Biorefineries in Europe

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Current Status of Advanced Biorefineries in Europe using (Bio)chemical Processing of Biomass

Feedstocks: Lignocellulosic materials, MSW, Other organic wastes, Algae

Lignocellulosic ethanol, higher alcohols

Hydrocarbons from sugars (biochemical)

Hydrocarbons from sugars (chemical)

Algae

Biochemtex/BetaRenewables

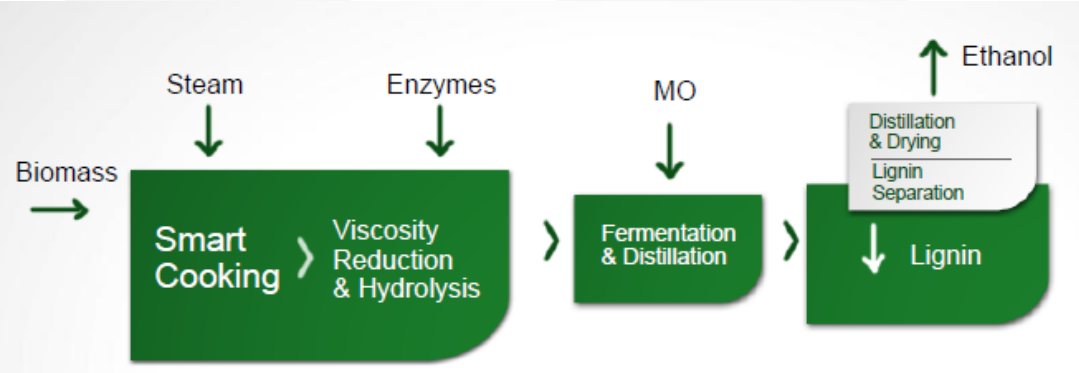
- First **commercial** cellulosic bioetanol plant in Europe has been deployed in Crescentino, Italy, since end 2013

Raw material: 270.000 ton/year cereals straw, (*in future*: *arundo donax)*

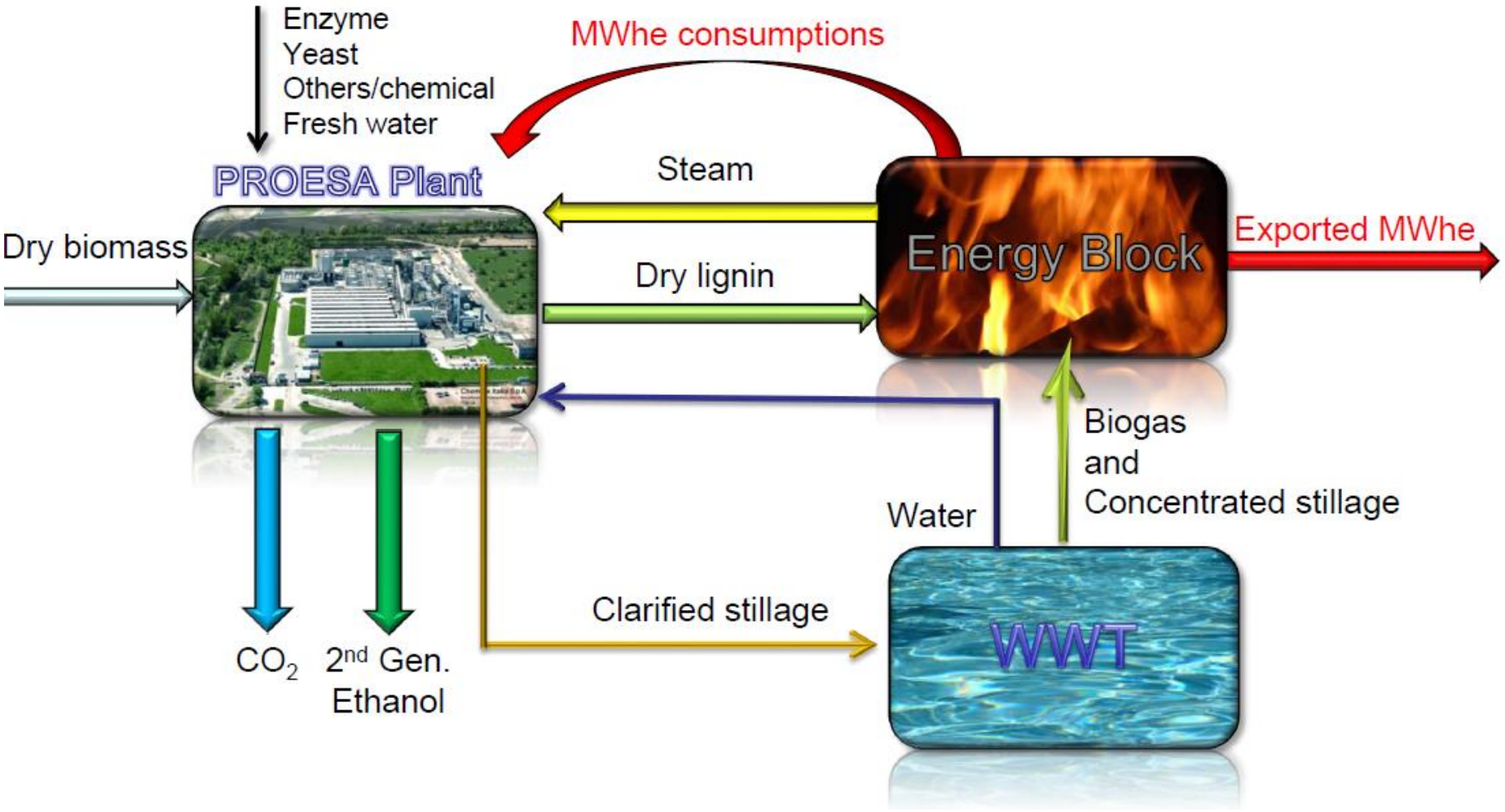
Product: Ethanol (60.000 ton/year), biogas, H_2, lignin for energy

Production process: uncatalyzed two-stage steam explosion, enzymatic hydrolysis and co-fermentation of C_5 and C_6

Proesa® technology – Phase 1



2G Ethanol plant configuration



Source: Dario Giordano (Biochemtex) at 4th ICLE

Proesa® technology (Biochemtex/Beta-renewables) – Phase II

PROESA® Cellulosic Sugar Technology

Pre-Treatment Section

Enzymatic Hydrolysis Section

BIOFUELS

- **Ethanol**
- **Bio-Jet**
- **Butanol**

BIOCHEMICALS

- **Fatty Alcohols**
- **1,4 Butanediol**
- **Farnasene**
- Acrylic Acid
- Succinic Acid
- Others

LIGNIN CHEMICALS

- Phenols
- Xylene
- Terephthalic Acid

Inbicon/Dong Energy

Local: Kalundborg (Denmark) – Demo plant

Start-up: 2009

Raw material: 30.000 ton/year wheat straw

Product: Ethanol (4.300 ton/year), C_5 molasses, lignin for energy

Production process: Hydrothermal pre-treatment, enzymes from Novozymes, enzymatic hydrolysis and co-fermentation of C_6 (phase 1); C5+C6 co-fermentation (phase 2). Stand-alone plant.

Demo

www.inbicon.com

Inbicon version 2 – C6+C5 mixed fermentation – proven in demo scale

Inbicon Concepts

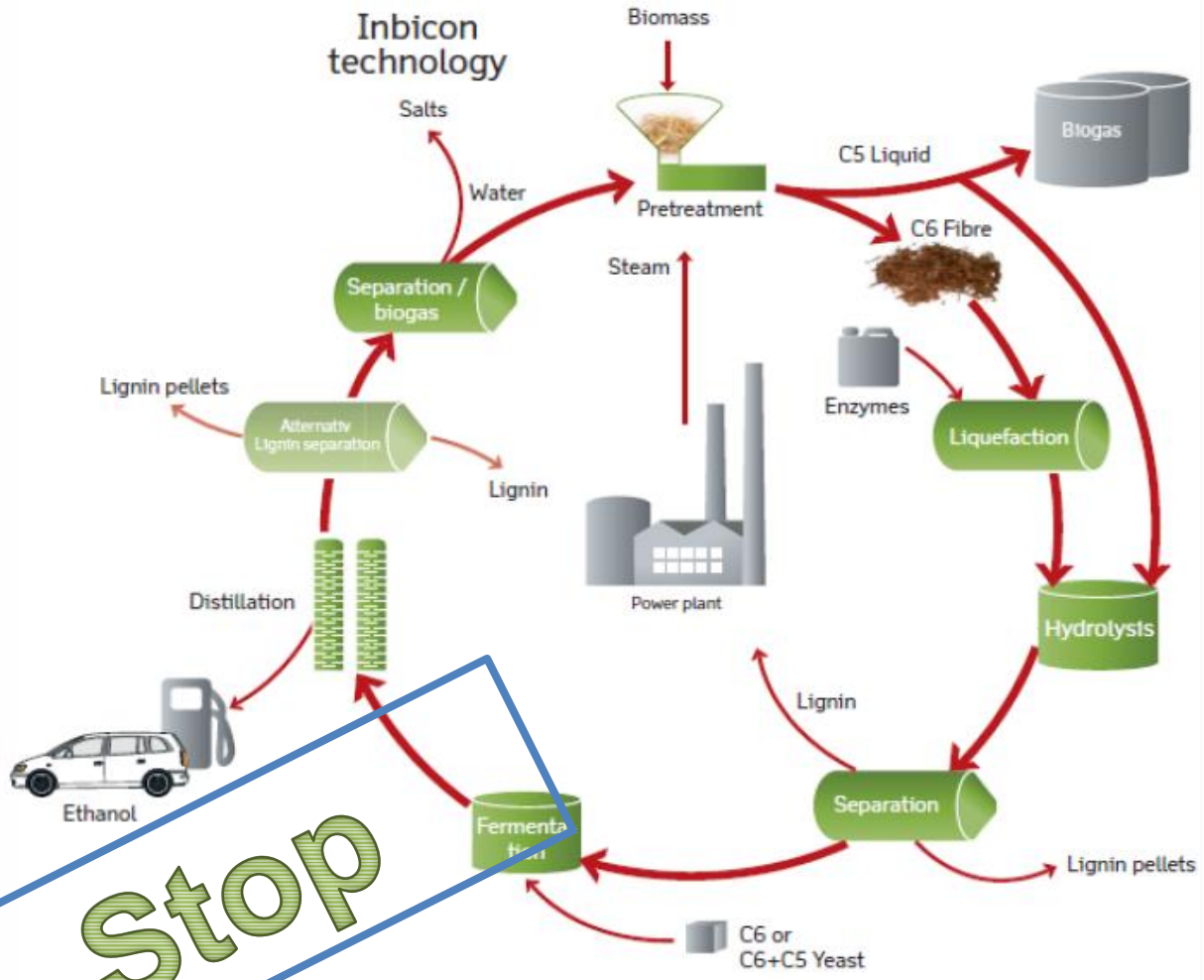
- Biomass
- Water
- Enzymes
- Advanced yeast (GMO)

⬇

- Bioethanol
- Solid Biofuel
- Vinasses

- Improving ethanol yield with 40% in comparison to Inbicon version 1

- Typical yield of 280-300 l etoh per ton of biomass dry matter



Stop

Clariant (ex- Sud-Chemie)

Local : Straubing (Germany)

Start-up: 2012

Raw material: cereal straw, agricultural waste

Product: Ethanol (1.000 ton/year)

Production process: steam explosion pre-treatment, enzymatic hydrolysis and co-fermentation of C_5 and C_6

Demo

Sunliquid® technology - STAGE 1

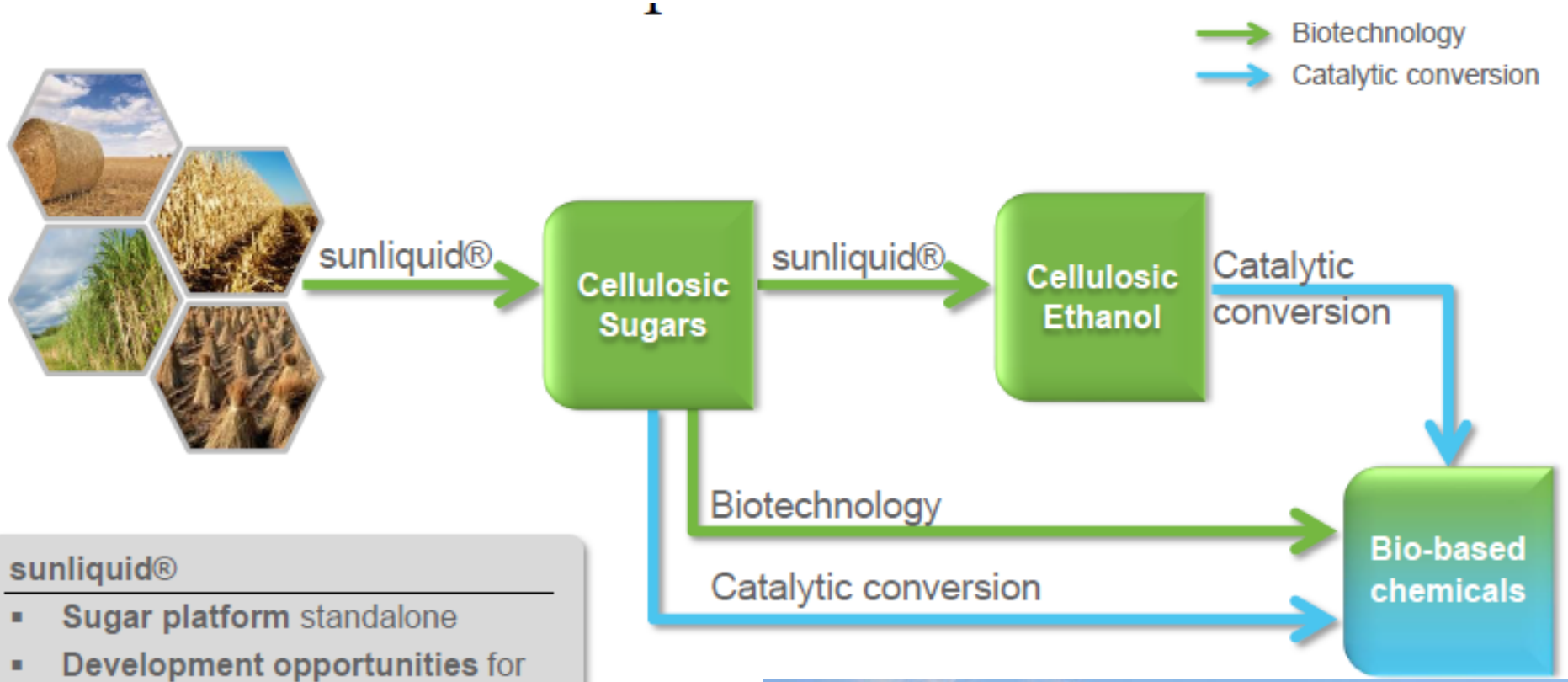
FEEDSTOCK | PRE-TREATMENT | HYDROLYSIS | FERMENTATION | CELLULOSIC ETHANOL

INTEGRATED ENZYME PRODUCTION

Key features and advantages

- Integrated enzyme production
- Fermentation of C6 and C5 sugars into ethanol
- Feedstock and process specific enzymes
- Energy saving ethanol separation technology

Sunliquid® technology – STAGE 2



sunliquid®

- **Sugar platform** standalone
- **Development opportunities** for biobased products
- **Extensive know-how** in biocatalysis, strain optimization and heterogenous catalysis

Borregaard Industries AS

Local: Sarpsborg (Norway)

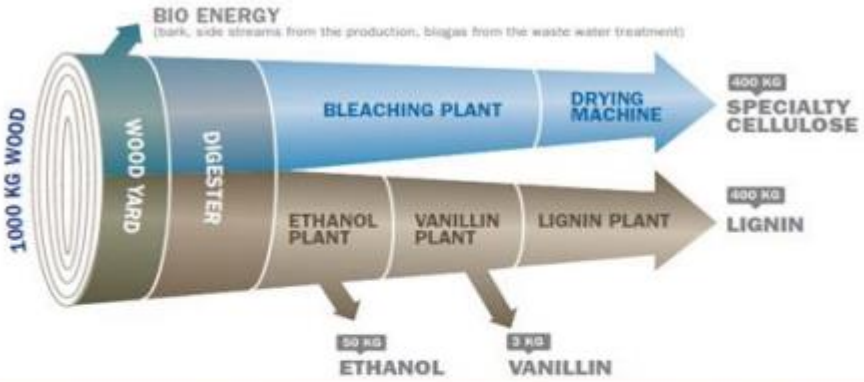
BALI™ technology

Start-up: 2013

Raw material: 50 kg/h; cereal straws, sugarcane bagasse

Product: Ethanol (110 ton ethanol/year or 22º ton sugars C_5/C_6/year; 200 ton/year specialized products of lignin)

Production process: Organosolv (BALI Technology); Biorefinery concept (chemical pretreatment, HE, Fermentation



Cellulose	Lignin	Vanillin	Ethanol
Construction materials	Concrete additives	Food	Car care
Cosmetics	Animal feed	Perfumes	Paint/ varnish
Food	Dyestuff	Pharmaceuticals	Pharmaceutical industry
Tablets	Batteries		Bio Fuel
Textiles	Briquetting		
Filters	Mining		
Paint/ varnish			

www.borregard.com

Demo

Abengoa Bioenergy (W2B)

Local: Babilafuente, Spain (2G Ethanol pilot plant retrofitting)

Start-up: 2011- 2015

Raw material: Organic fraction from MSW

Product: Ethanol (yield: 42% w/w)

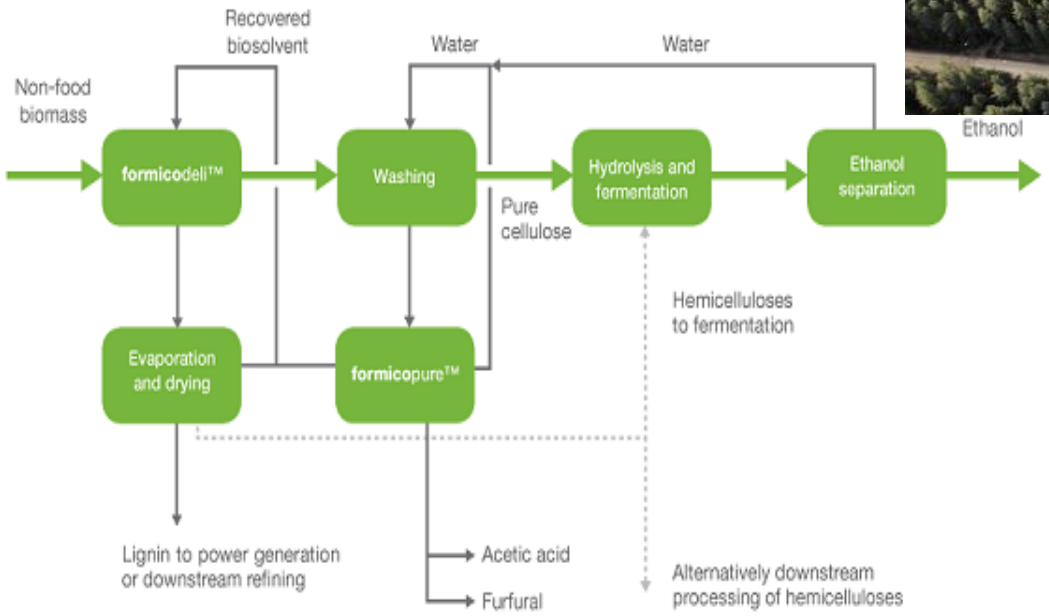
Sold!

Demo Plant

www.abengoabioenergy.com

Chempolis Ltd.

Local: Oulu (Finland)
Start-up: 2008
Raw material: 25.000 ton/year straws
Product: Ethanol (5.000 ton/ear), acetic ac., furfural, lignin for energy
Production process: organosolv pre-treatment, enzymatic hydrolysis and co-fermentation of C_5 and C_6



Demo

www.chempolis.com

ALLMICROALGAE

Local: Pataias-Leiria (Portugal)

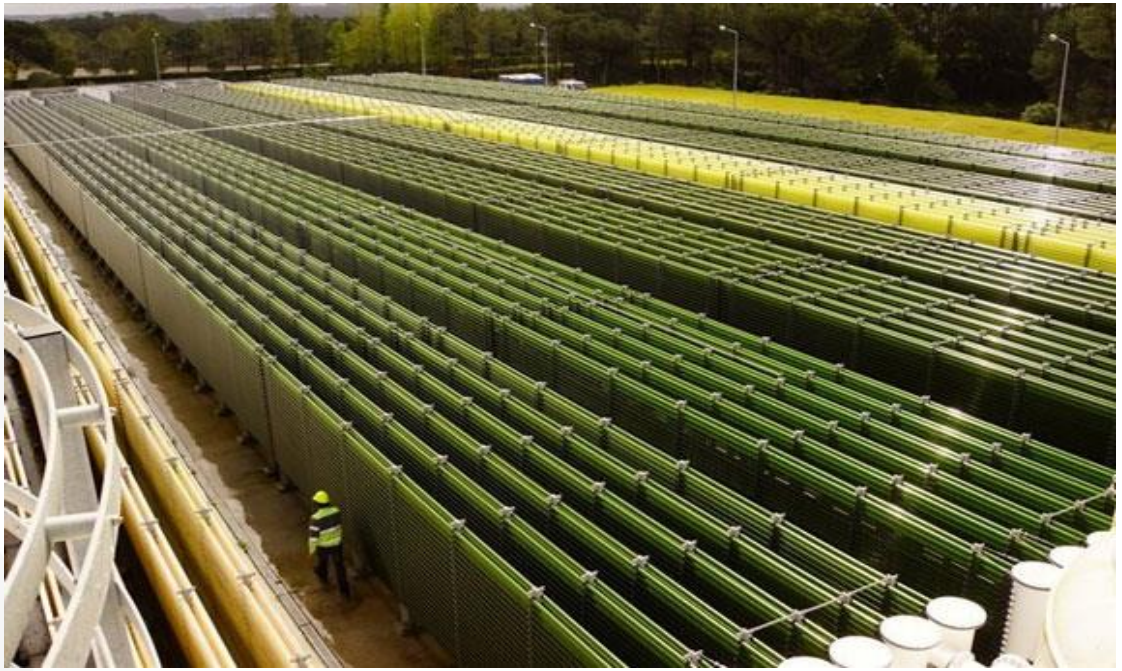
Start-up: 2013 (ex-Algafuel)

Raw material: CO_2 (*flue gas* of cement plants), fertilizers, sunlight

Product : 1300 m^3 of FBR for microalgae (for food and cosmetics); ~100 ton/year d.m. algae biomass

Production process: Microalgae cultivation, harvesting through microfiltration, pasteurization, spray-drying and final packaging

- Owned 100% the the Portuguese cement company SECIL.
- Since 2015 it becomes the new world supplier of Allma Chlorella
- Current target: delivery high quality algae ingredients for food, beverage and dietary supplement applications



Commercial

A4F (Algafuel)

Local: Lisboa (Portugal), LNEG CAMPUS.

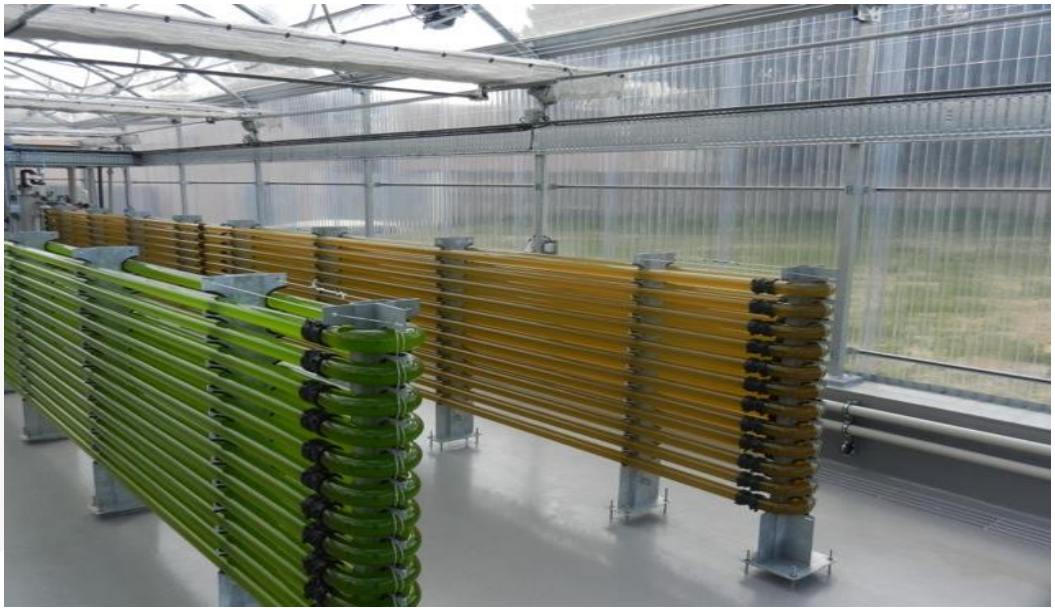
Start-up: 2014

Raw material: CO_2 , fertilizers, sunlight

Product : 3 m^3 of FBR for recombinant microalgae (for bioethanol)

Production process: Biochemistry

- Direct ethanol production from an engineered cyanobacteria
- In-situ ethanol recovery through pervaporation membranes
- Microalgae recovery for further processing; HTL for bio-oils, or directly spray-dried for food, feed and pharmaceutical applications



www.a4f.pt

1st Unit in Europe GMO-compliance for microalgae growth

Pilot

BuggyPower S.L.

Local: Porto Santo, Madeira (Portugal)

Start-up: 2011

Raw material: CO_2 , fertilizers, sunlight

Product : 60 ton/yr d.w. microalgae biomass (for food and cosmetics)

Production process: Biochemistry

- 1,100 m^3 of closed photobioreactors with air-lift 8 m high and arranged in sequence to optimize solar capture and bacteriological control for a maximum quality of microalgae biomass

Demo

www.buggypower.eu

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All-Gas Project (FP7 Algae Cluster)

Local: Chiclana de la frontera, Spain

Start-up: 2014

Raw material: CO_2 , fertilizers, sunlight

Product : up to 40 kg/day d.w.microalgae biomass converted into biomethane (5 kg/day)

Production process: Microalgae cultivation in open ponds, harvesting + anaerobic digestion to biogas and upgrading to CH4

Key technologies are:

- Low cost high rate algal ponds
- Low energy demand for harvesting (two-step process)
- Anaerobic digestors for biogas production from algae
- Water reuse at low energy demand during wastewater treatment with algae and flotation (0.15kWh/m3)

Demo

InteSusAl Project (FP7 Algae Cluster)

PBR MICROALGAE SYSTEM:

- 1 Ha site made up 4 x 15 m^3 tubular photobioreactors, 1 x 200 m^3 open pond raceway and 3 x 1 m^3 heterotrophic fermentation systems
- One further 1m^3 heterotrophic fermentation systems (Heterotrophic pilot line #1) was retained at CPI, Middleborough, United Kingdom, to be operated in parallel with the 3 x 1m^3 heterotrophic fermentation systems

Local: Olhão, Portugal

Start-up: 2015

Raw material: CO_2 , fertilizers, sunlight

Product : ~110 kg/day d.w.micro-algae biomass; main product – bio-diesel; Other products to be identified

Production process: Microalgae cultivation PBR (either phototrophically or heteretrophically), harvesting.

Demo

BIOFAT Project (FP7 Algae Cluster)

BIOFAT TECHNOLOGY in Pataias:

- Inoculum production in GWP
- Production in TPBRs and
- Production/starvation in CRWs
- Harvesting includes pretreatment with filtration and centrifugation

Local: Pataias, Portugal and Camporosso, Italy

Start-up: 2013 (Pataias), 2015 (Camporosso)

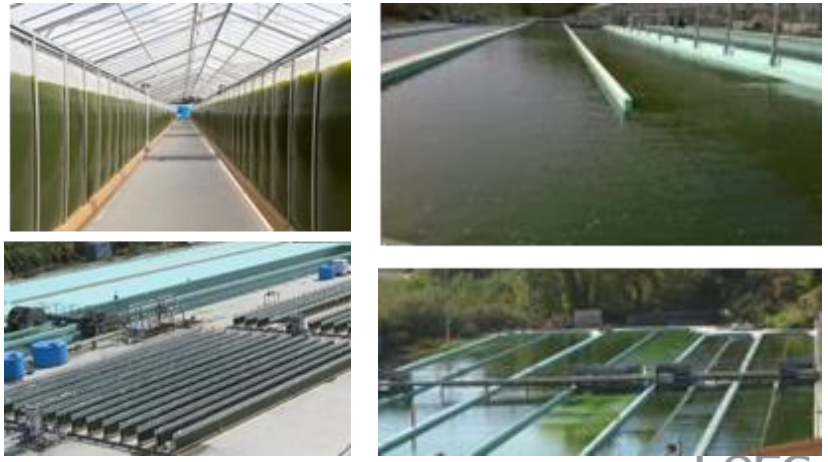
Raw material: CO_2 , fertilizers, sunlight

Product : ~34kg/day (Pataias), ~20 kg/day (Camporosso) d.w.micro-algae biomass; main product – algal biomass; In future: *Nannochoropsis* oil into biodiesel

Production process: Microalgae cultivation and harvesting.

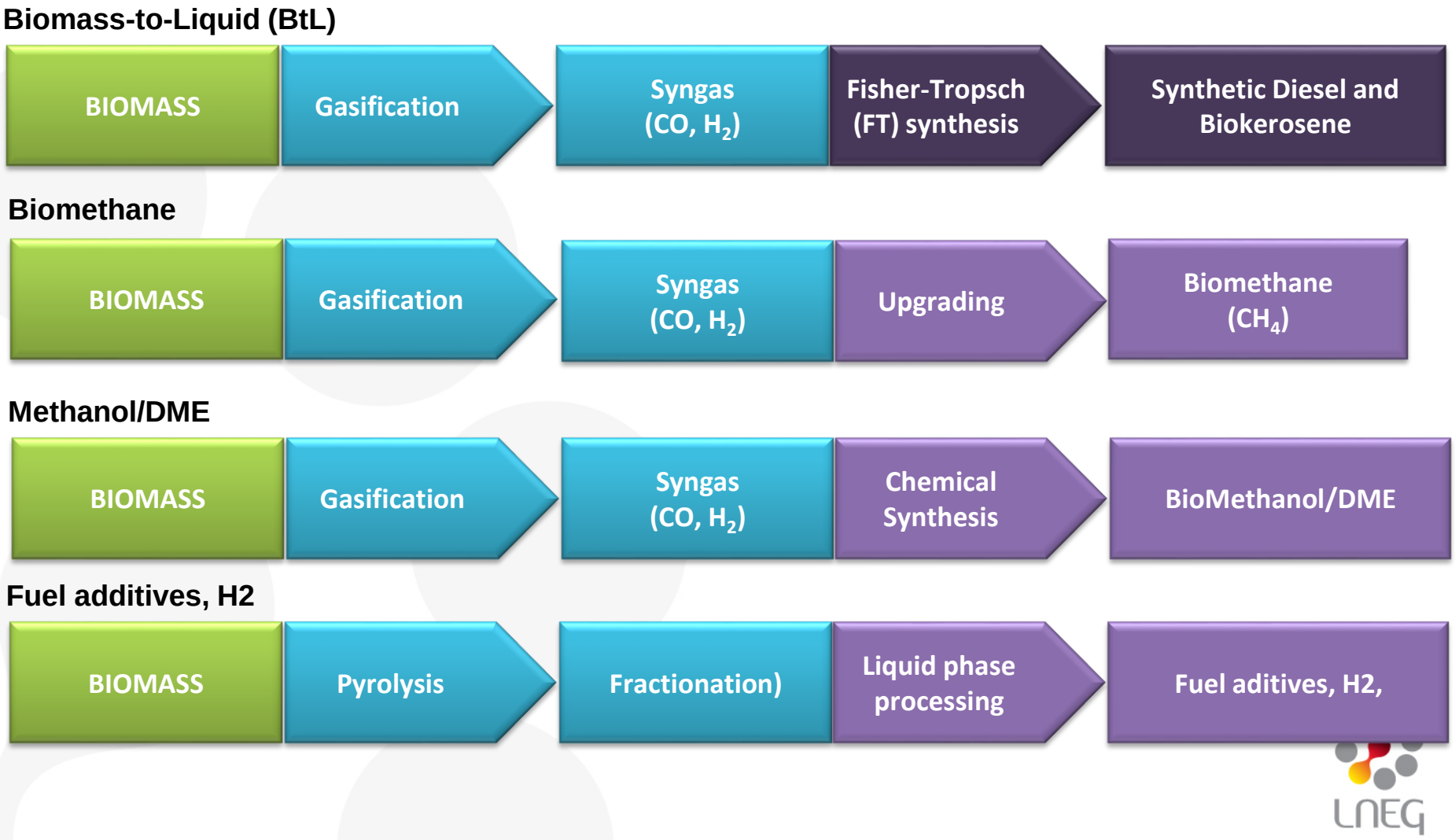
Pataias, PT

Camporosso, IT



Demo

Current Status of Advanced Biorefineries in Europe using Thermochemical Processing of Biomass



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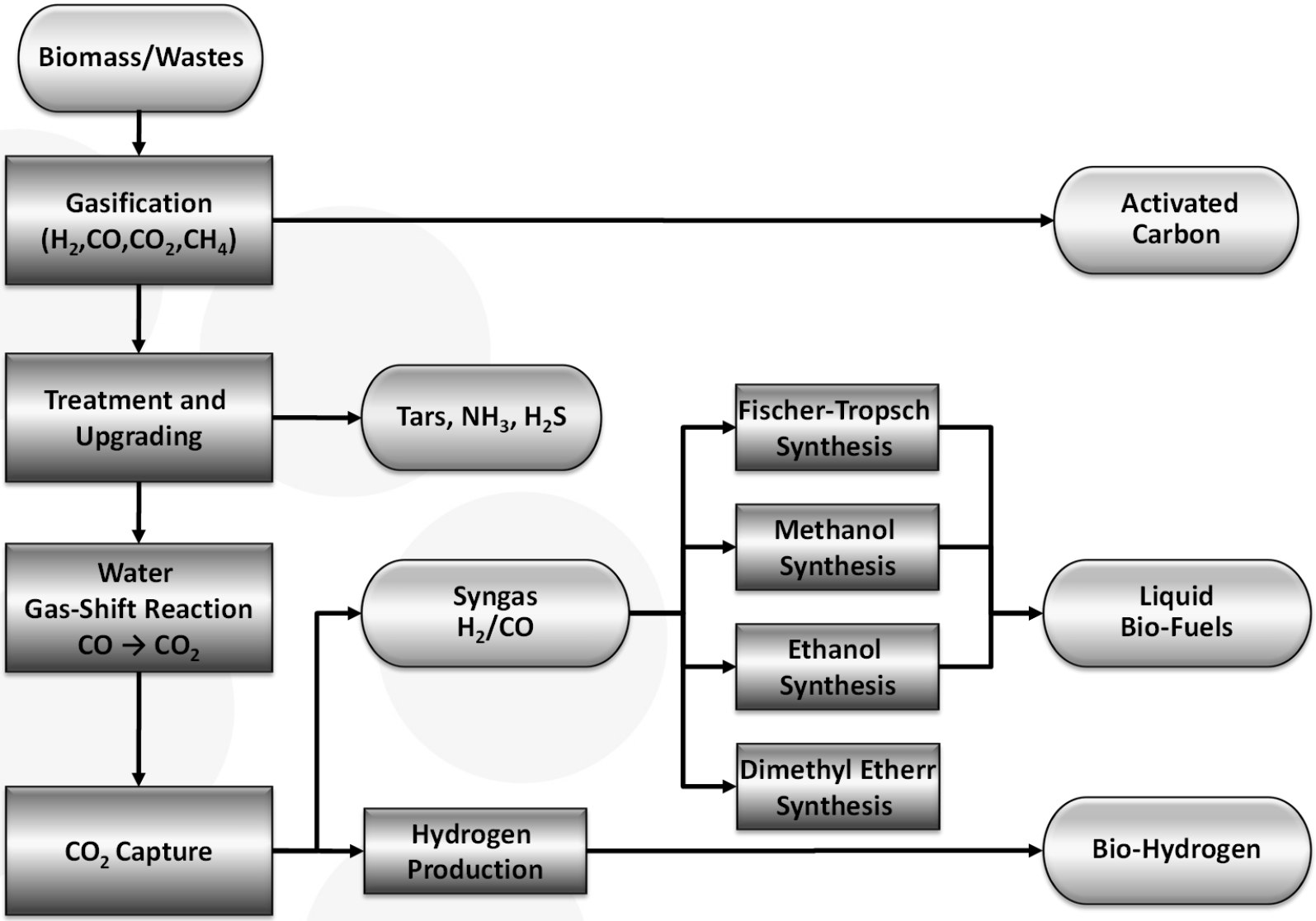
Gasification Processes & Products



Source: Gírio et al, 2016

UPM

Local: Lappeenranta (Finland)

Start-up: Jan 2015

Raw material: **Tall oil** (by-product from the pulp and paper industry)

Product: 100.000 ton diesel BtL drop-in

Production process: gasification and Fischer-Tropsch reaction followed by hydrotreatment provided by Haldor Topsoe.

- Co-located with a pulp and paper mil.
- CAPEX of 175 Mio€
- Key technology is the Hydrotreatment

www.upmbiofuels.com

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Commercial

Goteborg Energi (GoBiGas Phase I)

Local: Gothenburg (Sweden). Done by Valmet under a licence from Repotec,

Start-up: 2013

Raw material: wood pellets (6.8 ton/h at 5.5% moisture). It is currently shifting to forest residues (8.9 ton/h at 20% moisture);

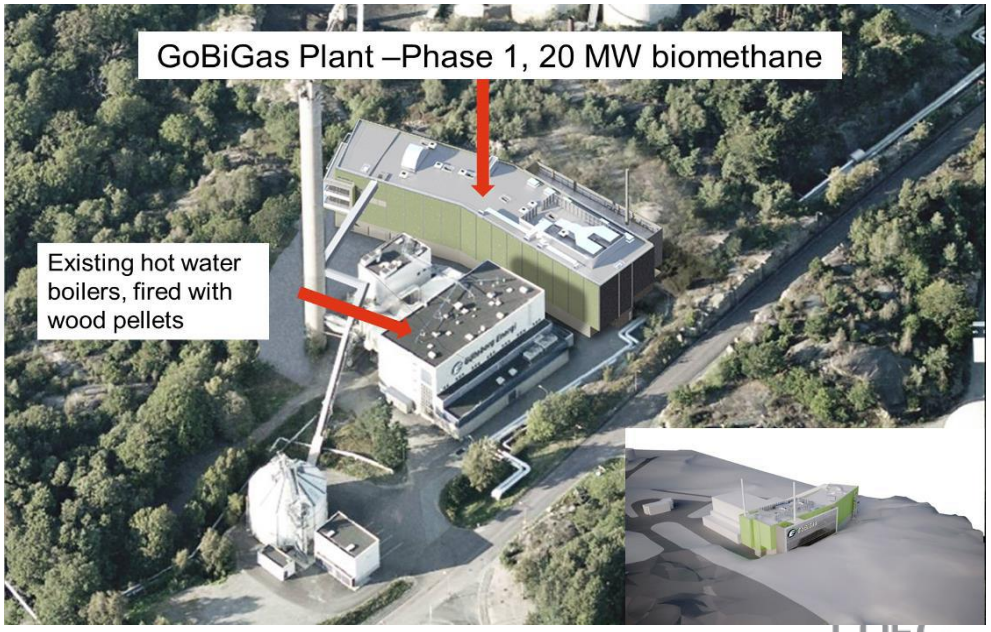
Product: SNG (biomethane, 11.200 ton/year; ~20MW biomethane), heat for district heating.

Production process: gasification and methanation in fixed bed. Includes tar removal via scrubbing and active carbon filters. Acid gas removal technology in in-place.

PHASE 2

Biomass for ~200 MW_{SNG} / SNG (on hold)

- Biomethane requires wood methanation of the cleaned syngas followed by CO2 removal
- Very exothermic and very selective
- The process is driven to high CO conversion



Demo

www.goteborgenergi.se

SNG Biomassekraftwerk, Güssing

Local: Güssing, Austria – Demo plant

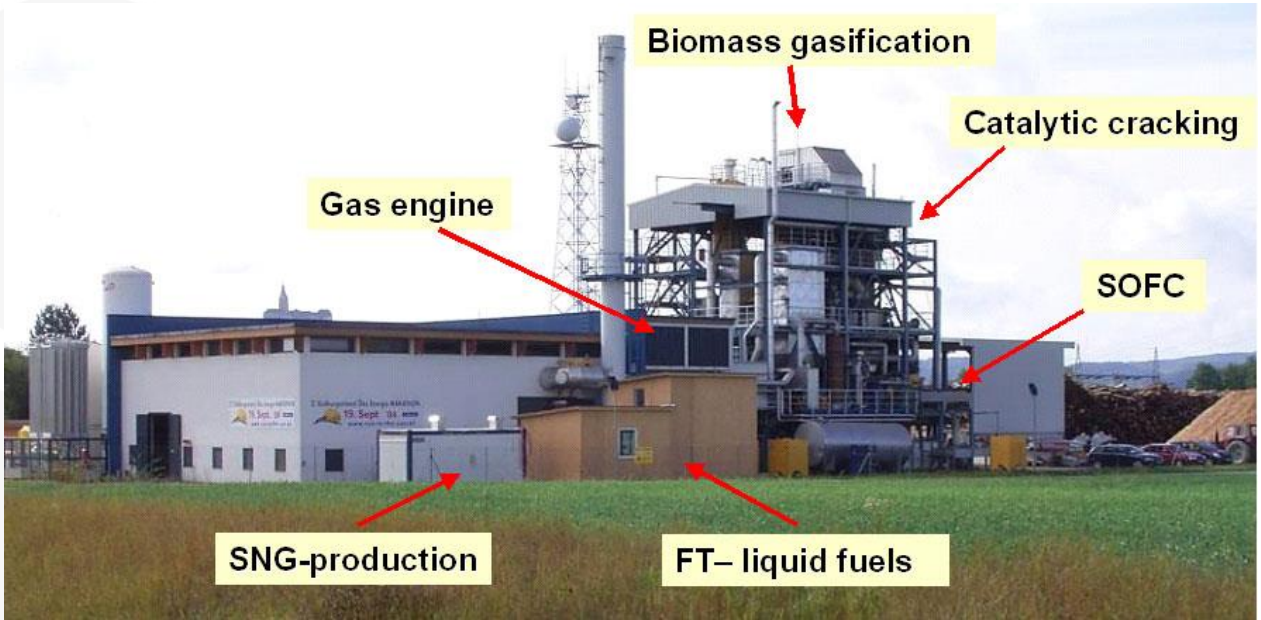
Start-up: 2009

Raw material: 350 Nm^3/h of syngas (from wood chips)

Product: 576 ton/year; 100 Nm3/h of SNG

Production process: Syngas from the existing gasifier in Güssing is purified before being introduced to the catalytic reactor for conversion to methane, which operates at a temperature between 300 and 360° C and a pressure range from 1 to 10 bar.

Demo



Chemrec AB (current owner: Lulea Technology Univ.)

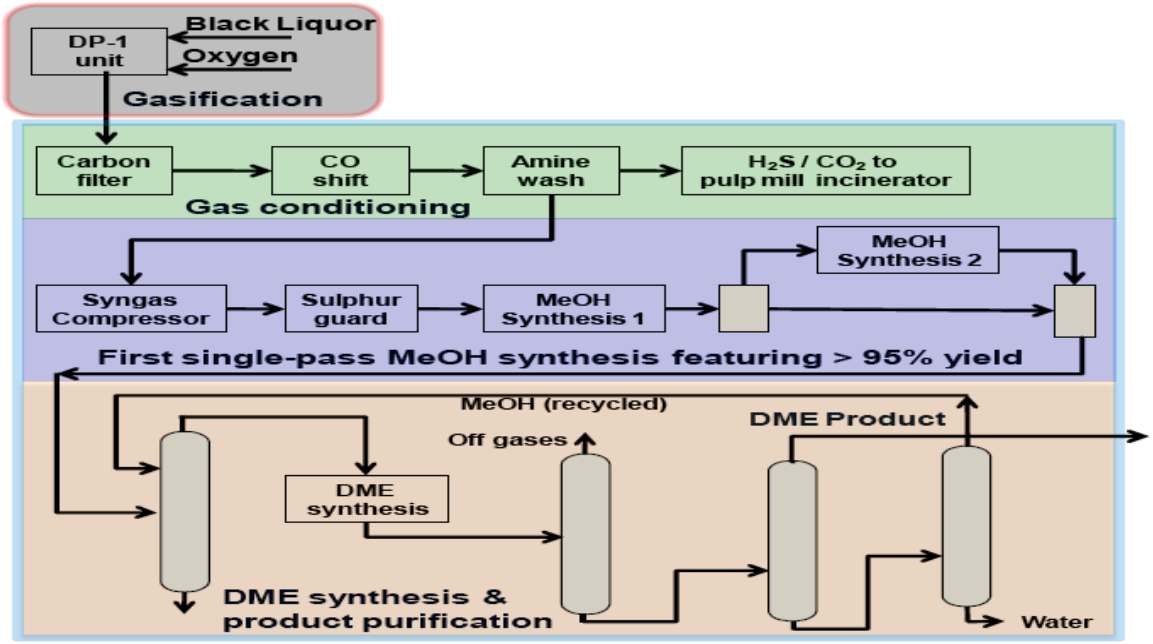
Local: Pitea (Sweden)

Start-up: Nov 2011

Raw material: 20 ton/day kraft black liquor (from pulp unit). Can also use sulphite liquors.

Product: **Bio-DME** (1.800 ton/year)

Production process: Chemrec gasification (~3MPa), syngas purification, chemical synthesis of bio-methanol, chemical conversion to DME.



www.chemrec.se

Demo

BioMCN

Local: Farmsum (Netherlands)

Start-up: 2009

Raw material: **Crude glycerine**, biogas (CO_2)

Product: **Bio-methanol** (200.000 ton/year)

Production process: Purification of glycerine, conversion into synthesis gas, bio-methanol synthesis (with Co catalyst, at 6-10 Mpa and about 260ºC) followed by distillation (water is a by-product)

- Exothermic conversion
- Very selective
- ~80% syngas energy is transfered to methanol (+95% C conversion)

<u>PLANNED UNIT (in stand-by):</u>

- 413,000 ton of Bio-metanol from 1.5 Mton/yr of imported forest residues
- Pretreatment by torrefaction, gasification, syngas purification, chemical synthesis of bio-methanol

Commercial

www.biomcn.nl

Gogreengas

Local: Swindon, UK (a partnership between National Grid Gas Distribution, Advanced Plasma Power, Progressive Energy and Carbotech)

Start-up: 2016

Raw material: 0.4 ton/day of dried **Refuse Derived Fuel** (RDF) and biomass feedstocks

Product: Bio-SNG 0.050 MW (biomethane)

Production process: two stage gasification process using APPS Gasplasma TM technology.(fluidized bed gasifier at atmospheric pressure coupled with a plasma converter).

- The plasma stage removes tars leaving syngas composition with mainly CO and H2, followed by catalytic methanation
- CO2 is removed using PSA unit to produce Bio-SNG

Pilot

Pyrolysis Technologies

- **Fast pyrolysis** → gasification or co-gasification with e.g. black liquor→synthesis to biofuel product (KIT, LTU)
  - Bio-oils with low quality due to high water content (~25%); unstable

- **Fast pyrolysis → (stabilization) → co-feed to refinery Fluid Catalytic Cracking (FCC)** (UOP, PetroBras; Repsol, Grace).
  - Still under tests.

- **Fast pyrolysis → stabilization → Hydrodexygenation and Hydrocracking** (BTG Biomass Technology Group BV (BTG), US Department of Energy - Pacific Nortwest National Laboratory (PNNL)).

- **Catalytic pyrolysis → Hydrodexygenation and Hydrocracking** (Anellotech, Center for Research & Technology Hellas (CERTH)).

- **Hydropyrolysis (hydrogen + catalysts) → Hydrodesulphurization + Dearomatization** (Gas Technology Institute (GTI)/ CRI Catalyst Company (CRI)).

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BIOLIQUID (Karlshrue Institute of Technology)

Local: Karlsruhe, Baden-Wuerttenberg, Germany

Start-up: 2014 (**pyrolysis**+gasification+synthetic gasoline synthesis)

Raw material: 500 kg/h straw

Product: 5 ML/yr (methanol), Gasification (5 MWt) + DME/gasoline synthesis

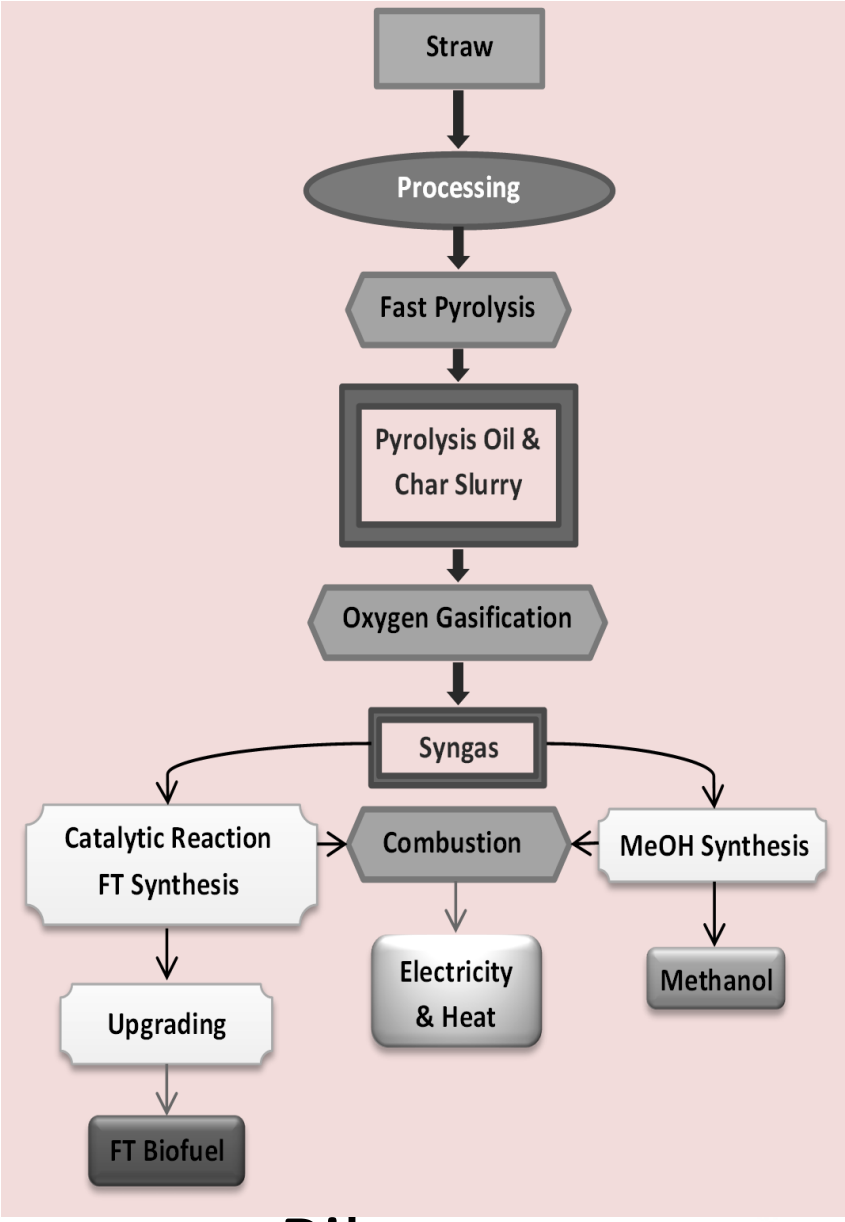
Production process: Fast pyrolysis + Entrained Flow Gasification (w/O2 at 4-8MPa) with cooling screen for SYNGAS

DME production:

- Methanol dehydration in presence of catalyst (eg, sílica-alumina)
- Slightly exothermic
- DME is stored under liquid state at 0.5MPa and RT, (like LPG)
- Alternatively, DME can be produced through direct synthesis using dual-catalyst system (metanol synthesis and dehydratation in one pot unit)

Synthetic Gasoline (via DME)

- This DME can be blended into today´s commercial gasoline grades



www.bioliquid.de

Pilot

Empyro, NL

Local: Hengelo, The Netherlands

Start-up: 2015

Raw material: 120 ton/day clean wood residues

Product: 77 ton/day **crude pyrolysis oils (~8MW)**

Production process: BTG-BtL pyrolysis process

BTG-BtL process:
A rotating cone reactor integrated in a circulating sand system composed by:

- Riser
- Fluidised bed char combustor
- Pyrolysis reactor
- Down-comer

- **Oil is the main product**
- Non-condensable pyrolysis gases are combusted to generate additional steam and power
- Excess heat is used for drying the feedstock

Demo/Commercial

Concluding Remarks

- Biorefineries concept means more eficiente use of resources and by-streams
- Key challenges in near future are:
  - sustainable supply of biomass
  - more eficiente biomass deconstruction
  - multi-products from the use of diferente LCF
  - Cluster-based biorefineries shall be more competitive
- Forestry Industry has specific advantages to be in the front line of Biorefineries Development

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- Forestry Industry has specific advantages to be in the front line of Biorefineries Development
- There are already numerous industrial Biorefinery projects for commercial plants of advanced biofuels in Europe, in particular:
  - **Cellulosic bioethanol**, the first worldwide commercial unit BioChemtex, (Crescentino, Italy) is working since 2013.
  - **Bio-methanol** from crude glycerine (residue from conventional process of biodiesel FAME production), since 2009 there is a commercial unit Bio-MCN operating in the Netherlands.
  - **Biodiesel HVO** (hydrogenated vegetable oil) in Finland (Neste Oil), they have environmental advantages and superior techniques to conventional biodiesel FAME type

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  - **Biodiesel HVO** (hydrogenated vegetable oil) in Finland (Neste Oil), they have environmental advantages and superior techniques to conventional biodiesel FAME type
- ❑ The **main problems** of today's advanced biofuels projects in Europe are:
  - Competitiveness with either gasoline/diesel or with 1G.
  - Price, logistics and availability of large-scale biomass supply.

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www.lneg.pt

Thanks

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