Delivery of sustainable supply of non-food biomass to support a resource-efficient Bioeconomy in Europe

S2Biom summer school, Athens, Greece, 17-20 May, 2016

Overview of Technologies for Converting Lignocellulosic Biomass to Energy and Fuels

Dr. T.M. Lammens

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Matching Biomass & Technology

- Role of BTG in S2Biom: Design a tool to match biomass and technology.
- Tool input:
  - Database of technology requirements
  - Database of biomass characteristics
- How to optimally use the available lignocellulosic biomass?

Learning objectives

- Gain an overview of the most important technologies for converting lignocellulosic biomass into energy and fuels.

- The focus is on real implementation (the ‘state of the art’):
  - What are the feedstocks and products in practice?
  - What are typical plant sizes?
  - What is the technology maturity?
  - What are the short term (2020) and longer term (2030) developments?

- Biomass conversion technology development:
  The road from an idea to a commercial process (and beyond).

Contents

- Towards a bio-economy in 2030: contribution of energy & fuels.
- Biomass conversion technology for energy & fuels: state of the art.
  - Thermal and thermochemical conversion processes
  - Biochemical and chemical conversion processes
- Technology development: the fast pyrolysis case.
- Lignocellulosic biomass conversion technology: status in 2020.

Towards a bio-economy

The Goal[1]

- Economic growth and jobs in rural, coastal and industrial areas.
- Reduce fossil fuel dependence.
- Improve the economic and environmental sustainability of industries.

The Challenge[2]

- Save up to 2.5 billion tons of CO_2 equivalent per year by 2030.
- Increase markets for bio-based raw materials and consumer products.

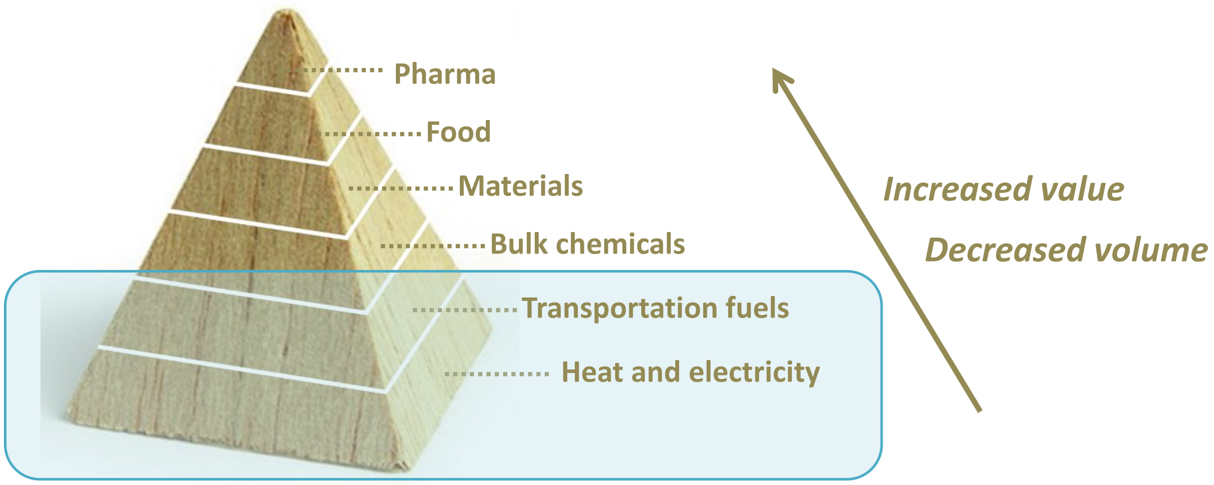
The Way[2]

- Move from fossil-based to resource-efficient bio-based processes.
- Create reliable, sustainable and appropriate supply chains of biomass, byproducts and waste streams.
- Create a wide network of bio-refineries throughout Europe.

[1] EC bioeconomy strategy, 2012; [2] EU H2020/Bio-Based Industries

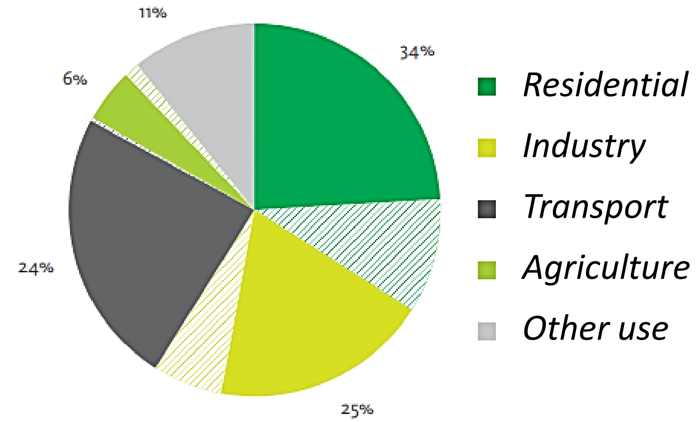
Energy & fuels in a biorefinery

- Bio-refinery: “The sustainable processing of biomass into a spectrum of marketable products.” *(IEA task 42)*
- Energy and fuels form the basis of the bio-based pyramid.

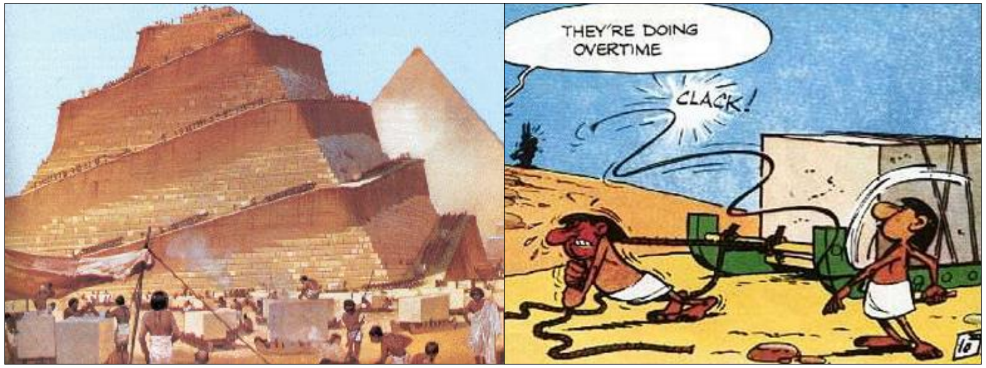


Why bioenergy?

- Only a small part of the energy use in N/W-Europe is electricity.
- Industry and residents use lots of heat.
  - ➢ Bio-energy is very suitable for this.



Gross energy use in the Netherlands
in 2013, the shaded parts are electricity.
Source: ECN 2015



- A pyramid cannot exist without its basis.
  - ➢ The bio-based economy will not develop without bioenergy!

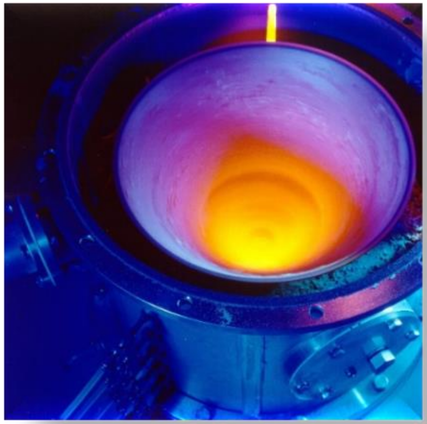
Product-Market Combinations

- ECN modelled the market demand for 10 bio-based (lignocellulosic) products, and the biomass input required for them.
  - Energy and fuels form the majority by far.

Product	Market	PJ-2020	PJ-2030
Heat	Heating	3242	4740
Electricity	Power market	743	1040
L.C. biofuels	Transport fuel	112	629
C5 & C6 sugars	Polymers, surfactants, solvents, etc.	8	23
Methane	Grid, transport	64	188
Aromatics	(Petro-)chemical industry	9	26
Methanol	Transport, chemical industry	3	13
Hydrogen	Transport, chemical industry	2	19
Ethylene	Transport, chemical industry	0	23

Source: S2Biom Deliverable 7.2, 2015

Conversion technologies



Thermal / Thermochemical:

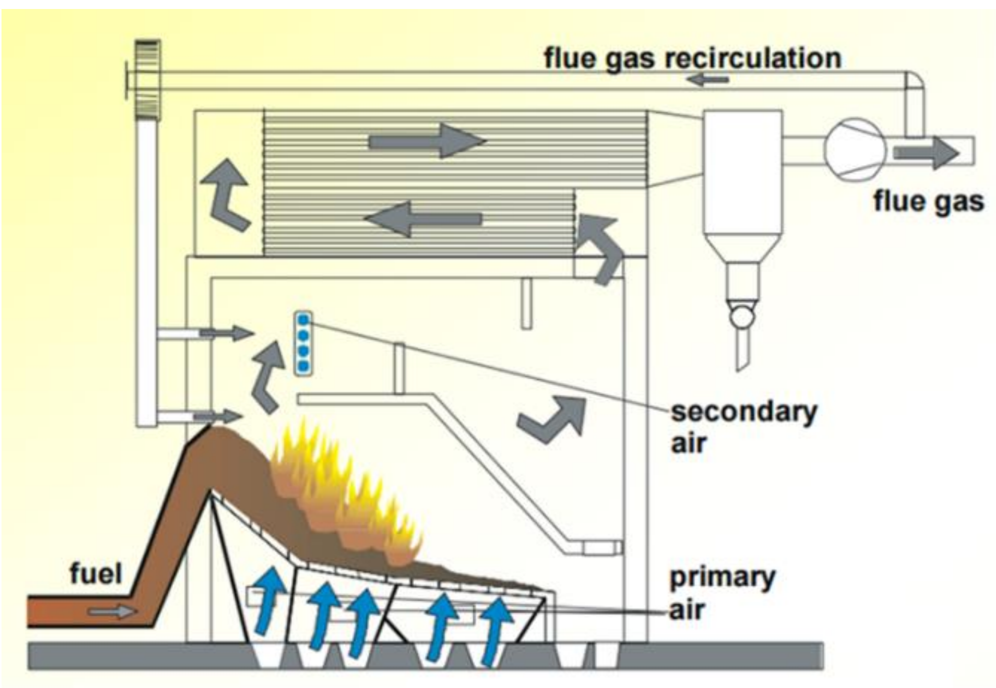
- Combustion
- Gasification
- Torrefaction
- Fast pyrolysis

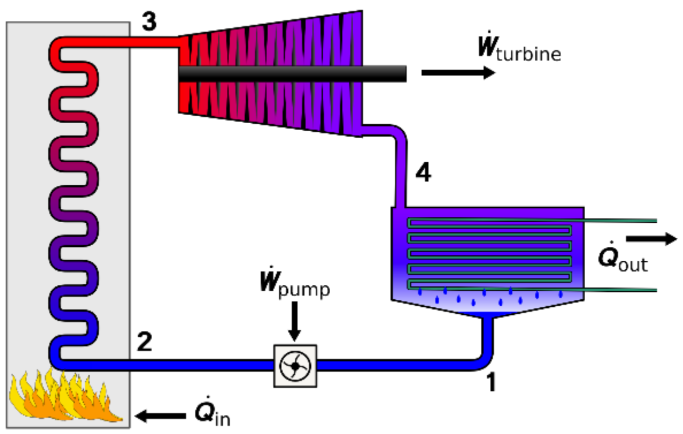
Biochemical / Chemical:

- Anaerobic digestion
- Pretreatment, hydrolysis, fermentation
- Pulp & Paper technologies

Combustion: general

- Biomass ($CH_{1.4}O_{0.6}$) + O_2 (excess) $\rightarrow$ CO_2 + H_2O + heat.
- Goal is to turn the released heat into useful energy: direct use, hot water, process steam, or electricity.





Combustion: state of the art

Products:

- Hot water / steam
- Electricity

Feedstocks:

- Wood chips / pellets
- Straw, reed
- Biogas
- Pyrolysis oil
- Torrefied biomass
- …

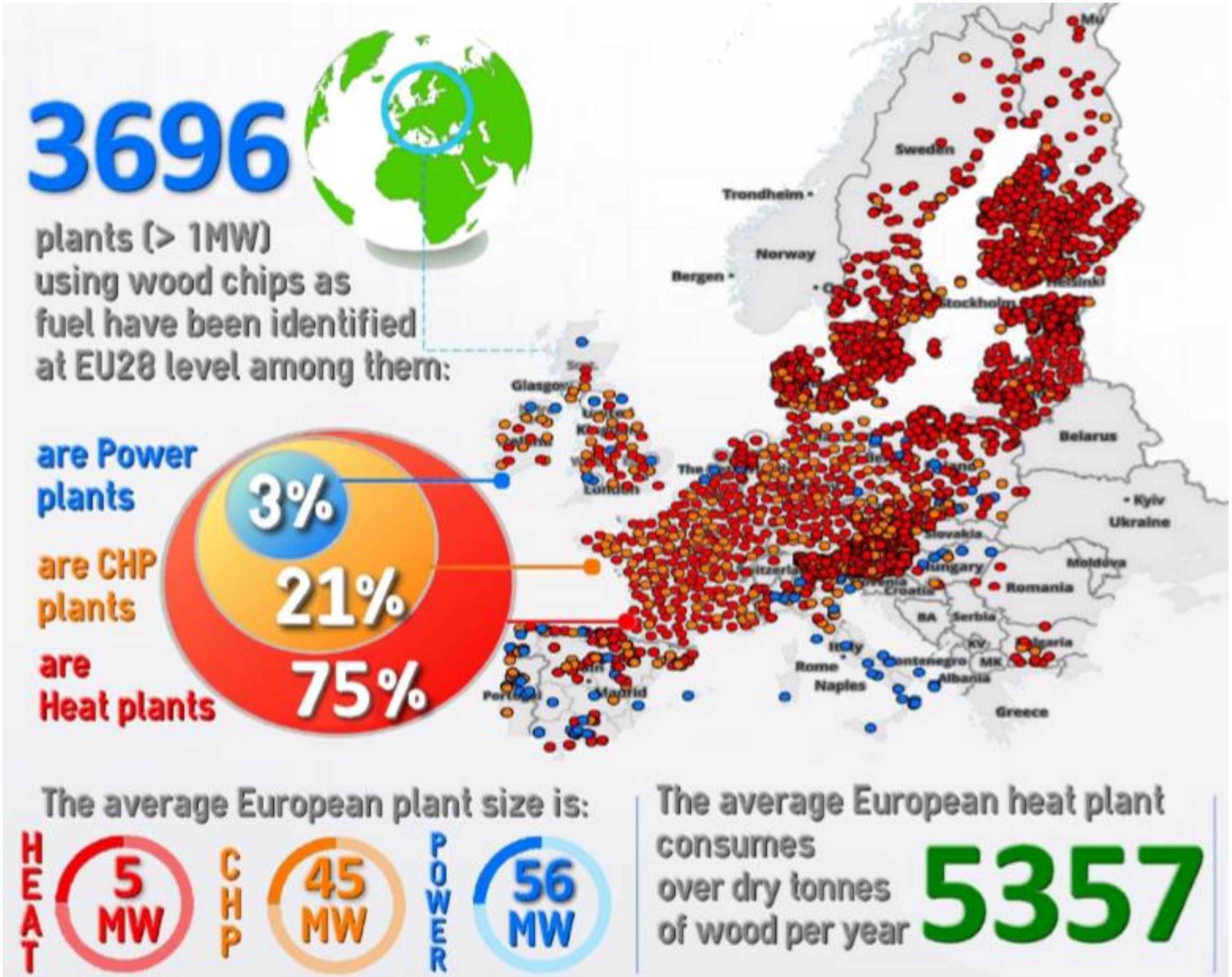
Typical sizes and types:

- 10-100 kW   Stove / pellet burner
- 0,1-15 MW   Stand-alone grate boiler
- 5-100 MW   Stand-alone fluidized bed
- >100 MW   Co-combustion with coal

Technology status:

- Mature technology (25 GW installed in EU)
- Short future: move to lower feedstock quality.

Combustion: EU implementation



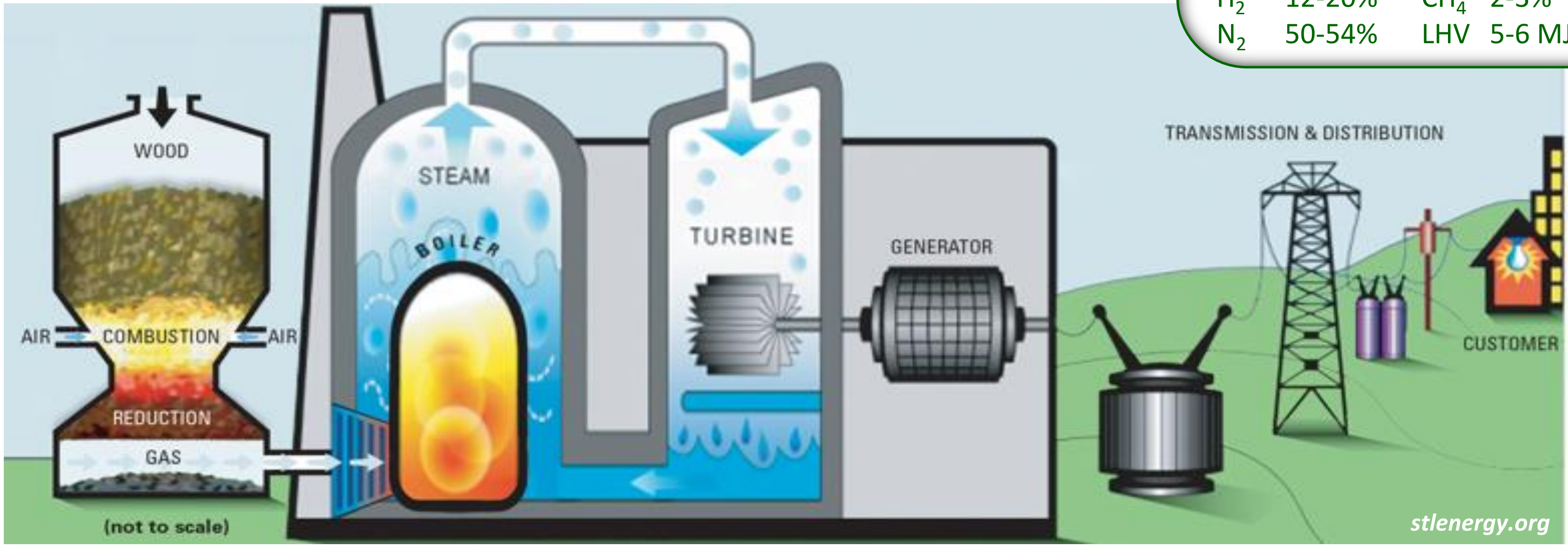
Source: AEBIOM 2015

Gasification: general

- Biomass ($CH_{1.4}O_{0.6}$) + O_2 (deficient) + heat $\rightarrow$ CO + CO_2 + H_2 (700-1100 °C)
- Goal is to turn the released molecules into useful energy or products:
  - Gas combustion to heat for direct use, hot water, process steam, or electricity.
  - Gas conversion into other products.

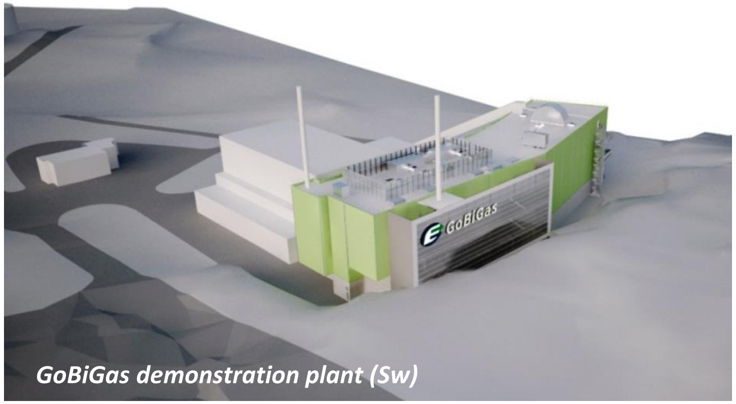
Gas composition (typical):

CO	17-22%	CO_2	9-15%
H_2	12-20%	CH_4	2-3%
N_2	50-54%	LHV	5-6 MJ/Nm^3



Gasification: state of the art


Güssing demonstration plant (Au)



GoBiGas demonstration plant (Sw)

Products:

- Hot water / steam
- Electricity
- Synthetic natural gas (SNG)
- Liquid fuels / chemicals

Feedstocks:

- Wood chips / pellets
- Straw
- …

Typical sizes and types:

- < 5 MW Stand-alone fixed bed
- 10-100 MW Stand-alone fluidized bed
- >100 MW Co-combustion with coal

Technology status:

- Mature technology for heat and CHP
- Short future: SNG production (eg. GoBiGas)
- Longer future: syngas upgrading to fuels and chemicals

Gasification and upgrading

BIOMASS

Gasification to synthesis gas

Syngas cleaning and conditioning

Fischer-Tropsch synthesis
- Hydrocarbons

Refining
- LPG
- Naphtha
- Kerosene
- Diesel
- Wax
- Detergents

Methanation
- Methane (SNG)

Shift reaction
- Hydrogen

Synthetic Fuels and Chemicals

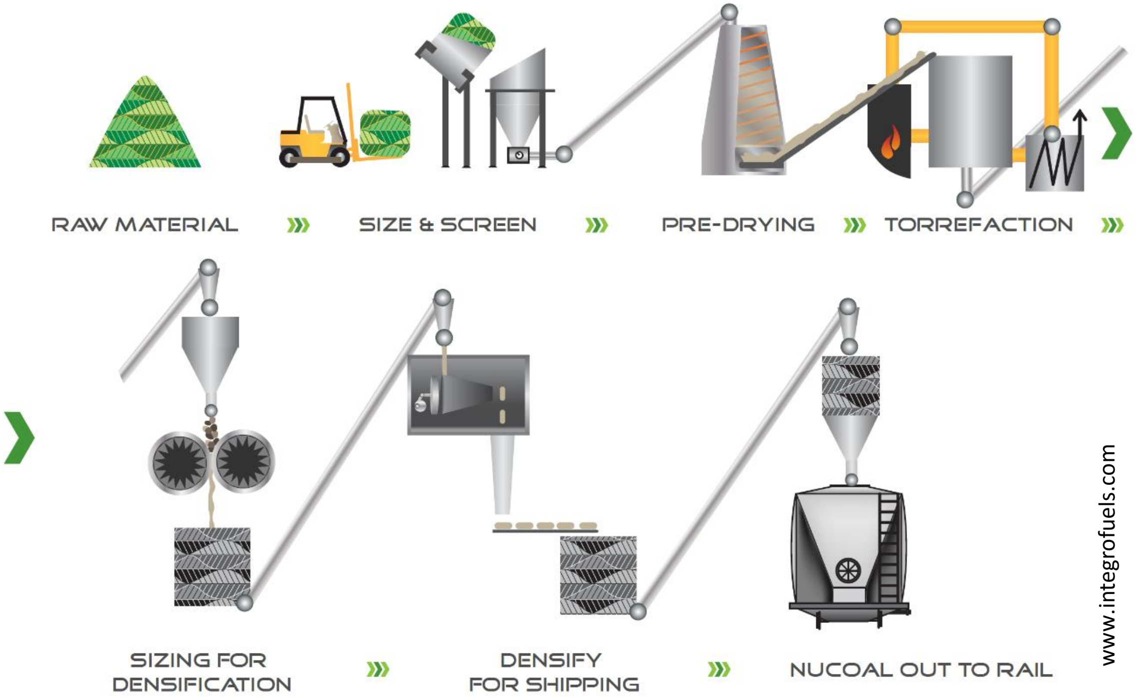
Methanol synthesis
- Methanol

Further processing
- Dimethyl ether
- Ethylene
- Propylene
- Gasoline
- Advanced fuels
- Oxygenates

Adapted from Van Swaaij et al. 2015

Torrefaction: general

- Biomass ($CH_{1.4}O_{0.6}$) + heat (no O_2) $\rightarrow$ char + gas (~ 300 ^oC)
- Goal is to turn the biomass into a more energy-dense product (from 10 to 20 MJ/kg), to be used for combustion.



Torrefaction: state of the art

Product:

- Torrefied pellets or ‘bio-coal’, for heat and power.

Feedstocks:

- Wood
- …

Typical size:

- 20-50 kt/yr (eq. to 20-50 MW)

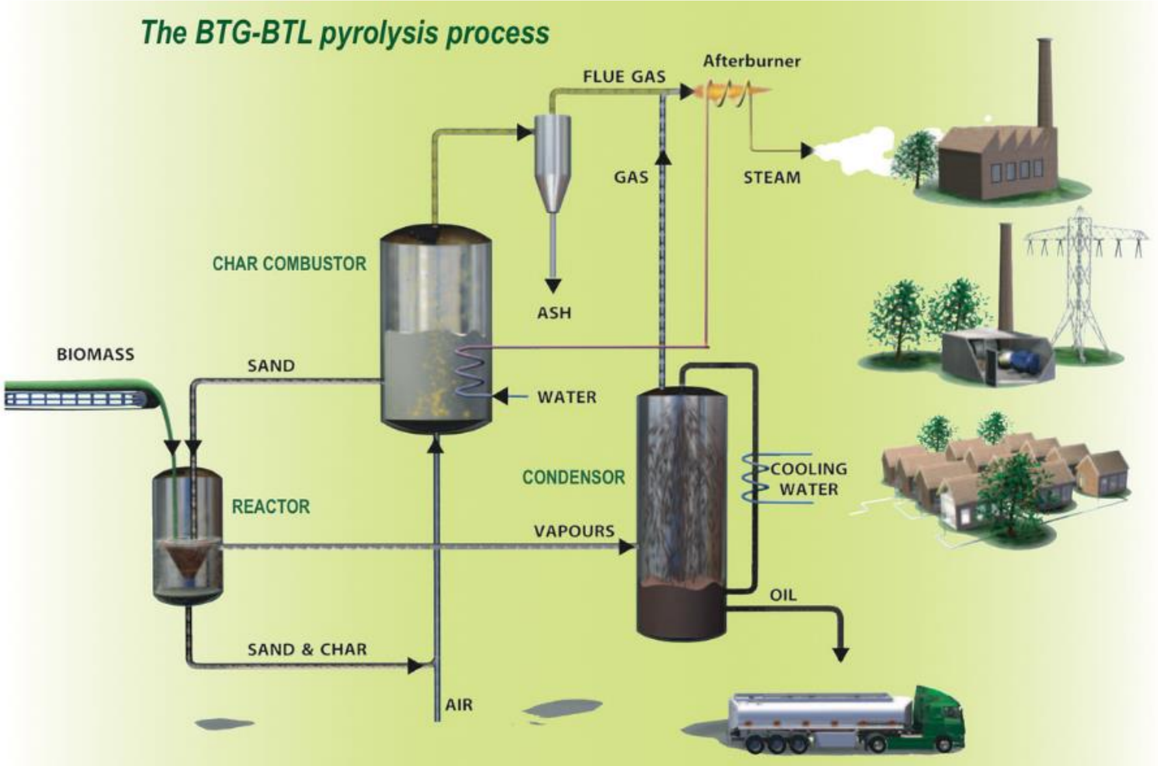
Technology status:

- Some commercial demo-units are in operation, but the past five years progress has been slow.[1]
- Co-firing of torrefied pellets with coal is proven.
- Short future: commercialization outlook is unclear due to the difficult market situation.

[1] *IEA 2015, Status overview of torrefaction technologies*

Fast Pyrolysis: general

- Biomass ($CH_{1.4}O_{0.6}$) + heat (no O_2) $\rightarrow$ liquid, gas, char (400 - 600 °C, few sec)
- Goal is to turn the biomass into a more energy-dense liquid product (from 10 to 20 MJ/kg), to be used for combustion or other products.



Fast Pyrolysis: state of the art

Products:

- Pyrolysis liquid or 'bio-oil', for:
  - Heat and power
  - Transportation fuels
  - Chemicals

Feedstocks:

- Wood
- ...

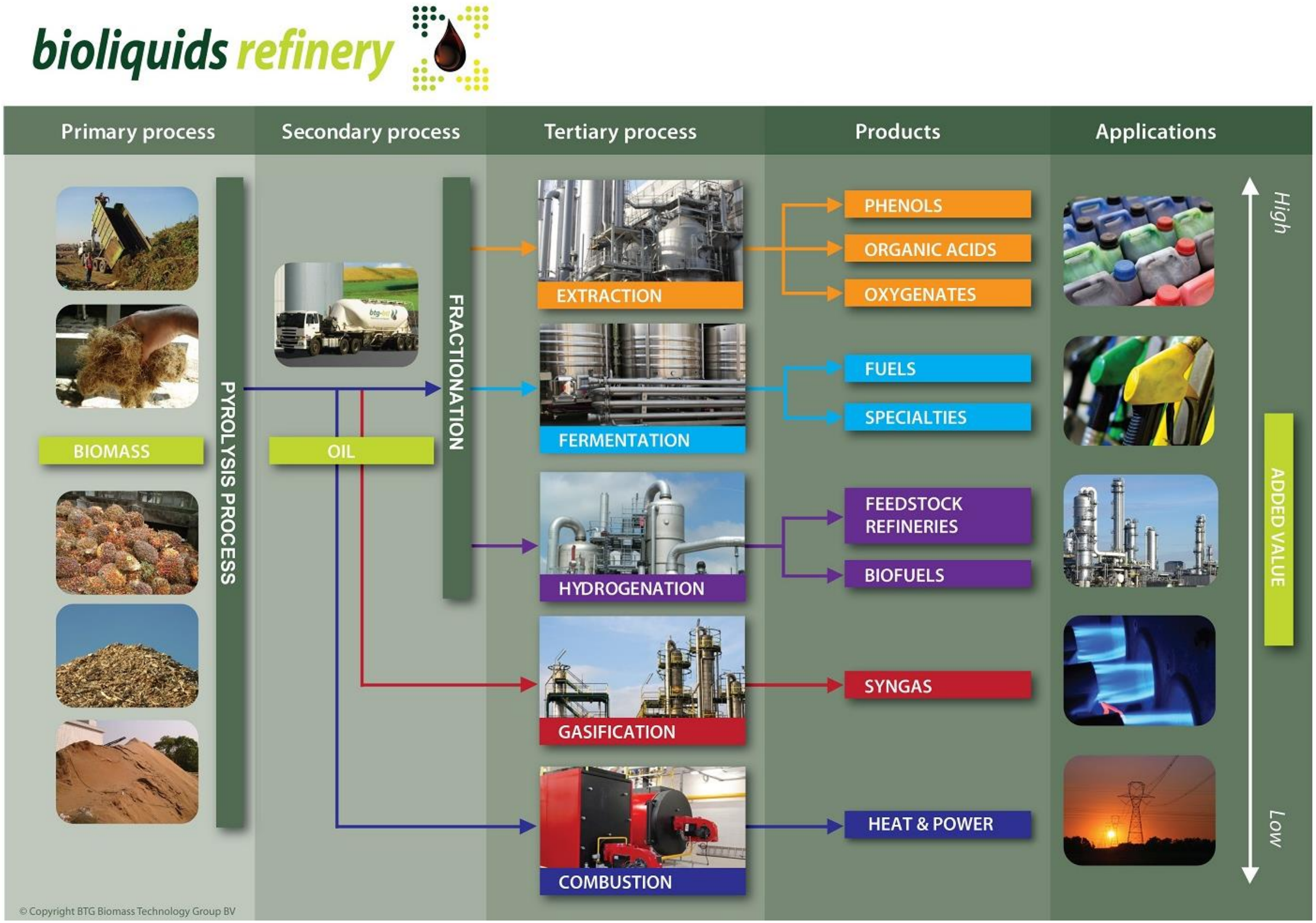
Typical size:

- 20-50 kt/yr (eq. to 20-50 MW)

Technology status:

- Commercial demo-units in operation.
- Application of pyrolysis oil for heat is proven.
- Short future: use in small-scale CHP units and move to lower feedstock quality (residues).
- Longer future: production of fuels and chemicals (co-processing, catalytic upgrading).

Fast Pyrolysis and upgrading



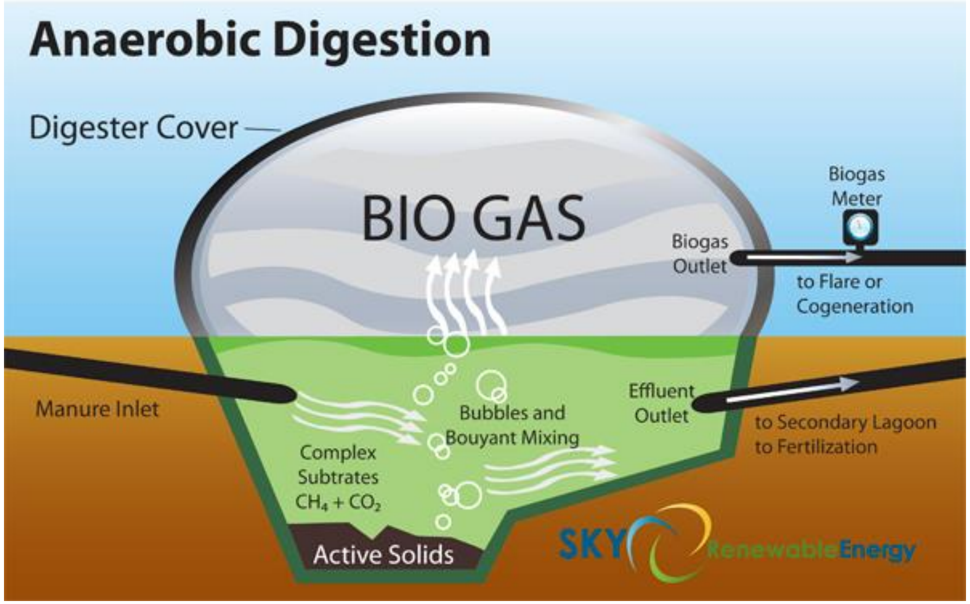
Anaerobic digestion: general

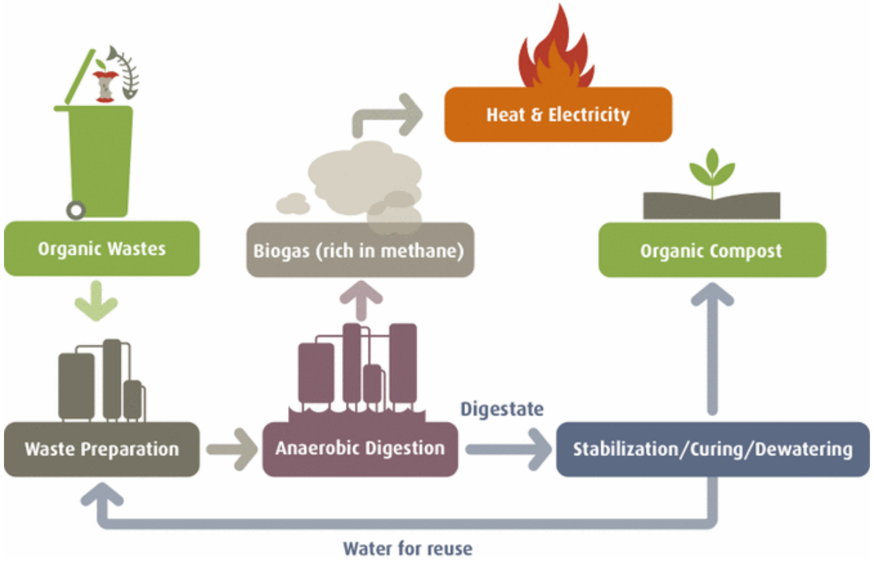
- Biomass ($CH_{1.4}O_{0.6}$) (no O_2) $\rightarrow \rightarrow CH_4 + CO_2$
- Various bacteria turn the biomass (stepwise) into biogas and digestate.

Gas composition (typical):

CH_4	55-70%	CO_2	27-44%
H_2S	0-3%	N_2	0-10%

LHV 20-25 MJ/Nm^3





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Anaerobic digestion: state of art

Product:

- Biogas, for:
  - Heat and power
  - Biomethane / Green gas

Feedstocks:

- Manure
- Agricultural residues
- Organic (municipal) waste
- Waste water effluent
- …

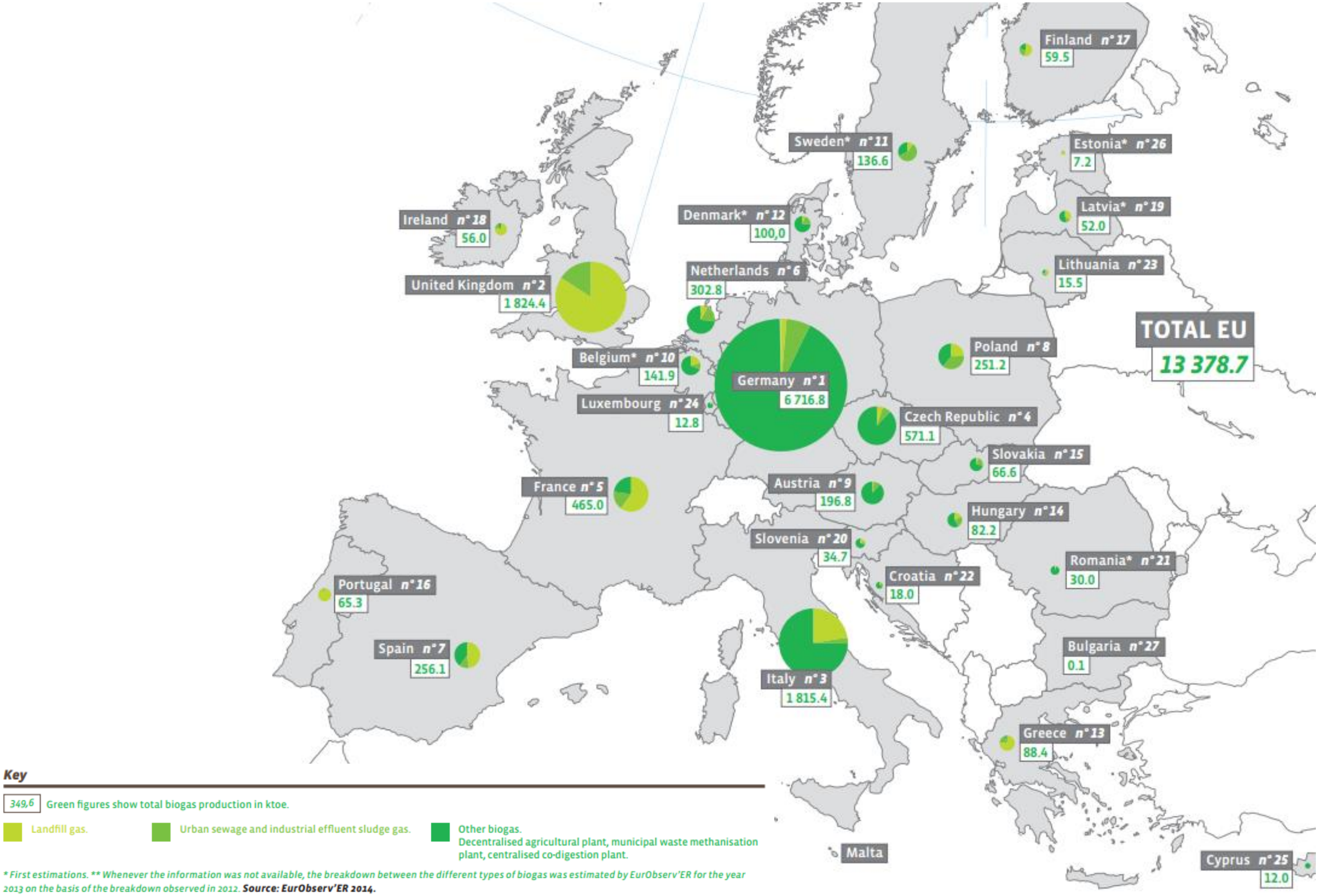
Typical sizes and types:

- 100 kW / 10 m^3/hr — Continuous
- <5 MW_{el} / 200-2000 m^3/hr — Batch

Technology status:

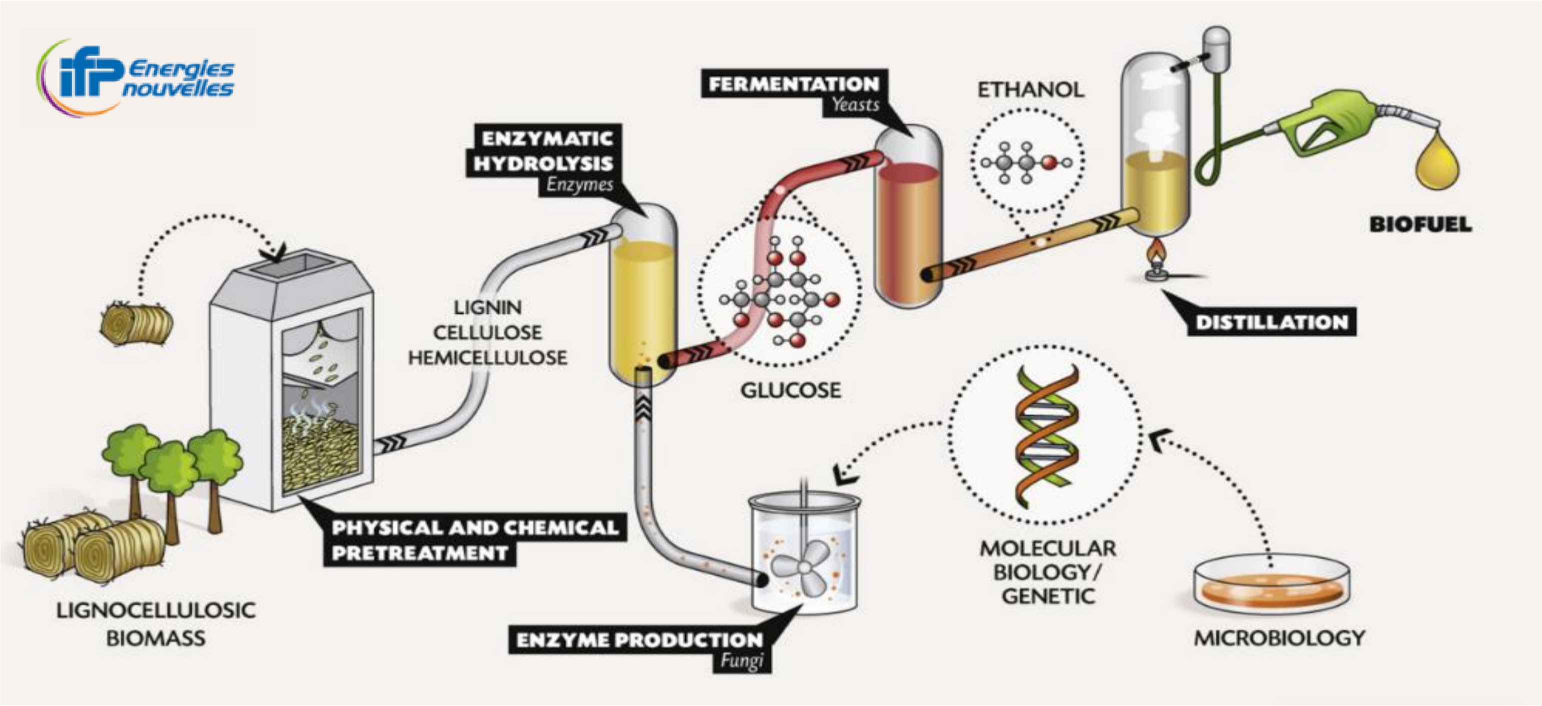
- Mature technology
- Biogas capacity EU: 8 GW_{el} (13 mtoe, 14500 plants)
- Biomethane cap: 1.3×10^9 m^3 (1.2 mtoe, 258 plants)

Anaerobic digestion in the EU



Biochemical conversion: general

- Step 1: Pretreatment to separate (hemi-)cellulose from lignin.
- Step 2: Enzymatic hydrolysis of (hemi-)cellulose to sugars.
- Step 3: Fermentation of sugars to end-products such as ethanol.



Biochemical conversion: S.o.A.

Biochemtex ethanol plant (IT)

POET-DSM ethanol plant opening (USA)

Products:

- Fermentable sugars
- Ethanol
- Chemicals

Feedstocks:

- Wheat straw
- Maize stover
- Bagasse
- Wood
- …

Typical sizes and types:

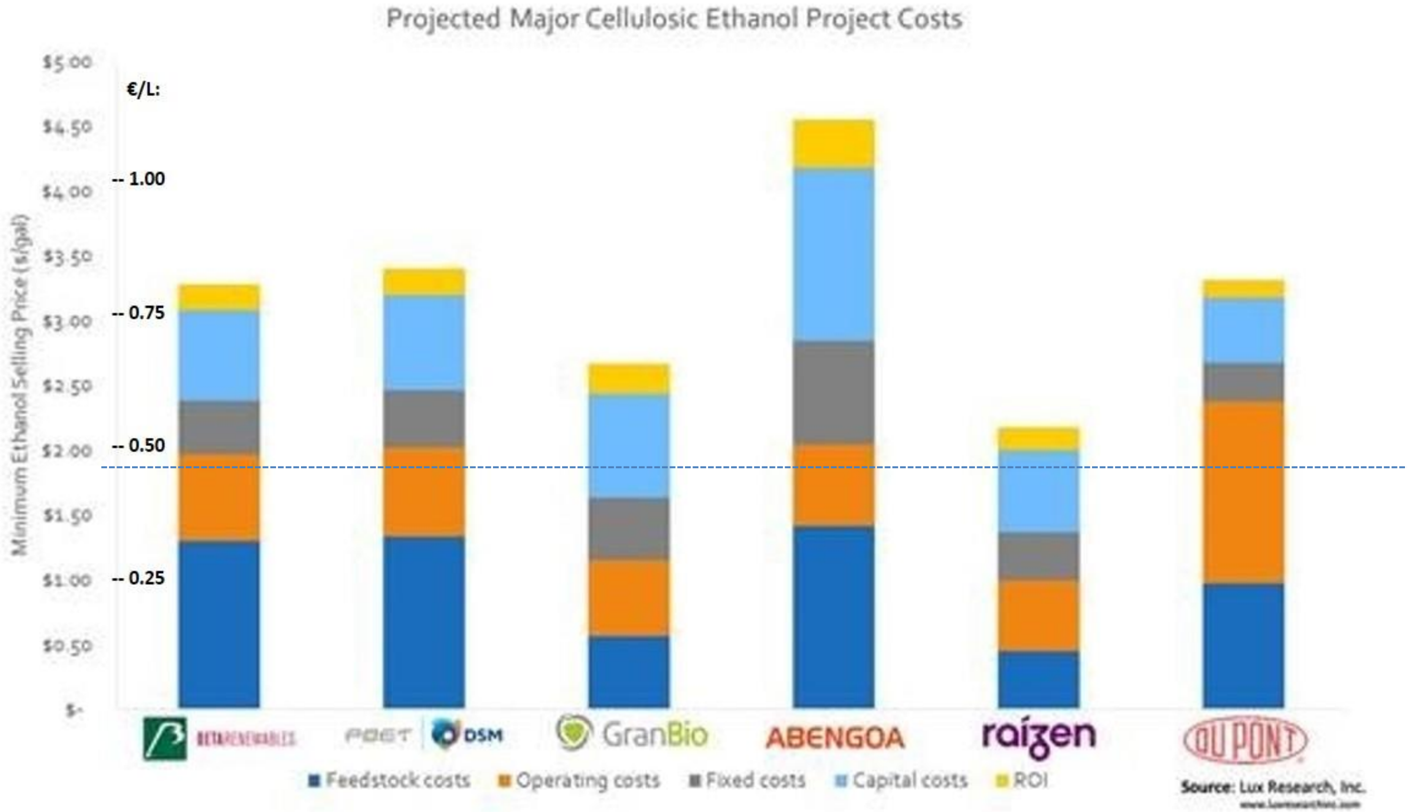
- Pretreatment: acidic / alkaline / steam explosion
- Fermentation: C6 or C5+C6 sugars to ethanol
- Typical size: 300 kt/yr biomass, 100 ML ethanol

Technology status:

- First commercial plants are operational.
- Short future: commercial operation at capacity and growth of capacity.
- Longer future: other fermentation products.

Lignocellulosic ethanol costs

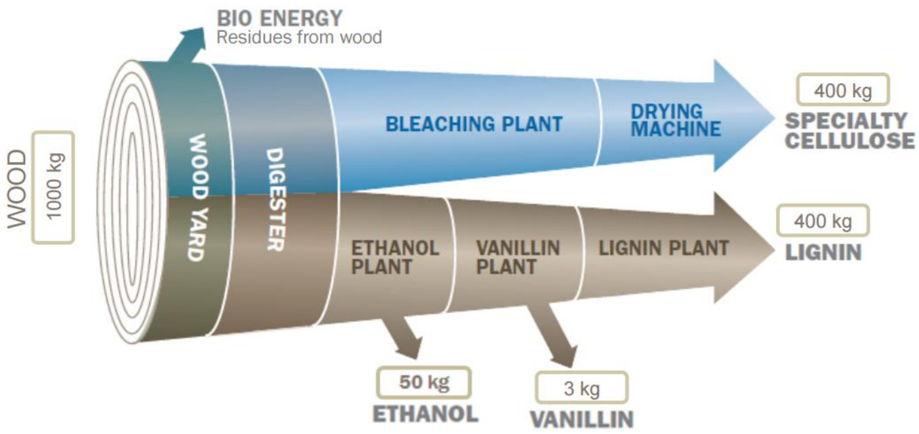
- L.C. ethanol has difficulties to compete financially with other (bio-)fuels.
- Technological challenges have led to slow start-up of commercial plants.



Production costs 1G ethanol[1] and gasoline[2], 2015 (order of magnitude)

[1] *Irwin 2016*
[2] *US EIA 2015*

Pulp & Paper: state of the art



Products:

- Cellulose-products
- Lignin-products
- Ethanol
- Chemicals

Feedstocks:

- Wood

Typical sizes and types:

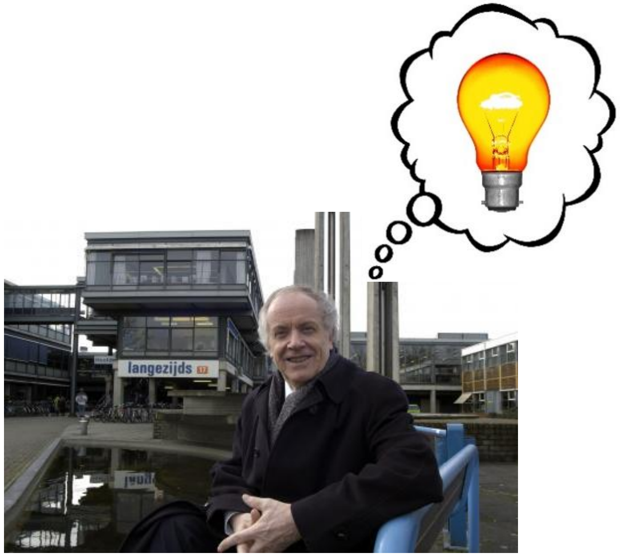
- Typical size of a pulp mill: 400 kt/yr wood input.
- Sulphite spent liquor ethanol: 5-20 ML/yr.

Technology status:

- Kraft and sulphite pulping are very mature.
- Lignocellulosic ethanol production since 1909!
- Short and longer future: creation of added value through bio-based products.

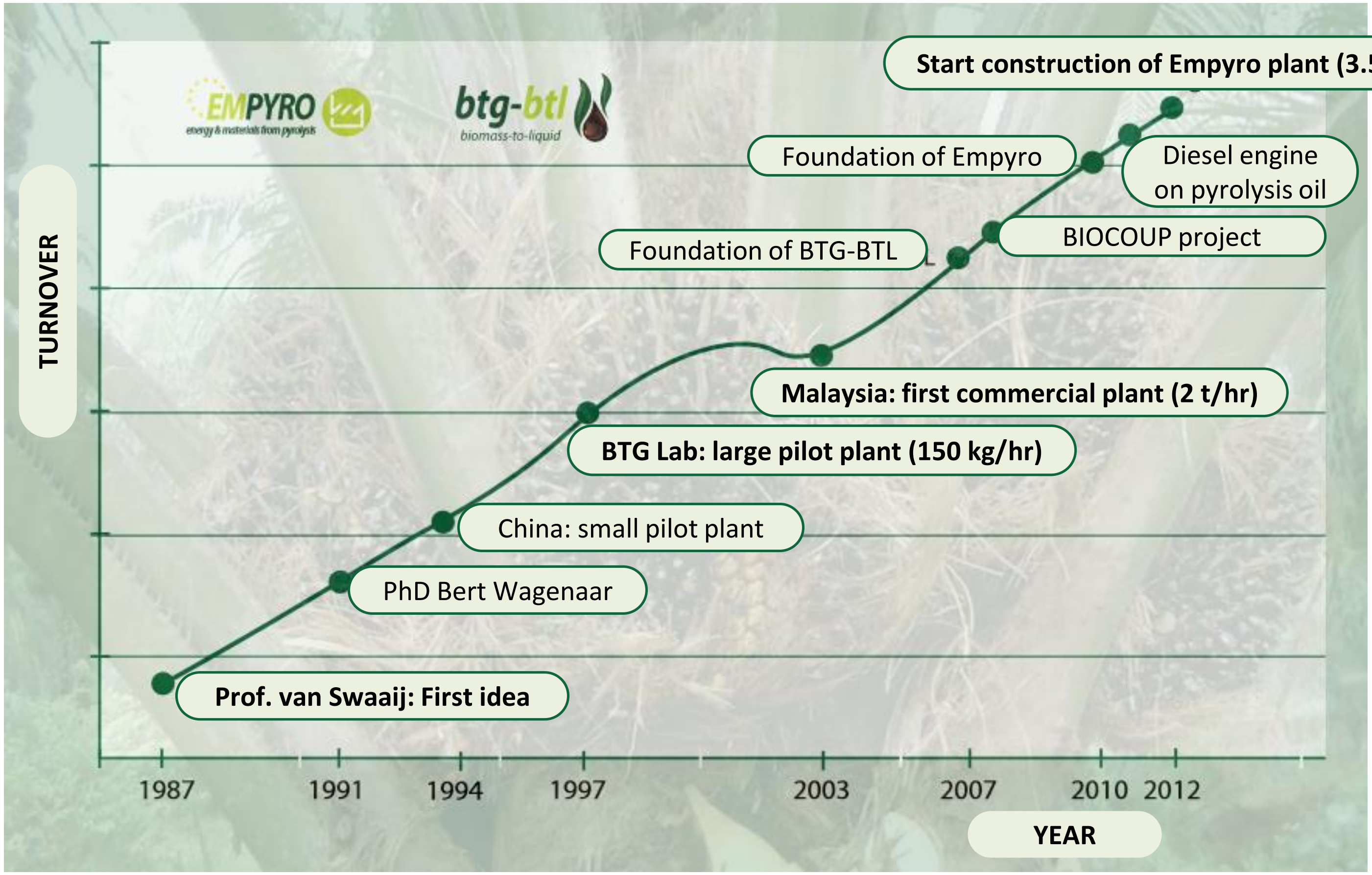
Technology development

- What does it take to move from an idea to a commercial process?



- The case of fast pyrolysis development by BTG in the Netherlands.

Technology development case



- It took 30 years from the first idea in 1987 to the 2016 state of the art!

Technology development case

2016
Apr 2016: > 2 million litres of pyrolysis oil produced
Oct 2015: 1 million litres milestone
First pyrolysis oil delivery to FrieslandCampina
Production of first pyrolysis oil

2015
Initial start-up – process commissioning
Cold & hot commissioning
Mechanical completion
Start construction & site work

2014
Financial closure
Pyrolysis oil contract with FrieslandCampina
Detailed engineering finished
Steam delivery contract with AkzoNobel
SDE⁺ subsidy Empyro (Heat & Electricity)
Biomass contracts for 10 years

2013
TKI – BBE subsidy

2012
All permits obtained (environment, construction, water, Natura2000, etc.)

2011
Basic engineering & cost estimate completion

2010
Project approval by EC; start of Empyro project

2009
Start up of Empyro BV (company) april 2009
Start development of Empyro project

2008
Start up of BTG Bioliquids BV (spin-out company from BTG) - Dec 2007

Technology development case

2015 – State of the art:

- Commercial production of pyrolysis oil from wood. (Empyro)
- Pyrolysis oil replaces natural gas for industrial steam production.
  (Friesland Campina, Akzo Nobel)

2015 – Pipeline:

Fuels (hydrotreating) Fuels (co-processing) Materials (fractionation) P.O. from residues

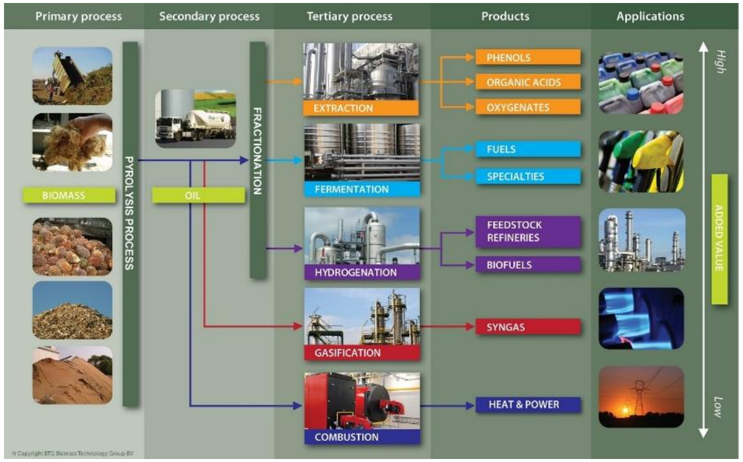
Technology development case

2020 – State of the art:

- Commercial: expansion of pyrolysis oil production from wood.
- Commercial: expansion of pyrolysis oil use for heat and power.
- Demonstration: pyrolysis oil from lower quality feedstocks.
  (e.g. straw, grass, etc.)
- Demonstration: fuels, chemicals and materials from pyrolysis oil.

2030 – State of the art:

- Commercial: 'pyrolysis biorefinery', for fuels, chemicals and materials from lignocellulosic biomass.



Conclusions

Thermochemical processes in 2020

- Commercial production of heat and power by combustion, gasification, torrefaction, fast pyrolysis, also using lower quality feedstock.
- Demonstration projects of fuels and other bio-based products, through gasification and fast pyrolysis.

Biochemical processes in 2020

- Increasing biomethane production for fuels by anaerobic digestion.
- Increasing ethanol production from lignocellulose.
- First commercial projects of non-fuel bio-based products (e.g. lactic acid), but mainly demonstration projects.

Outlook for 2030

- Large-scale production of **heat, power, and fuels** from lignocellulose **in 2020**, develops markets, technology, and infrastructure for **a bio-economy in 2030**.

Thank you for your attention!

Tijs Lammens

BTG Biomass Technology Group B.V.

Contact details:

Lammens@btgworld.com

Tel: +31 (0)53 486 1186

www.btgworld.com

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Topics for discussion

- Are these technology descriptions and outlooks in line with your views within your field of expertise?
  - ➢ If not, how do they differ?

- Are there any gaps / missing technologies in this overview?
  - ➢ If so, which?

- What do you believe to be the most promising conversion technology for lignocellulosic biomass?
  - ➢ Why?
  - ➢ When will it be commercial?

Suggestions for further reading

- Van Loo & Koppejan, *The handbook of biomass combustion and co-firing*, 2008.
- H.A.M. Knoef, *Handbook biomass gasification*, 2nd ed. 2012.
- M. Cremers *et al.*, IEA task 32, *Status overview of torrefaction technologies*, 2015.
- PyroWiki, www.PyroKnown.eu.
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- European Commission DG Move report, *State of the Art on Alternative Fuels Transport Systems in the European Union*, 2015.
- Biofuels Digest, www.biofuelsdigest.com.