



# Using Straw and MSW for Biorefineries in Denmark – Technical Developments and Demonstration Activities

Henning Jørgensen

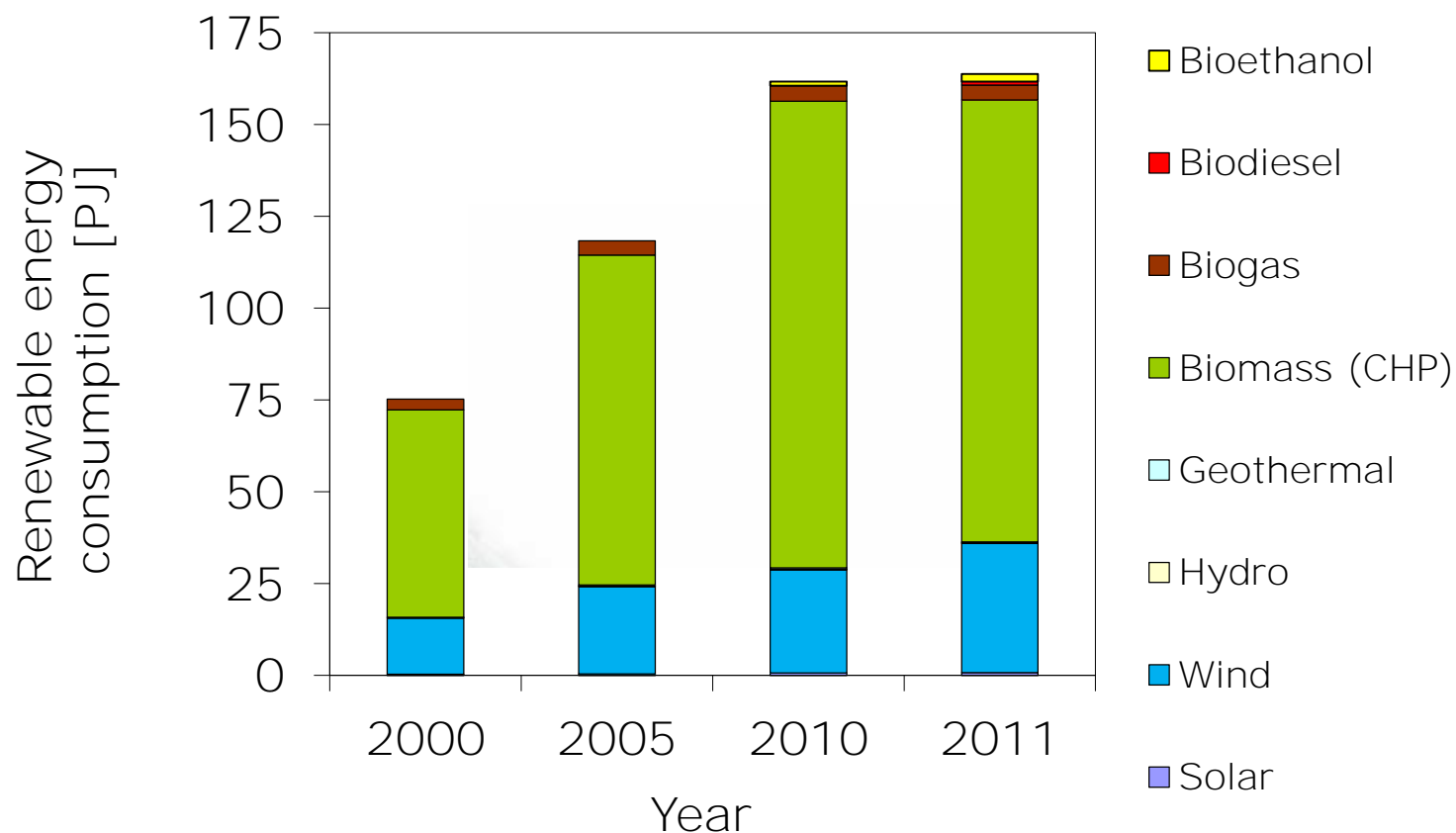
Department of Geosciences and Nature Resource Management  
Faculty of Science

University of Copenhagen

(E-mail: [hnj@life.ku.dk](mailto:hnj@life.ku.dk))



## Renewable energy in the Danish energy system



In 2011 24% of the Danish energy consumption was supplied from renewable energy and bioenergy accounted for 68% hereof. Liquid biofuels accounted for 4% of transportation fuel in 2011



## Denmark is an agricultural country

- 14% of land is forest
- 61% of agricultural land
- Produce 8-9 million tons of grain and 5 million tons of straw
- 0.5 million cattle/cows but 28.5 million pigs (5.5 million humans)
- Straw and manure are plenty resources for bioenergy or biorefining



## Danish expertise on use of straw for energy

- More than 20 years of experience with logistics, handling and incineration of straw
- 1.5 million tons collected for heat and power generation annually (around 1/4 of annual production)
- Several technologies for generation of liquid biofuels from straw being developed in Denmark



## Danish companies involved in bioenergy/biorefining

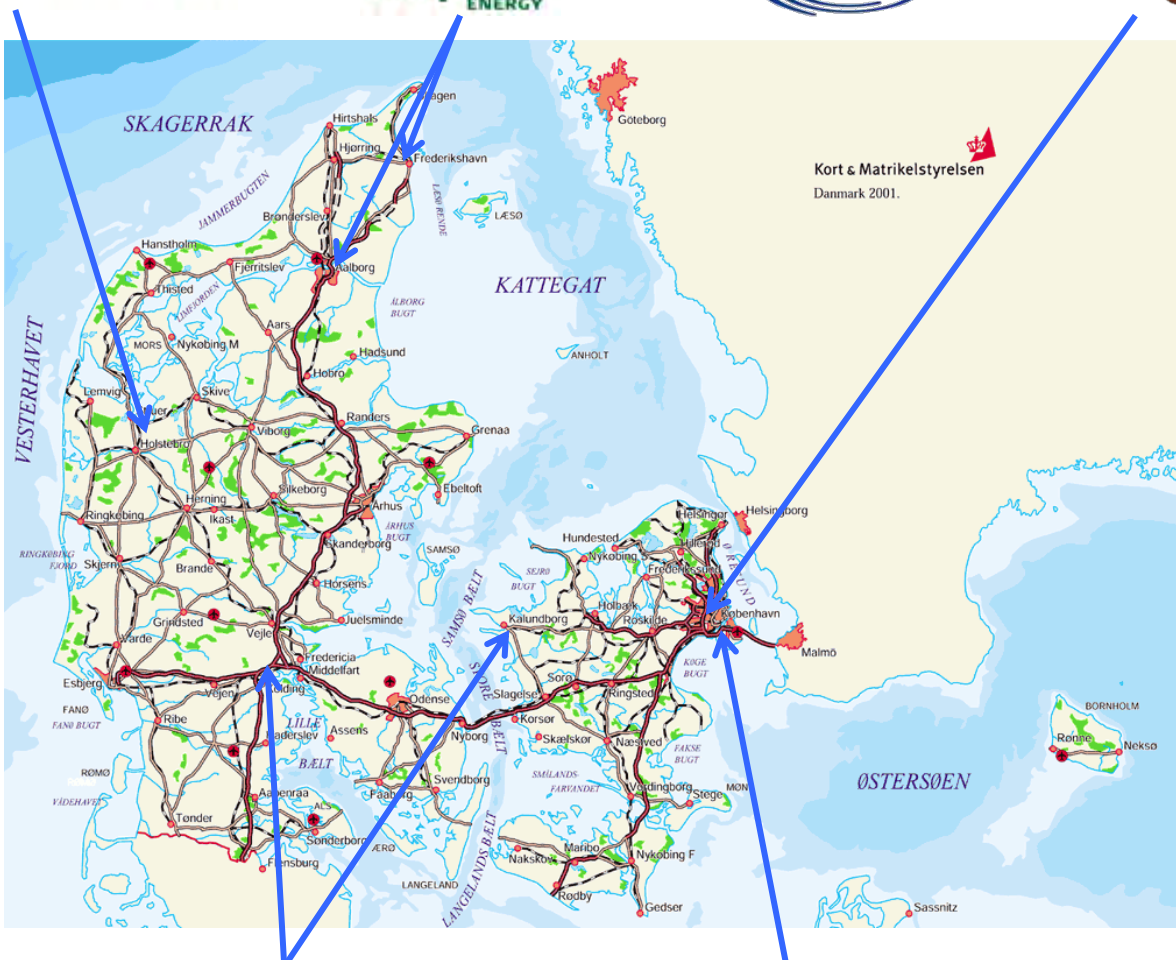
- **DONG Energy**
  - Inbicon - Bioethanol production from biomass (Pilot + Demonstration)
  - Pyroneer – low temperature biomass gasifier (demo)
  - REnescience - Utilisation of MSW (Pilot)
- **Biogasol and Estibio**
  - Bioethanol and biogas production from biomass (pilot + part of process in demo). Process technology and microorganisms
- **Steeper Energy**
  - Hydrofaction™ **technology for production of** biooil from biomass
- **Haldor Topsøe**
  - Technologies (catalysts) for production of liquid fuels from syngas (pilot), catalytic conversion of sugars to chemicals
- **Terranol** – Yeast for 2. generation bioethanol
- **Novozymes** - world leading enzyme company



# The Danish biorefinery landscape



MAABJERG ENERGY CONCEPT  
HOLSTEBRO STRUER



Kort & Matrikelstyrelsen  
Danmark 2001.



REnescience  
value from waste

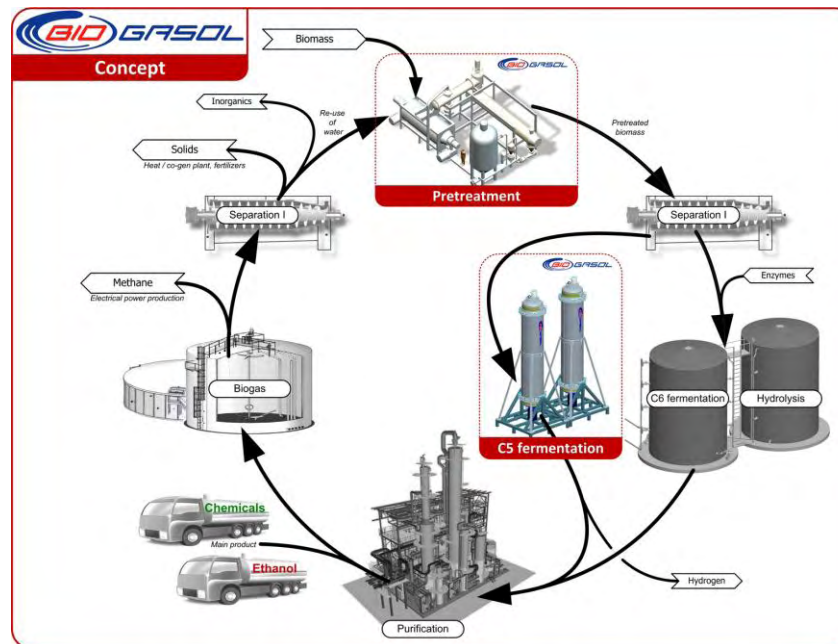


# BioGasol and Estibio



BioGasol and sister company Estibio develop biochemical process technologies for the renewable energy and chemical industry

Core technologies:  
The Carbofrac<sup>®</sup> pretreatment system and the Pentocrobe<sup>®</sup> fermentation organism



Copenhagen Biofuel Project (2011-2015) - Plant located near Copenhagen. 4t/h pretreatment incl. biomass handling, separation and smaller scale fermentation. Second phase will comprise the whole integrated process plant incl. large scale fermentations and distillation.



# Pretreatment – Carbofrac™

*Industrial solutions for small-scale production*



**Small demo pretreatment**



Continuous pretreatment units delivering homogenous pretreated biomass with high sugar release

Tested at demo scale (1 t/h)

First units sold to Sweetwater Energy in USA



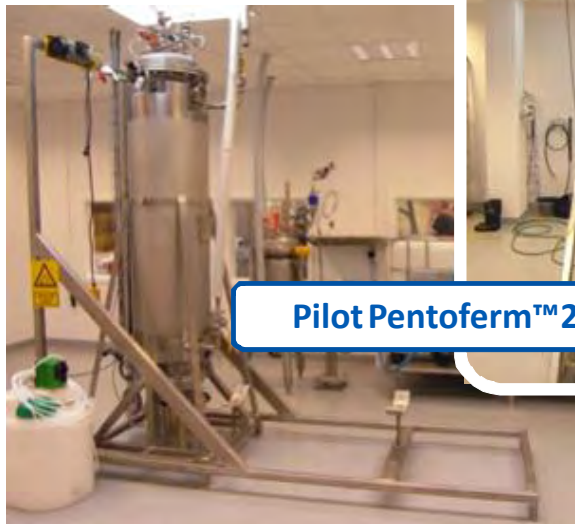
**Pilot pretreatment**





# Pentoferm™ – C<sub>5</sub> Fermentation

40% more ethanol from 1 ton of biomass



Pilot Pentoferm™ 250L



Pentocrobe™



Pilot Pentoferm™ 2.5m<sup>3</sup>

A continuous thermophilic (70°C) fermentation of **all** lignocellulosic sugars incl. C<sub>5</sub>

**Pentoferm™** upflow reactor system design, installed and operated:  
2L → 250L → 2.5m<sup>3</sup>

**Pentocrobe™** production organism which has been genetically modified to avoid production of lactate and acetate

## Products

**Pentocrobe™ 463S and 463X**

- Ethanol productivity: 1-4 g/L/h
- Sugar conversion: above 95% of total sugar monomer (including arabinose)
- Ethanol yield: above 0.48 g ethanol per g consumed sugar
- High ethanol titre
- C<sub>6</sub>/C<sub>5</sub> co-fermentation

## DONG Energy new bio solutions



<b>Inbicon</b>	Enzyme-based bio-refining of straw and other biomass that enables fermentation to bioethanol and production of other products such as biofuel pellets.
<b>REnescience</b>	Innovative sorting of household waste into solid and organic fractions and pretreatment using enzymes enables efficient energy utilisation.
<b>Pyroneer</b>	Low-temperature gasification results in efficient conversion to thermal biogas and efficient energy utilisation of residual biomass from agriculture and industry.



**REnescience**<sup>®</sup>  
value from waste

**Pyroneer** ●●●  
Biomass Gasification

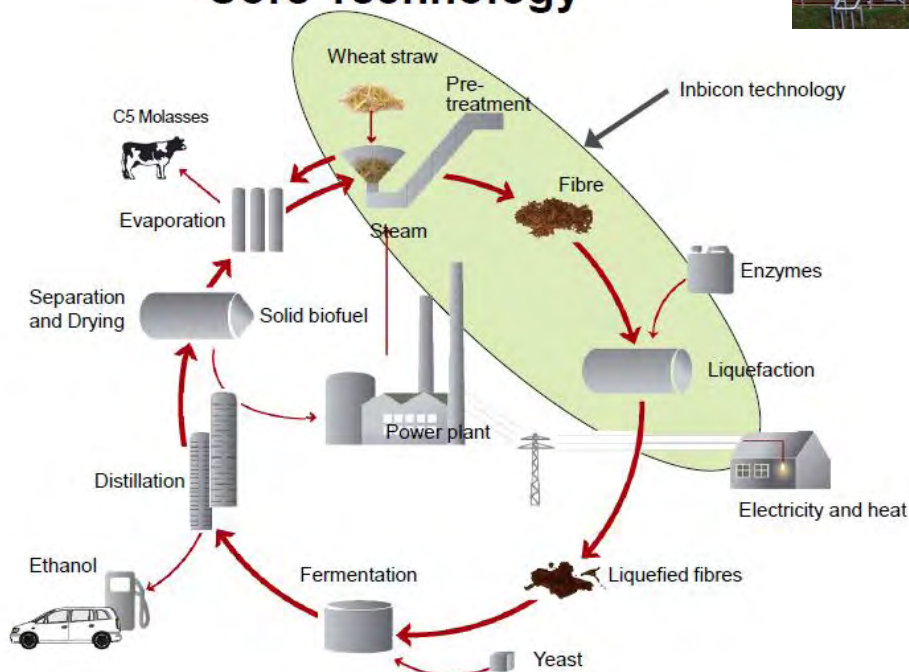


## Inbicon – biomass to ethanol

- Been operating pilot scale unit since 2003
- Operating fully integrated demo scale plant since 2009



### Inbicon Biomass Refinery™ Core Technology



### Facts demo plant

- Fully automated – 3 operators
- 4 ton/hr of straw
- 5.4 mill l of ethanol/yr
- 13,100 tons of ligning pellets/yr
- 11,250 tons of C5-molasses/yr
- Rebuild in 2013 to include C5 fermentation using GMO yeast

## Inbicon core technologies features

- Simpel process
- Yield of ethanol 180-200 l ethanol/ton straw (86% DM) from C6 only
- High dry matter in pretreatment (35%) and hydrolysis (25% WIS) resulting in high ethanol concentration in beer (10 v/v %)
- Integrated contamination control (no antibiotics)
- Successful tests with C5-fermenting yeast strains (from partners)
- Tested with multiple feedstocks in pilot scale: wheat straw, sorghum, miscanthus, corn stover, bagasse, palm oil residues

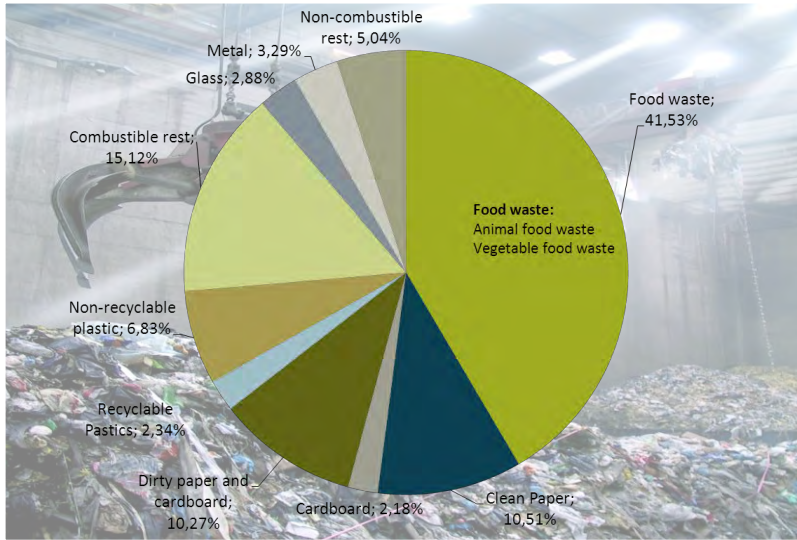


Pilot plant operating in Tawau, East Malaysia. Converts empty fruit bunches into 2nd generation bioethanol. The project is part of an on-going collaboration between Inbicon, Mitsui Engineering & Shipbuilding and Teck Guan.



# REnescience

## Conventional incineration



Biodegradable    Recyclables    Combustible



## REnescience process



Biodegradable    Recyclables    Combustible



Biodegradable    Recyclables    Combustible



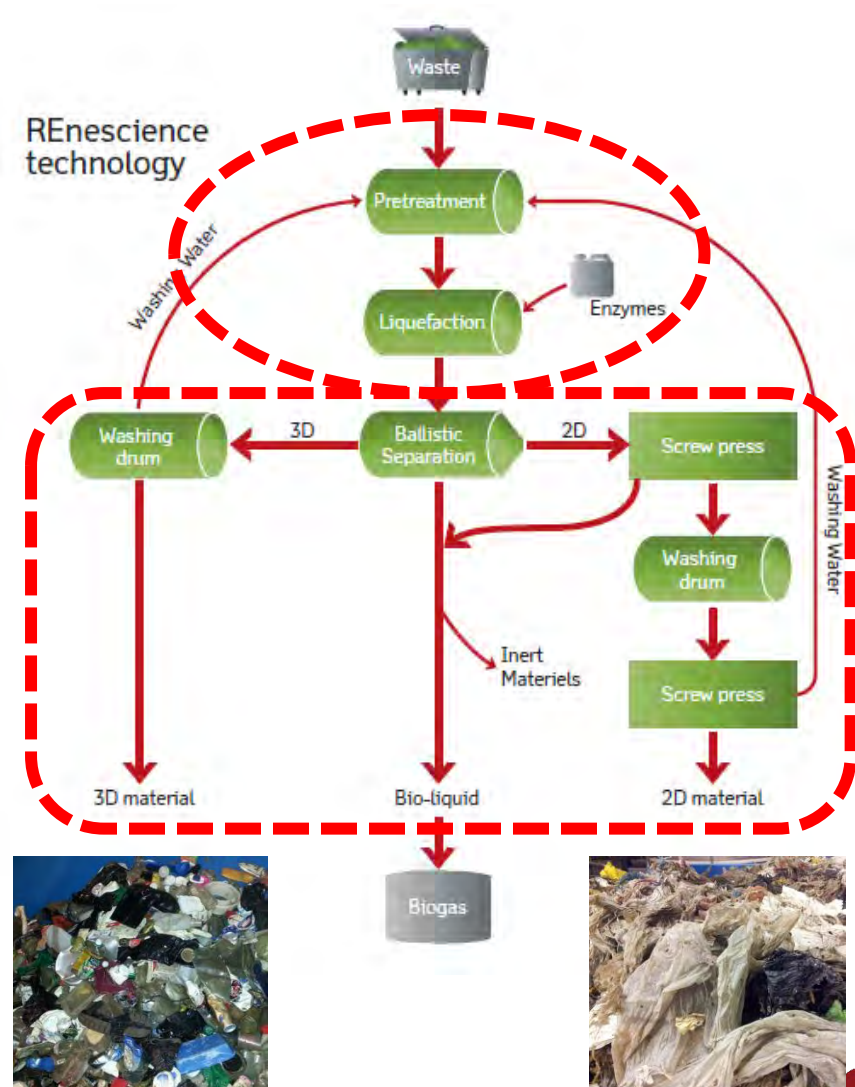
## REnescience – refining mixed municipal solid waste

Enzymatic degradation and liquefaction of bio degradable materials:

- Core technology
- Makes the solid – liquid separation and sorting possible

Downstream processing is all of known technology

- Stable process

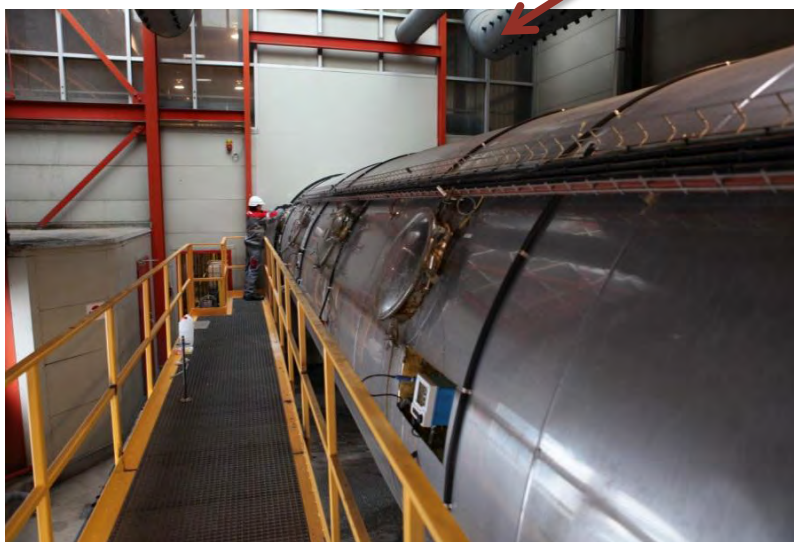
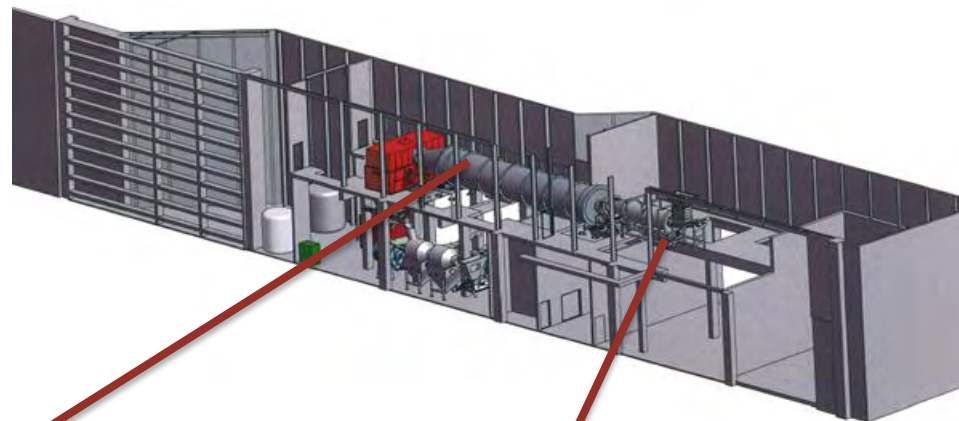


## REnescience pilot plant

Pilot plant (800 kg/h) situated on Amager Ressource Center in Copenhagen

It has been in operation since December 2009

More than 8.000 operating hours



## Enzymatic treatment opens for efficient biogas production

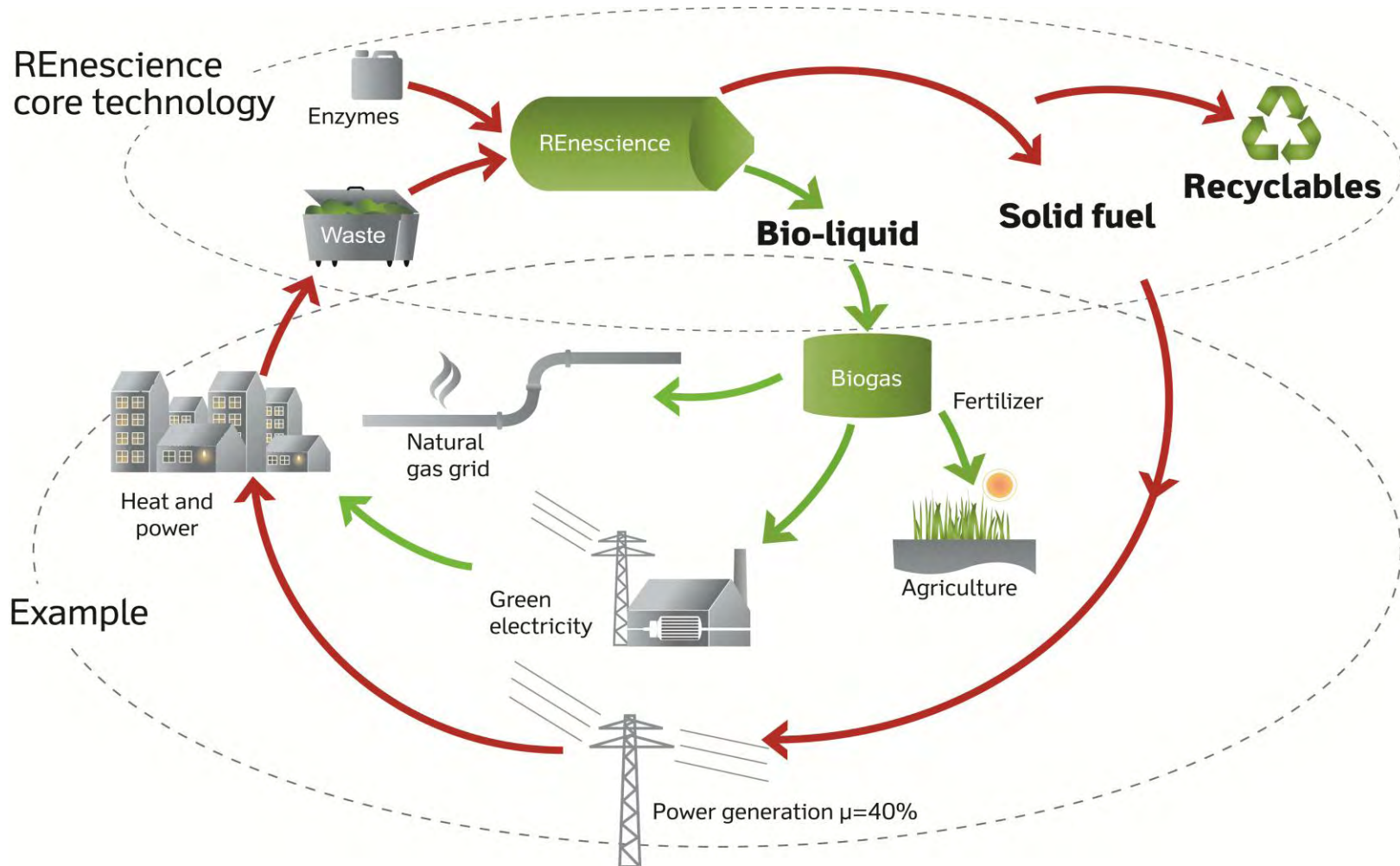
- > 90 % capture of organic material including paper and cardboard in bio-liquid (contains fibres, carbohydrates, fat, protein)
- 12 – 25 % DM in bio-liquid (depending on settings)
- Mesophilic and thermophilic bacteria are stable on bioliquid. Even when lowering retention time to 15 days
- No pH regulation even though bioliquid has pH of 4.2

Feedstock	Biogas potential (Nm <sup>3</sup> CH <sub>4</sub> /ton VS)	Nm <sup>3</sup> CH <sub>4</sub> /ton feedstock
Animal manure	250	10
Slaughter-house waste	500	32
Source-separated waste	300	60
Waste - Bioliquid	385	95





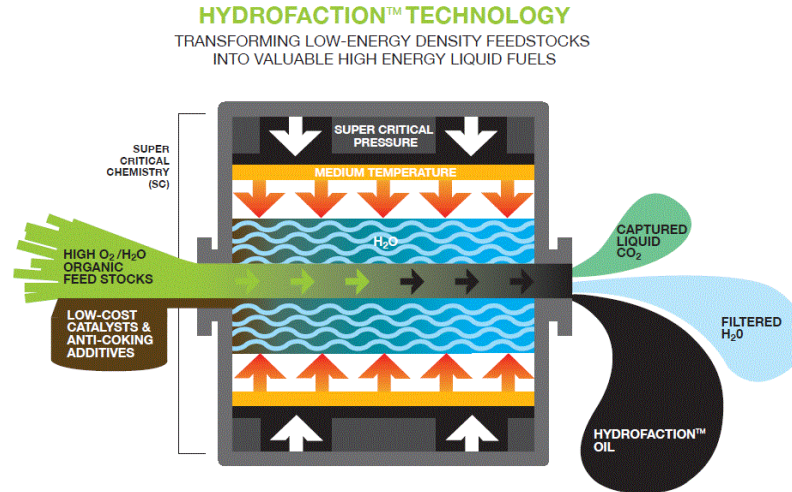
# The REnescience Waste Cycle



# Steeper Energy



The Steeper Energy Hydrofaction™ technology uses super critical conditions (300 bar and 400° C) to transform low-energy density organic feedstocks into valuable high-energy density products (biooil)



Bench/pilot scale plant operated at Aalborg University since early 2013 – 15-20 kg biomass/h resulting in 3 l/h biooil

Commercial plant in Frederikshavn for production of 50.000-150.000 tonnes/yr of marine diesel under developmet



## Technology development and demonstration in Denmark

- Denmark has 20 year of experience with logistics and handling of biomass for bioenergy
- Several companies with potential, promising and proven technologies ready for commercialization
- Presence of companies with competences within the whole process chain from biomass to bioenergy
- Close collaboration between companies and universities





E-mail: [hnj@life.ku.dk](mailto:hnj@life.ku.dk)

Thank your for your attention

Contacts:

BioGasol – [www.biogasol.com](http://www.biogasol.com)

Estibio – [www.estibio.com](http://www.estibio.com)

Inbicon – [www.inbicon.com](http://www.inbicon.com)

REnescience - [www.dongenergy.com/renescience](http://www.dongenergy.com/renescience)

Steeper Energy – [www.steeperenergy.com](http://www.steeperenergy.com)

Biorefinary Alliance - [www.biorefiningalliance.com/english](http://www.biorefiningalliance.com/english)



Financial support  
Danish Energy Agency  
Energy Technology Development and Demonstration Program

