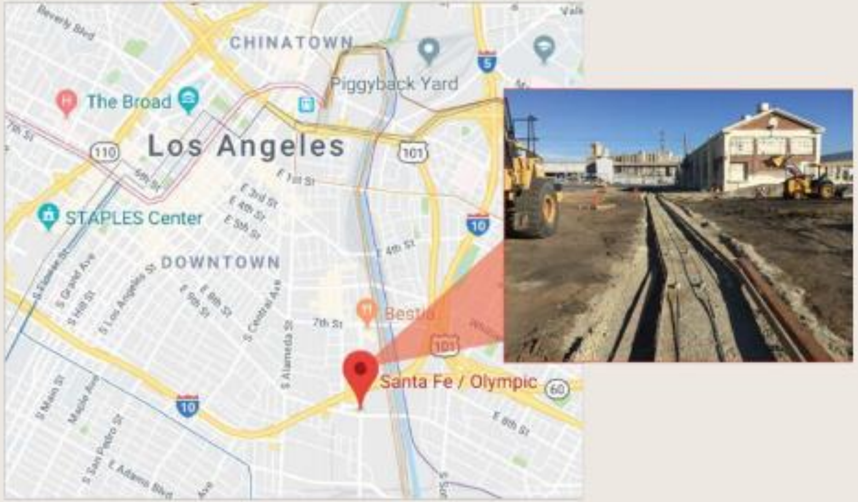
http://www.tcrpc.org/announcements/Biosolids/13_wirtel.pdf


Kore
Kore
Feed
Biochar
Pyrogas
Kore's modular high-temperature pyrolysis system is designed and operated to optimize hydrogen and calorific value for various feedstocks.
High-temperature pyrolysis >600°C
Plug flow reactor
T and t controlled to achieve C
3

Kore will begin a commercial-scale demonstration project in Los Angeles in 2018

Permitted by SCAQMD and City of Los Angeles

Full-scale commercial system:
30 tons per day feed



SoCalGas
A Sempra Energy utility

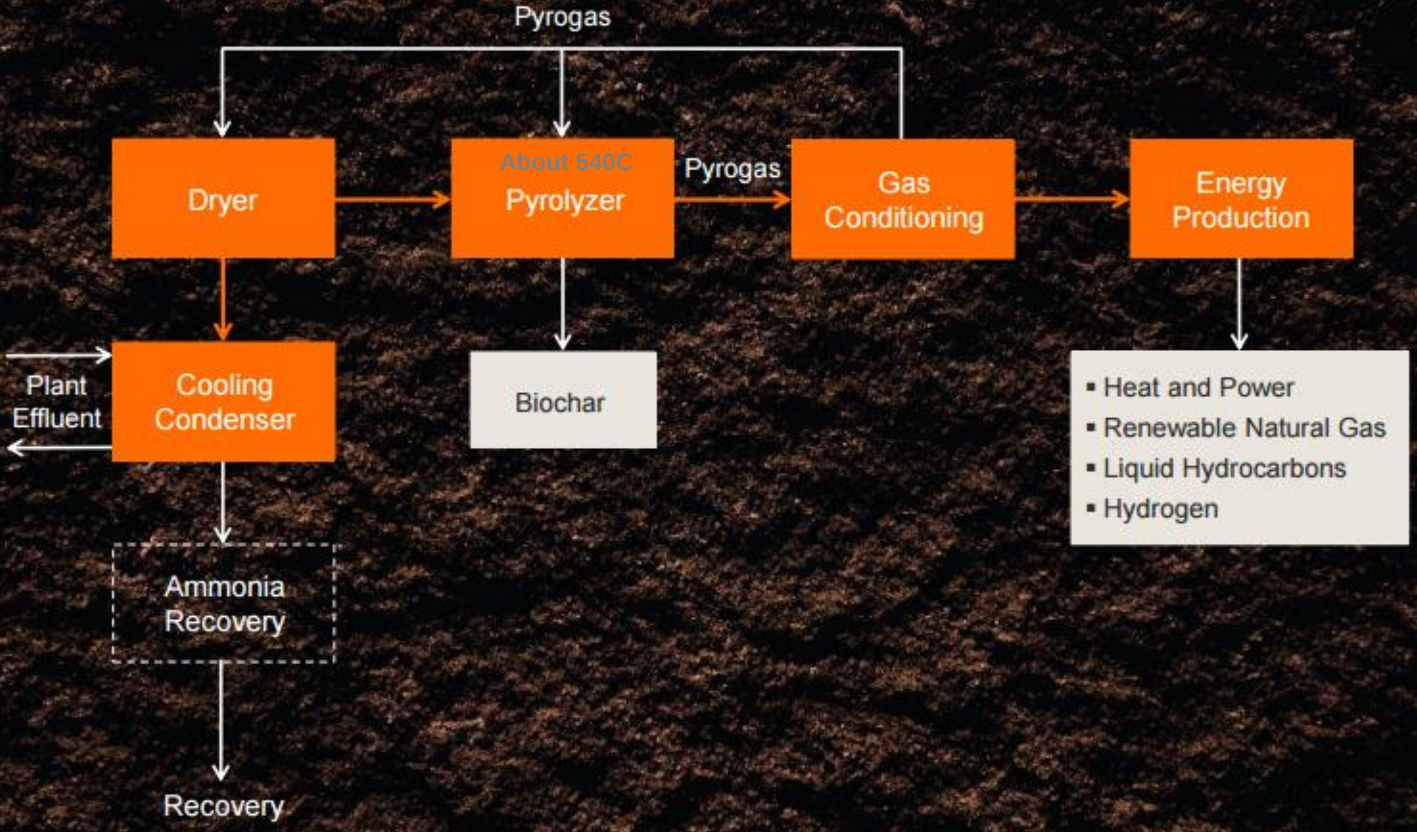
South Coast AQMD

The Kore pyrolysis process provides a cost effective, non-land based solution to organic waste management.

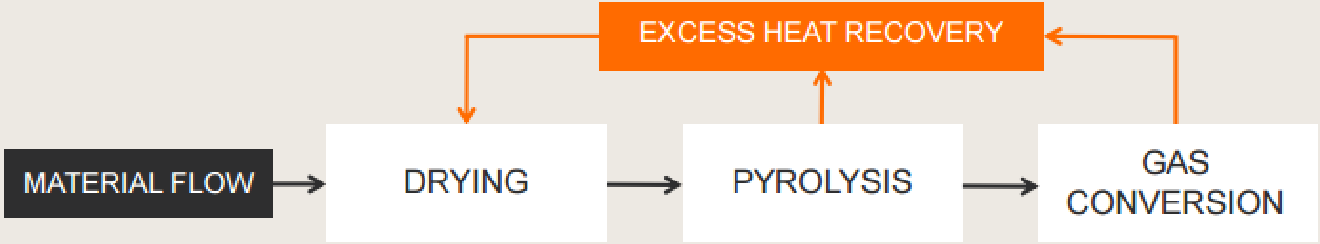
1. >90% Volume reduction
2. Energy self-sufficient (carbon neutral)
3. Biochar = Effective nutrient management
4. Compact, efficient design
5. Potential to generate low carbon fuel: renewable H_2

3

All outputs of the pyrolysis process are products, not wastes.

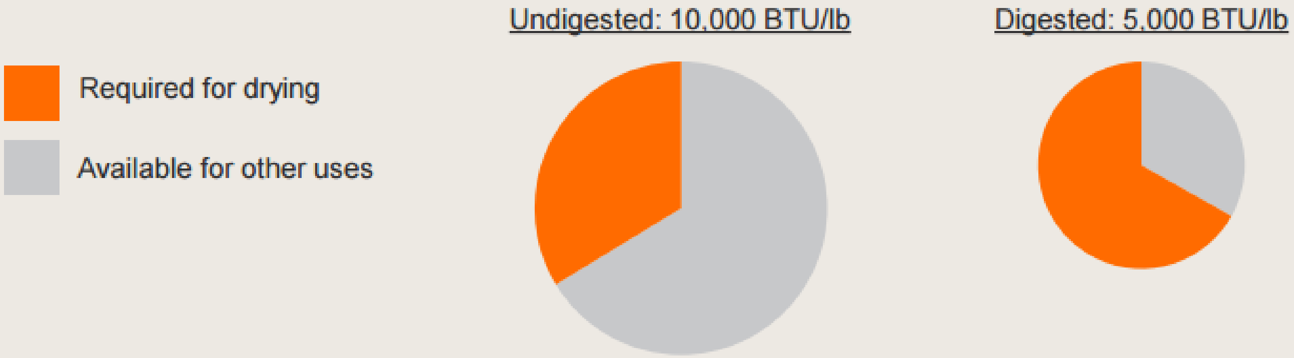


Process recovers excess heat at every step to meet its overall energy needs.



Undigested raw sludge yields more gas and liquid products.

HEAT VALUE: BTU PER POUND, DRY BASIS



Material handling is designed to receive and process municipal biosolids.

BIOSOLIDS RECEIVING

Fully odor-controlled, enclosed biosolids handling facility

Biosolids are unloaded into a live-bottom, below-ground trough

INDIRECT DRYING

Andritz Gouda indirect paddle dryer, waste heat is primary heat source

Biochar production delivers multiple beneficial outcomes.

Provides renewable energy

Can be used as a renewable coal substitute (e.g., in cement kilns), to lower lifecycle environmental impacts; qualifies as refuse derived fuel.

Mitigates climate change

Locks carbon in the soil and reduces emissions of other greenhouse gases.

Improves soils

- Increases crop yields by improving soil fertility, soil structure, water-holding capacity, cation exchange capacity, and soil microbial activity.
- Increases efficiency of fertilizer use, decreases nutrient run-off, and binds contaminants.

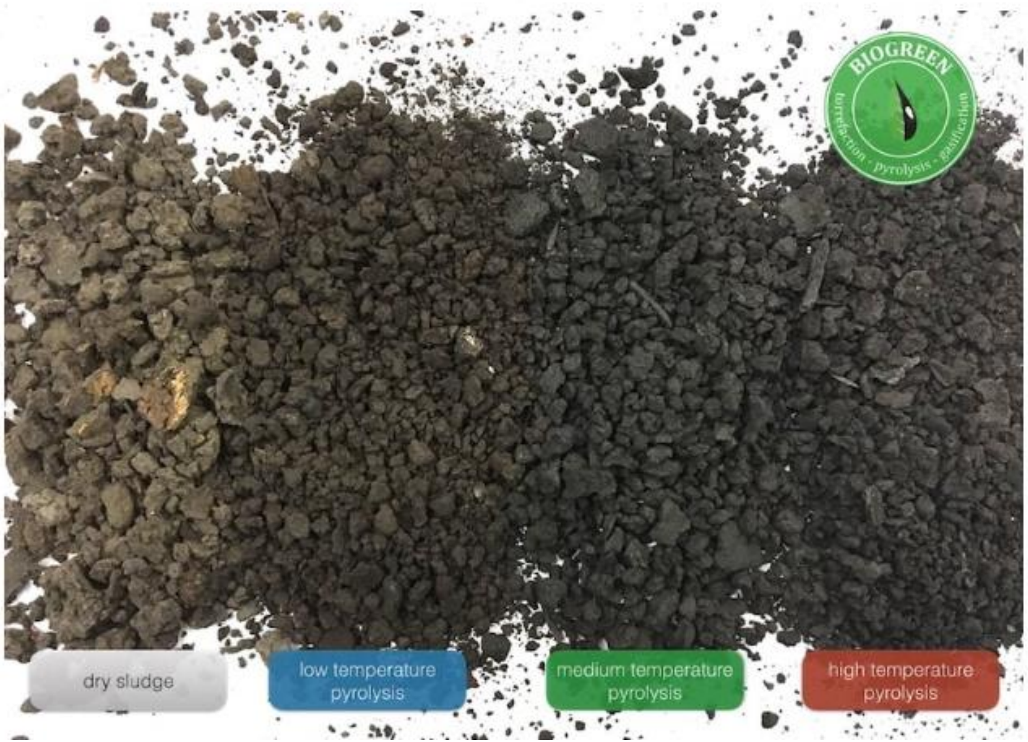
Eliminates waste

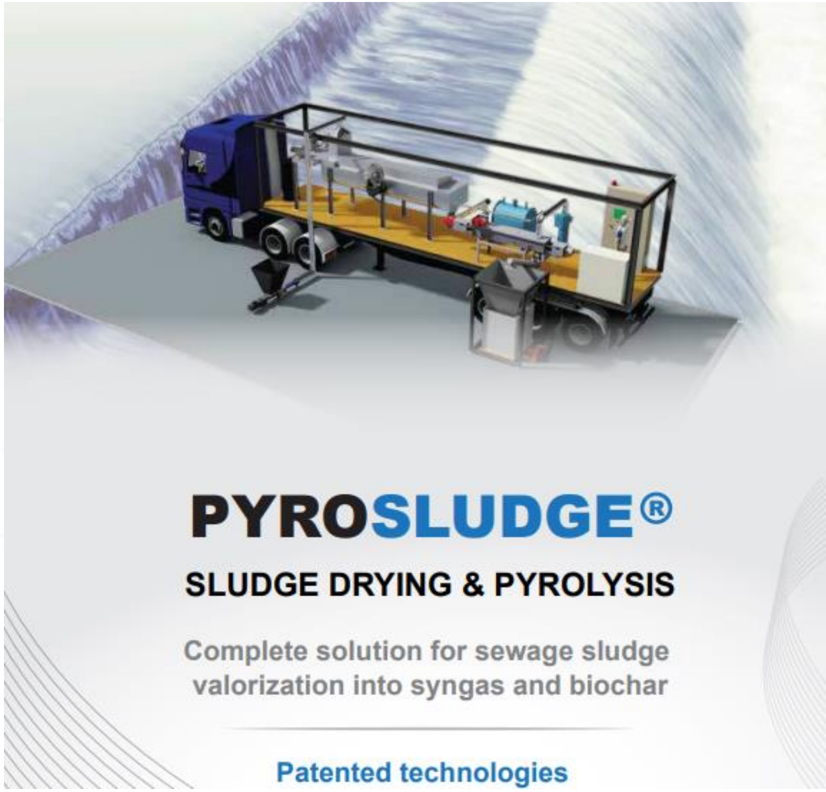
- Converts waste into a valuable product.
- Lowers environmental impact of waste management practices.

VTT

Biogreen®

Sewage sludge treatment at 800°c	
Bio-char	16-30 %
Syngas	35-45 %
LHV (MJ/m3)	15-20





Biogreen®

ETIA offers two solutions:

1 / Drying of sewage sludge with the KENKI dryer

- 50-1000 kg/h of wet sludge
- Sludge input: 80% moisture / sludge output: <10% moisture

2 / Sludge pyrolysis based on unique Biogreen® process

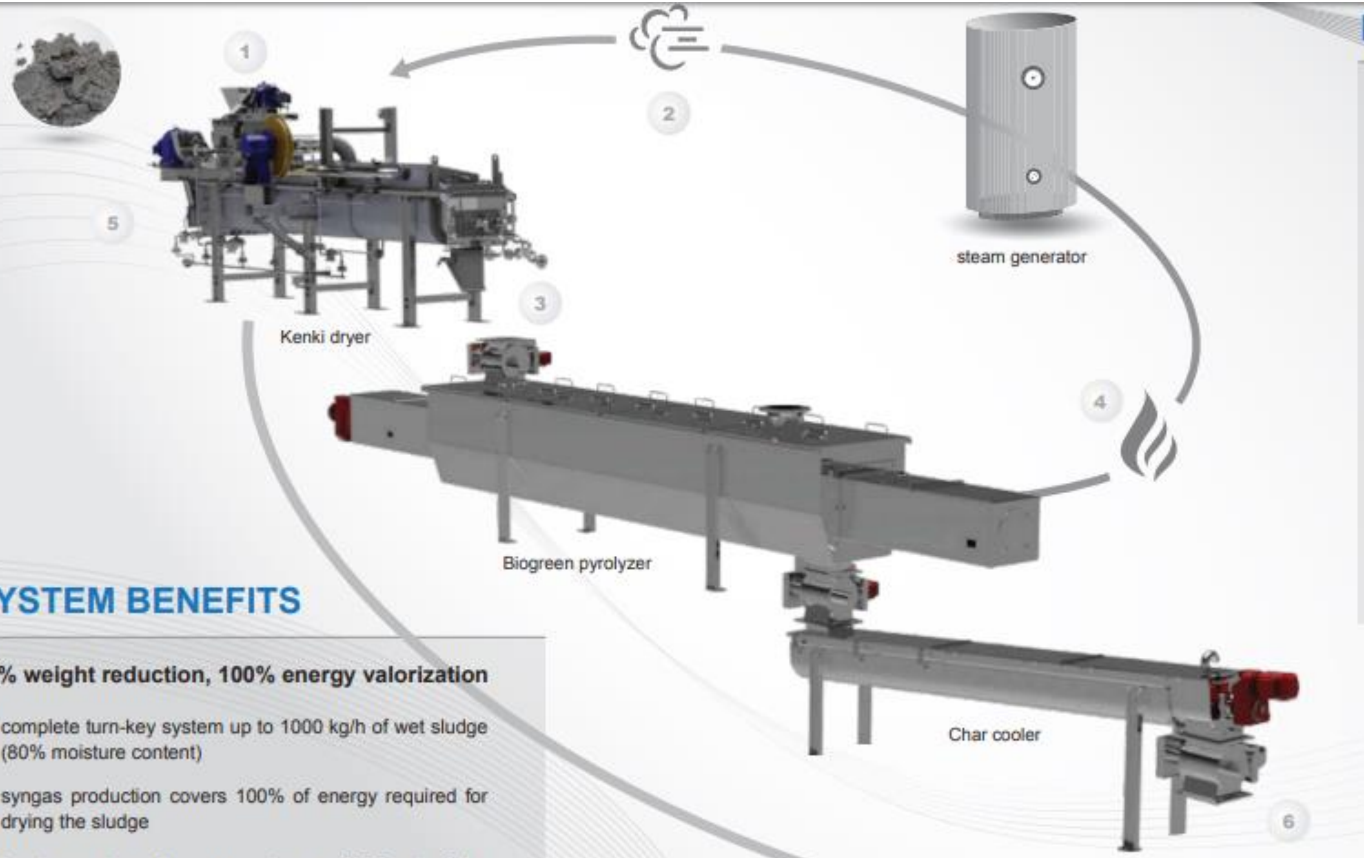
After drying to 85-90% DM, sludge is provided to the continuous Biogreen® pyrolysis system. Conversion is performed in oxygen-free atmosphere in unique construction of pyrolysis chamber, which guarantees constant quality of product obtained from the treatment. Produced gas can be used to produce heat, steam, electricity and many more.

- ✓ Continuous treatment
- ✓ Low maintenance costs
- ✓ Low energy consumption
- ✓ Eliminate odors
- ✓ Sterilized product (no pathogens)
- ✓ Eliminate risk of fire due to organic matter
- ✓ Produce energy with obtained syngas (up to 20 MJ/Nm3)
- ✓ Produce biochar which can be use as fertilizer and soil amendment (contains P, N, Mg, S, Si, K, Ca...)
- ✓ Very simple and compact solution with low CAPEX and OPEX

PROCESS DESCRIPTION

Wet sludge (15-20% DM) from mechanical dehydration system (centrifuge or filter press) is introduced into the steam heated twin screw Kenki dryer (1) powered by technological steam (2). The drying process allows to dehydrate the sludge from 80 to 10%. Dried sewage (3) is presented to the Biogreen pyrolyser that transforms the sewage in temperatures 750-850 degree C. Obtained synas (4) is used for fueling the boiler that generates the steam for sludge drying. The exhaust air (5) can be treated and dezodorized with biofilter or activated carbon. Biochar (6) is quickly cooled down in the special solid product cooler.

The sewage sludge is reduced to ca. 5% of its weight, free of patogenes, contaminations and odors. The product of process is biochar that can be valorized as solid fuel or fertrilizer according to its composition.



SYSTEM BENEFITS

93% weight reduction, 100% energy valorization

- complete turn-key system up to 1000 kg/h of wet sludge (80% moisture content)
- syngas production covers 100% of energy required for drying the sludge
- low temperature dryer guarantees no VOC out of the process
- pyrolysis guarantees complete sterilization of the sludge
- biochar, sterilized and odorless can be valorized as solid fuel or fertilizer (high phosphorus content)

Biogreen®

Biochar from sewage sludge
Sterilized, odorless soil enhancer or solid fuel

VTT

Recycling of sewage sludges: pyrolysis

Turning waste into carbon-phosphorus-fertiliser

greenlife technology for a better world.

- In conventional waste treatment plants nutrients such as carbon and nitrogen are not used as soil fertilisers because they are converted into CO2 and N2. If the sludge is burned afterwards, the phosphorus goes by the wayside too.
- The innovative pyrolysis process is saving nutrients by converting energy-rich sewage sludges into a valuable carbon-phosphorus fertiliser. Each pyrolysis plant is converting 4.000 tons of dewatered sewage sludge (25% dry matter) into 500 tons of pure biochar. The costs for sewage sludge disposal can be minimized. This process needs less energy than conventional techniques, reduces CO2 emissions and was awarded the Austrian Climate Protection Prize 2012 [Österreichischer Klimaschutzpreis 2012].

Technical data

⇒ Capacity: 4.000 t dewatered sewage sludges with 25 % dry matter per year

⇒ Disposal of sewage sludges per plant: up to 50.000 population equivalents (p.e.)

⇒ Production biochar: up to 70 kg/h or 500 t/year (depending on fuel selection)

⇒ Nominal fuel capacity: up to 500 kW per plant

⇒ Maximum operation limits: calorific value > 6 MJ/kg, humidity < 50 %

⇒ Thermal output up to 150 kW exhaust gas heat (depending on fuel selection)

⇒ Power input: approx. 7,5 kWel

⇒ Weight of reactor: approx. 10 t

⇒ Dimensions of reactor: installation in 20-feet-container (approx. 8m x 2,5m x 2,5m)

⇒ Remote data transmission / standardized remote diagnosis and remote maintenance

Recycling of sewage sludges: pyrolysis

Turning waste into carbon-phosphorus-fertiliser

greenlife
technology for a better world.

VTT

Workflow

Section 1, drying: Dewatered sludges of about 25 % dry matter content (DM) are dried to approximately 65 % DM. For this processing step waste heat from the reactor is used. The drying is enclosed, so there is no smell emission or odor nuisance.

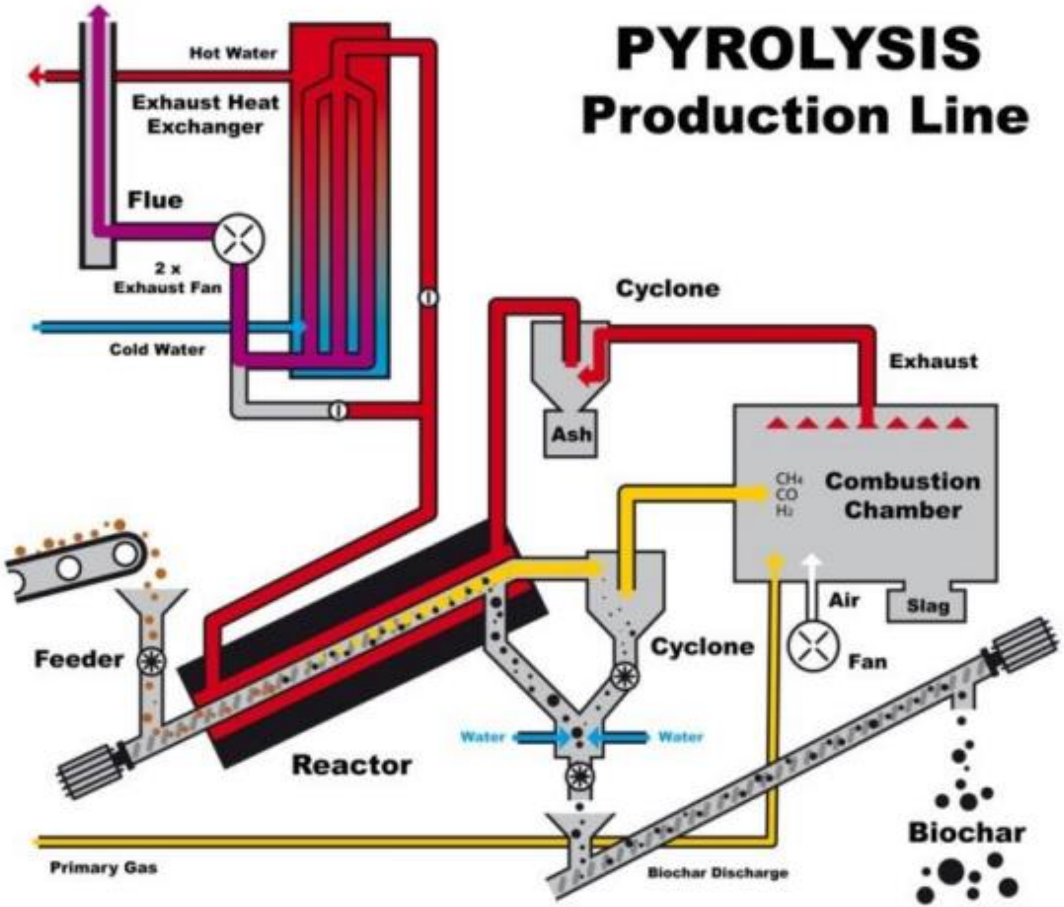
Section 2, feeding: The dry fuel is filled by wheel loader into the feed bunker and transported automatically via a scraper floor in the distributor bunker. From there, the material is introduced with a conveyor screw and via a rotary feeder into the reactor.

Section 3, reactor: The dried sewage sludge is conveyed through the reactor with a double screw and heated with exclusion of air to 600 degrees Celsius. The gas formed in the carbonisation process is extracted and fed into the combustion chamber. The material stays in the reactor for 30 minutes, so that hormonal contaminations are completely eliminated. What remains is pure carbon, which is conveyed after passing a water spraying system via a rotary feeder and a discharge screw in the biochar bunker. The resulting gases are burned in the combustion chamber at 1,100 degrees Celsius, and the flue gases are cleaned by a further cyclone. Subsequently, the gases are passed through the jacket of the reactor. Thus, the exhaust stream heats the material that has just been introduced in the reactor. In a subsequent heat exchanger, the residual heat of about 100 to 150 kW is removed and provided for the thermal drying of the sewage sludge.

Section 4, biochar bunker: The temporary storage for biochar, before it is used in soil conditioning or otherwise.

Greenlife Ressourcen GmbH, Habersdorferstraße 21b, A-8230 Hartberg
T. +43 3332 63374, office@greenlife.co.at, www.greenlife.co.at

Drying



- **Drying:** Dewatered sludges of about 25 % dry matter content (DM) are dried to approximately 65 % DM.
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Recycling of sewage sludges: pyrolysis

Turning waste into carbon-phosphorus-fertiliser

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- just been introduced in the reactor. In a subsequent heat exchanger, the residual heat of about 100 to 150 kW is removed and provided for the thermal drying of the sewage sludge.

Reactor components

⇒ **1: Combustion chamber**, for combustion of carbonisation gases
FLOX©-Burner, Pilot burner

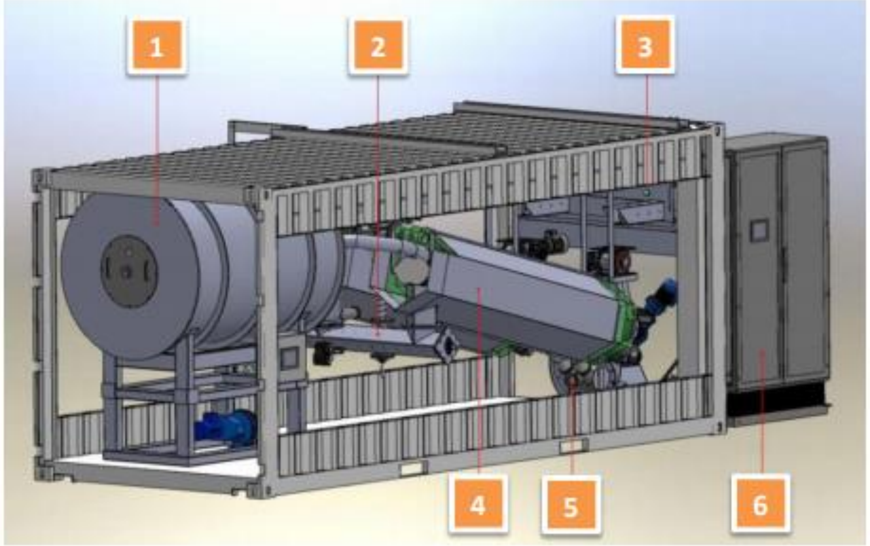
⇒ **2: Ash removal**, for quenching and removal of ash from the process
Screw conveyor to the rotary valve, water cooling system for biochar,
1 x rotary valve for air-tight discharge and burn-back protection

⇒ **3: Fuel distributor**, to introduce the fuel to the chutes at the reactor

⇒ **4: Reactor**, for heating and carbonization of the fuel
2 x rotary valves for anaerobic supply of fuel and burn-back protection

⇒ **5: Exhaust system** with optional heat extraction

⇒ **6: Cabinet for automation**, control system Siemens SPS7-300



Thermal drying of sludges

Types of water in sewage sludge

- Water content of the wet sludge can be as high as 98%
- The water fractions can be categorised into (i) free (or bulk) water, (ii) interstitial, (iii) vicinal (or surface) and (iv) chemically bound (or hydration)
- **Free water** can be removed via drainage, thickening, or mechanical dewatering.
- **Interstitial water**, trapped between the interstitial spaces of the flocs and organisms, can be removed by applying sufficient mechanical energy to squeeze the trapped water out.
- The dewatered sewage sludge contains about 73–84% of moisture.
- **Vicinal water**, multiple layers of water molecules held tightly to the particle surface by hydrogen bonding, its removal can only be achieved through the application of heat. Thermal drying can bring the moisture content down to about 5.6%.
- **Bound water**, the water that is chemically bound to the solid particles such as those associated with aluminium hydroxide [Al(OH)3] floc and slaked lime [Ca(OH)2]. The removal of this water requires changes in the structure or composition of the material, for example through thermal dehydration of [Ca(OH)2] to CaO. The amount of bound water in sewage sludge, however, is likely to be very small.

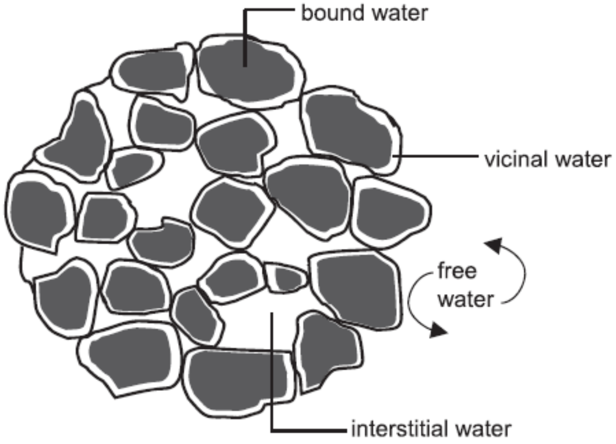


Fig. 3. Types of water in the sewage sludge.

98% > 73…84%

73…84% > 5.6%

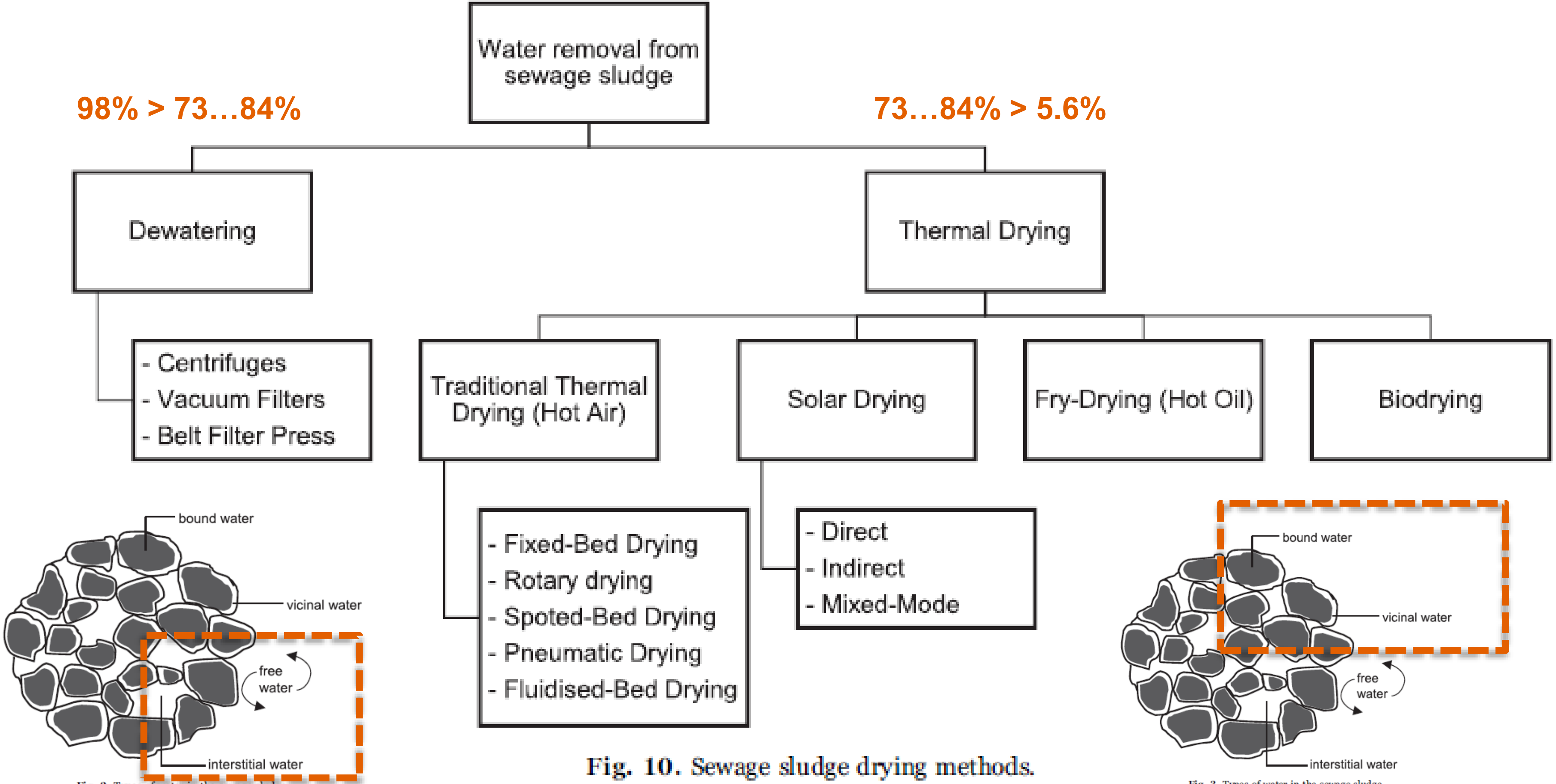


Fig. 10. Sewage sludge drying methods.

Fig. 3. Types of water in the sewage sludge.

Fig. 3. Types of water in the sewage sludge.

Goal of thermal drying

- **The process of sludge thermal drying is not a cheap activity mainly because of its highly energy demand. At least as long as there is no source of "waste" energy that can be reused for drying (e.g. biogas, flue gases of a comparatively high enthalpy, low parameter steam, …).**
- The main goals for sludge thermal drying, are:
  - to diminish the volume of sludge in order to make the transportation cost lower and the sludge storage easier
  - to increase the sludge caloric value, so that sludge could be easily incinerated without any additional fuel
  - to hygienize the sludge
  - to stabilize sludge
  - to improve the sludge structure before spreading by the agricultural equipment
  - to make sludge a fertilizer or a soil conditioner of higher market value.

Thermal dryers

- The classification of dryers is based on the method of supplying heat to the sludge particle. Dryers can be divided accordingly into:
  - **convective dryers** (represented by drum dryers) **in which sludge has a direct contact with the drying factor** (e.g. hot air);
  - **contact** (tray and layer) **dryers in which sludge has contact only with a hot surface, that is heated from the other side by the heating factor;**
  - mixed convective-contact dryers;
  - infrared dryers with the use of infrared radiation or high frequency currents.
  - **heat pumps**
- The choice of sludge drying facility will depend on the sludge type and the method of sludge utilization.
- Of the big variety of technical solutions of dryers contact and convective dryers are the most popular.

THERMO-SYSTEM®

Solar Sludge Drying System

Parkson's THERMO-SYSTEM® uses the sun as its main power source to generate 95% of the energy required for drying sludge. The result is significantly reduced operating costs compared to competing technologies like conventional gas or oil-fired dryers.

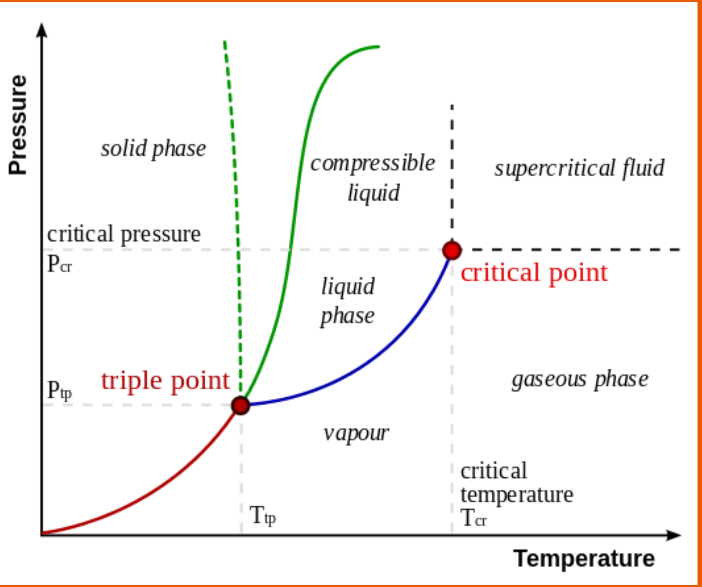
Our reliable solar sludge drying system is fully automated. A Programmable Logic Controller (PLC) carries a complex drying program that controls and monitors the entire drying process from start to finish, resulting in minimal operator attention or control. The system, which includes our sludge drying bed, is engineered to incorporate very few moving parts in order to maximize reliability and minimize maintenance costs.

The international award-winning Electric Mole® automatically turns, distributes and aerates the sludge to increase drying performance significantly.

Parkson's solar sludge drying system has been used in water and wastewater treatment plants ranging in size from 0.2 MGD to the world's largest solar drying installation of 80 MGD.

AFM Parts & Services | Quote Request | Contact Us

https://www.parkson.com/products/thermo-system



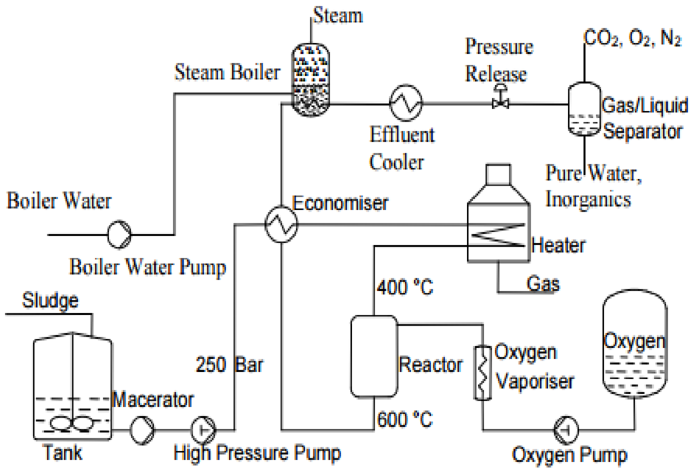
Hydrothermal conversion of biomass and waste

Hydrothermal processes (HTP)

		For wet feeds	Drying needed	
		Feedstock state		Temperature
		Wet	**Dry**	increase ↓
Primary product	**Solid**	HTC	Torrefaction	180-250C
	Liquid	HTL	Pyrolysis	250-350C
	Gas	HTG	Gasification	350-800C

- Hydrothermal process (HTP) is any process that involves liquid/supercritical water (critical point of water 374 C, 218 atm) at elevated temperatures and pressures
- http://task34.ieabioenergy.com (HTL)
- http://www.mobileflip.eu/index.htm (HTC)

Supercritical water oxidation (SCWO) wet oxidation/combustion



- SIAD has signed an agreement for the commercialization of the Aqua Critox® process, from the Irish company SCFI, Super Critical Fluid International, offered by SIAD in Italy, Austria and in many countries of Eastern Europe.

- SCWG destroys wet biomass such as sludge while efficiently producing marketable byproducts (e.g., heat, H2, and CO-rich fuel gases).
- SCWG can convert wet biomass directly, thereby avoiding high-energy drying processes.
- Air emissions include CO2, O2 and N2 with no NOx, SOx or VOCs, and minimal odour.
- Supercritical-water, fuel-gas production can be catalytically enhanced.
- Adding catalysts or oxidants to SCWG can further reduce operating costs by creating self-sustaining reactions under milder conditions with even shorter residence times.
- Advantages: small footprint, inert residuals, low air emissions, significantly reduced sludge volume, potential for recovery and recycling of heat and materials
- The water separated from the aggregate does not need further treatment.

Supercritical water (SCW) is a highly compressed fluid which exists at T > 374°C and p > 22.1 MPa.

HTL Overview

Hydrothermal Liquefaction (HTL)

Conversion of a biomass slurry (e.g., wet waste, wood, algae) to biocrude and aqueous product

- 300–350°C
- 2800–3000 psig

HTL


Slurry Feedstock

Biocrude Product

+

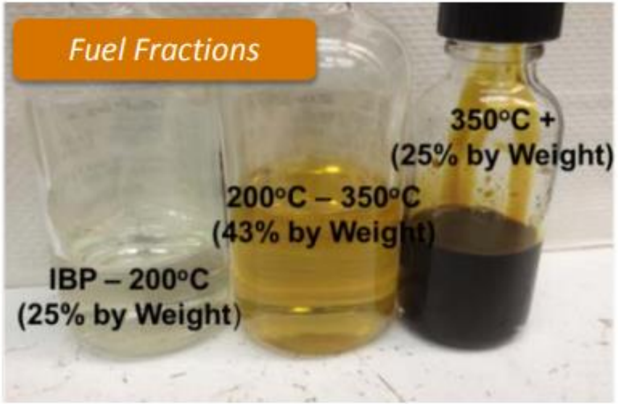
Aqueous Product (contains organics)

Catalytic Hydrotreatment

Hydrotreated Bio oil

Biocrude is upgraded via **Catalytic Hydrotreatment** and fractionated by **Distillation** to gasoline, diesel, jet fuel, and bottoms

Distillation



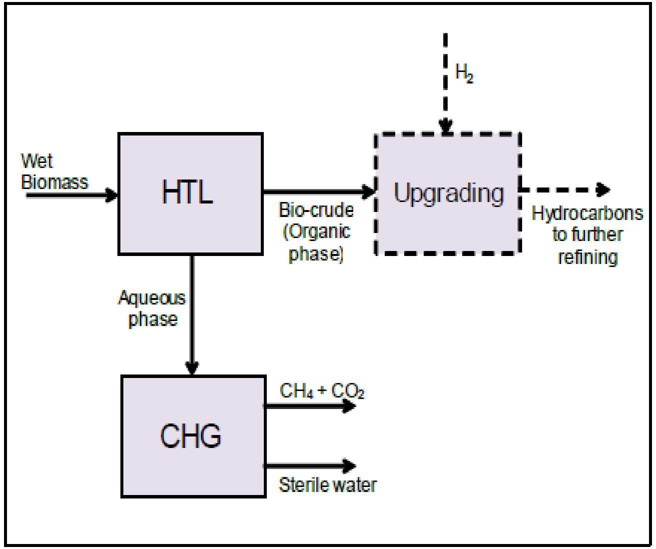
Hydrothermal liquefaction (HTL) of sludges

VTT

https://www.sciencedaily.com/releases/2016/11/161102134504.htm

- In HTL the feedstock is converted in the presence of hot compressed water, which acts both as a reactant and as a catalyst.
- HTL is typically carried out at 280-370°C between 10-25 MPa. Subcritical water has a lower viscosity, a lower dielectric constant and a higher ionic product than normal water. The combination of these factors results in a higher solubility of organic compounds and increased reaction rates of base- and acid catalysed reactions, which in turn makes subcritical water an excellent medium for converting biomass-derived organic molecules into value added products.
- Because drying of the feedstock is not required, HTL is a promising process for very wet feedstocks.

Hydrothermal liquefaction of sludges



Note: Dashed lines are optional

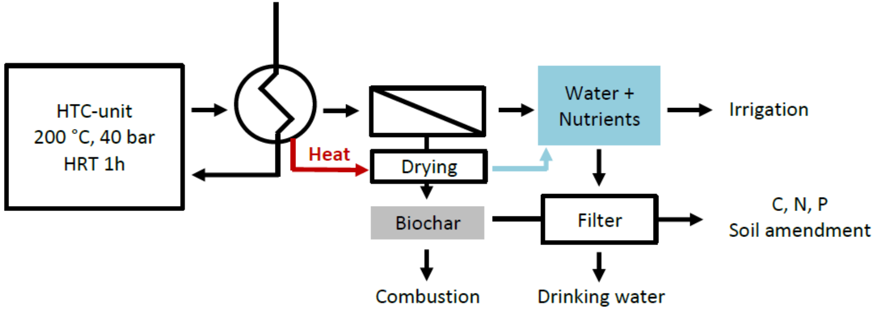
- PNNL (USA) has licensed its HTL technology to Genifuel Corporation, which is now working with Metro Vancouver, a partnership of 23 local authorities in Canada, to build a demonstration plant. Metro Vancouver plans to move to the design phase in 2017, followed by equipment fabrication, with start-up occurring in 2018.
- In addition to the biocrude, the liquid phase can be treated with a catalyst to create other fuels and chemical products. A small amount of solid material is also generated, which contains important nutrients.
- The aqueous product can be treated by catalytic hydrothermal gasification to obtain clean water and methane gas.

Hydrothermal carbonization (HTC)

- **HTC is carbonization of biomass in water at 180-250 °C from 2 to 8 hours at in self-generated pressures (< 50 bars)**
- The main product is **solid char**, hydrochar. Other products include non-condensable gases (mostly CO_2) and aqueous phase products (e.g. residues, sugars, organic acids) together with water.
- HTC is an ideal process for organic waste streams with high moisture content, such as sewage sludge. **One of the main focus areas in HTC development in Europe has been its use as a dewatering process for sewage sludge.**

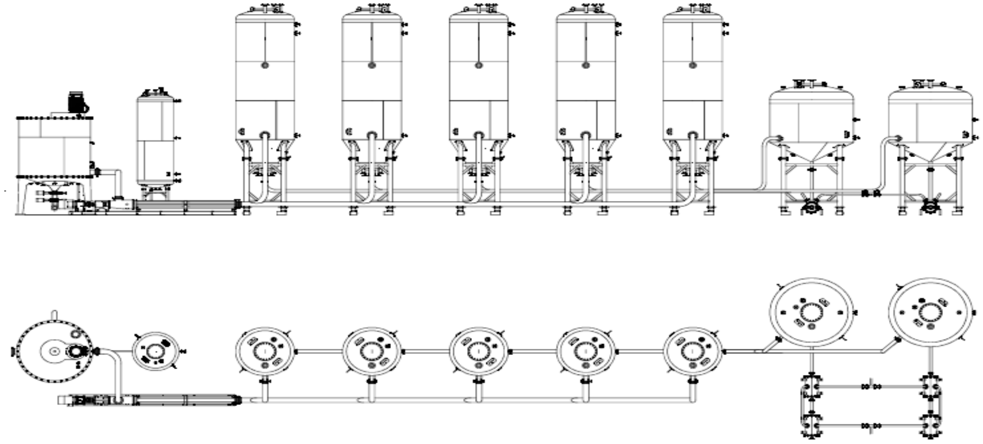
Sludge Valorization by HTC

- P is not the only valuable in sludge – C, N and H_2O are valuable resources
- Hydrothermal carbonization (HTC) enables the formation of hydrophobic biochar carbon and separation of H_2O with soluble P and N
  - Exothermic process, P auto-leaching by organic acids
  - Easy water separation
  - Destruction of organic pollutants & pathogens
  - Fertilizing soil amendment product



Pilot, demonstration plants

- HTC is used by **AVA-CO2** for the production of **high performance carbon materials** and for the energy efficient valorisation of municipal sewage sludge or other wet organic residues.
- The HTC procedure is a redundant multi-batch process. Due to the high redundancy and simple operations, the process excels in reliability. The excellent carbon balance of the HTC technology and the intelligent process management for the recirculation of HTC process water allows it to utilise more than 90 % of the carbon in the biomass. The plants are robust and reliable.



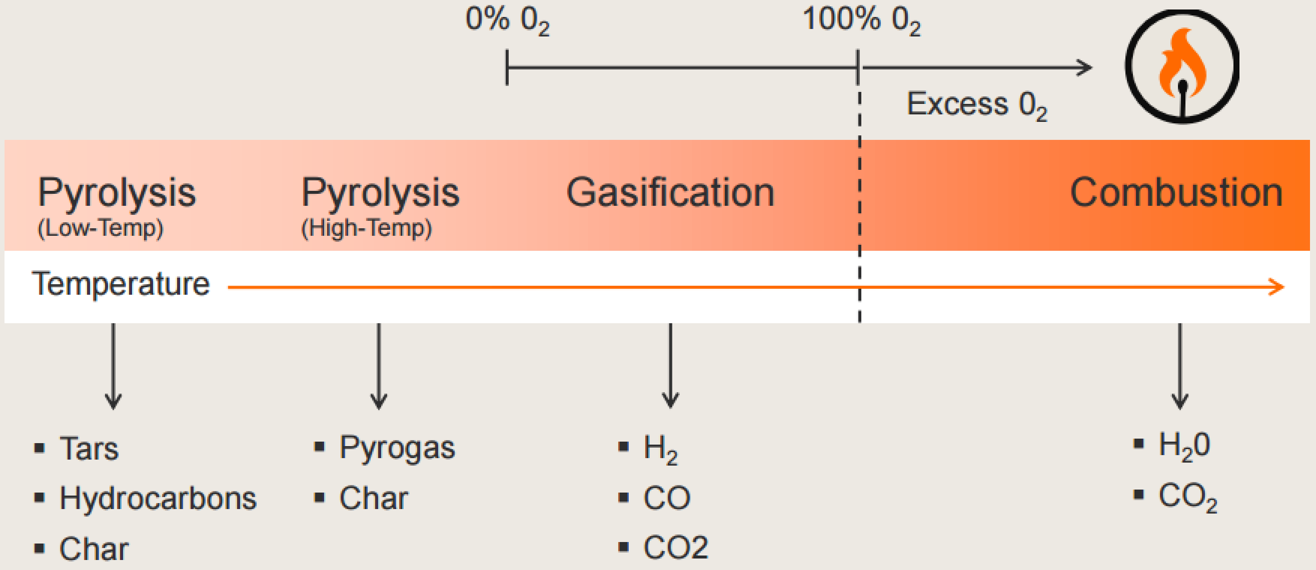
(AVA CO2, http://www.ava-co2.com/web/pages/en/technology/hydrothermal-carbonization.php)

Summary

Summary

- Traditional means of disposing sludge include landfilling, agricultural recovery and incineration. These methods will not any longer be available in the same extent as earlier due to tighter environmental standards and changing business environment.
- Pyrolysis and gasification can be a dominant method of sewage sludge disposal in the near future.
- The high moisture content is the biggest obstacle in the application of thermochemical process in converting sewage sludge to energy or fuel.
- The selection of the best strategy must take into account the overall energy balance of the system which depends largely on how the water in sludge is handled/removed and how the sludge is transported to its processing facilities.
- Hydrothermal processes offer an option to use directly the wet feed. HTC is the most mature technology to produce biochar.
- The usability of product and co-products will also determine the feasibility

Understanding the differences among thermal conversion technologies.



100% oxygen means sufficient oxygen to oxidize all combustible species.

http://www.ieabioenergy.com/