# The role of thermochemical conversion in biorefinery concepts – not just combustion

*ECN Biomass R&D in a biorefinery perspective*

Biorefineries – Science, Technology and Innovation for the Bioeconomy

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Concepción, Chile
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# Energy research Centre of the Netherlands (ECN)

## Bridge between science and corporate innovation

**Mission**
We develop knowledge and technologies that enable a transition to a sustainable energy system

- Not-for-profit research institute
- Founded in 1955
- 5 Commercial licensing deals / year
- 500 Employees
- +/-20 patents a year
- € 80 M annual turnover

ECN

# ECN Biomass R&D programme

## Biomass for chemicals, fuels, power and heat

*Focus on thermochemical processing*

**Feedstock**
- Characterization
- Property databases

**Pre-treatment**
- Torrefaction
- TORWASH
- Pyrolysis
- Fractionation

**Conversion**
- Combustion
- Gasification
- Biorefinery

**Separation**
- Gas cleaning
- Tar removal
- Gas conditioning
- Separation

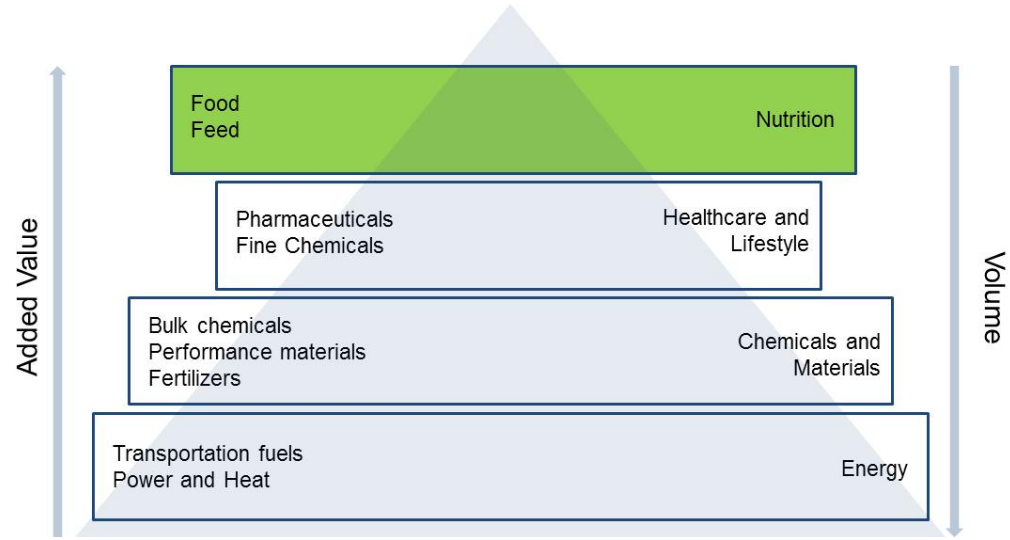
**Product Synthesis**
- Biofuels (incl. Synthetic Natural Gas (SNG))
- Biochemicals & -materials
- Power & Heat

» Higher efficiencies, higher availability, lower environmental impact, higher public acceptance, lower CAPEX/OPEX, new applications

Policy and strategy studies, feasibility studies, techno-economic evaluations, LCA, sustainability assessments

# Biomass use – markets and preferred options

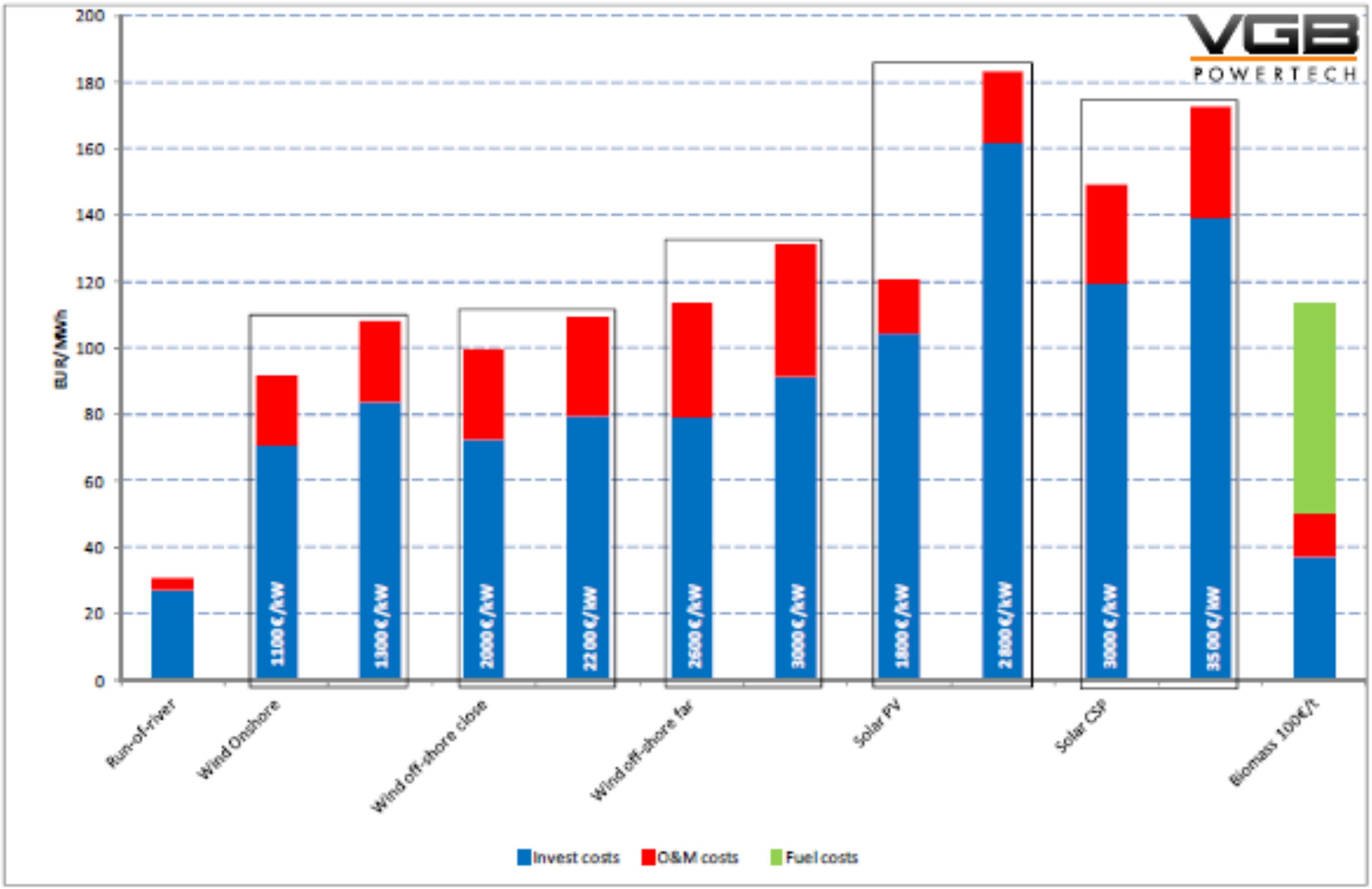
- Shift from focus on bioenergy to focus on biobased economy
- Use C and molecular capital
- Aim for maximum added value




- But:
  - Energy sector more than an order of magnitude larger than chemical sector
  - We need all renewable energy options, we cannot exclude major ones
  - There is enough sustainable biomass to make biomass a major renewable energy option (1/4 – 1/3 of future global energy use)
  - Some parts of the energy sector difficult to cover with other renewables (e.g., HT process heat, biofuels for heavy vehicles, aviation and marine applications)
  - Not all biomass qualifies for high-value applications (e.g., heterogeneous and/or contaminated streams)

# Renewables cost comparison

## For bioenergy, feedstock cost is a major cost factor




*Graph 2: Levelised Costs of Electricity 2011 – Renewables*

Options to decrease bioenergy cost:

- (Decrease CAPEX and OPEX)
- Maximise energy efficiency / heat utilisation (CHP)
- Use less expensive biomass (residues)
- Co-produce high added value products

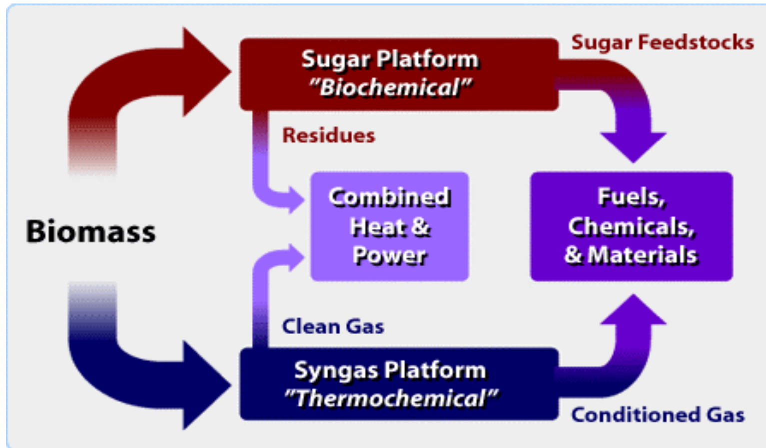
*VGB survey 2012, Investment and operation cost figures, September 2012*

# Biorefinery concepts

## The traditional approach

- Two main conversion routes:
  - Sugar platform: (bio)chemical
  - Syngas platform: thermochemical
- Sugar platform:
  - Natural monomer structure largely preserved
  - Saving energy in production of heterogeneous chemicals (containing e.g. O)
  - Small-to-medium scale (biochemical processing)
- Syngas platform:
  - Natural monomer structure fully destroyed ($H_2$, CO)
  - Robust process, build on coal experience
  - Large scale (economy-of-scale in gasification and gas processing)
  - Biomass needs pretreatment because of logistics and gasifier requirements (torrefaction, pyrolysis)

Biorefinery Concept



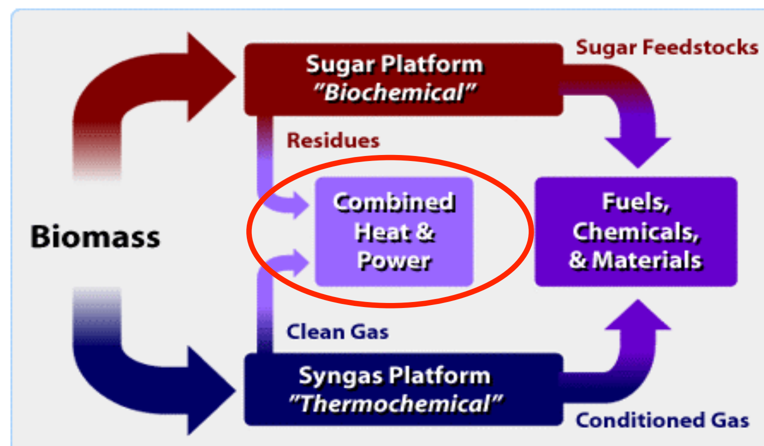

*National Renewable Energy Laboratory (NREL)*

# Biorefinery concepts

## The role of thermochemical conversion

- Biorefineries residues combustion not straightforward
- Other (more attractive) thermochemical options for biorefinery residues
  - Gasification
  - Pyrolysis
- Syngas platform not restricted to high-temperature entrained-flow gasification
  - High reactivity of biomass allows milder conditions

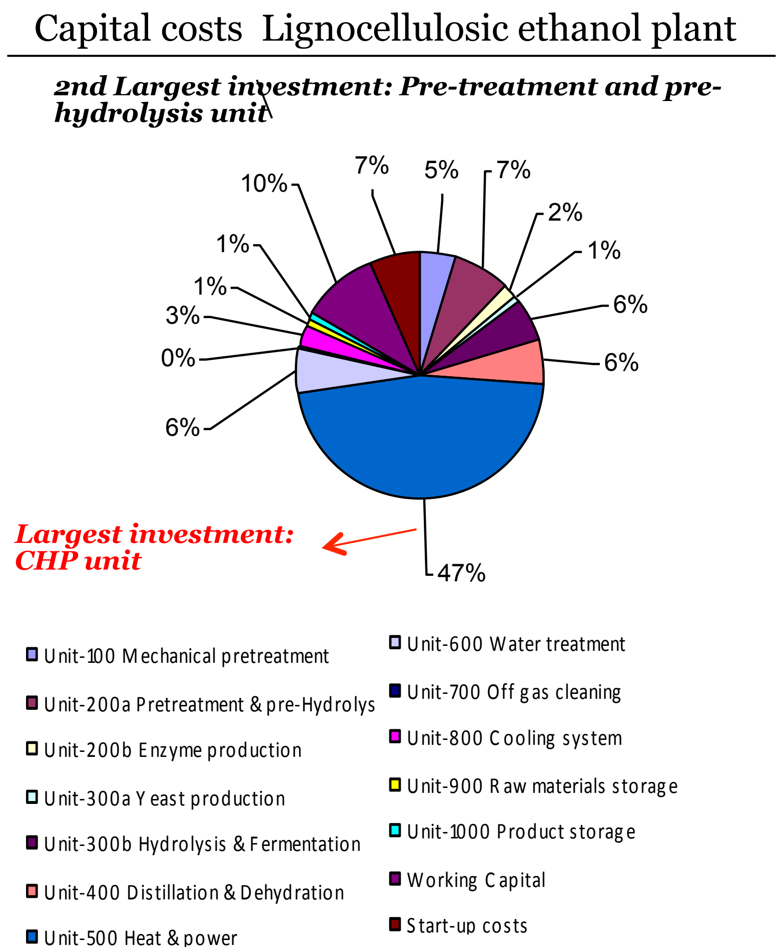
Biorefinery Concept




*National Renewable Energy Laboratory (NREL)*

# Energy island in biorefineries

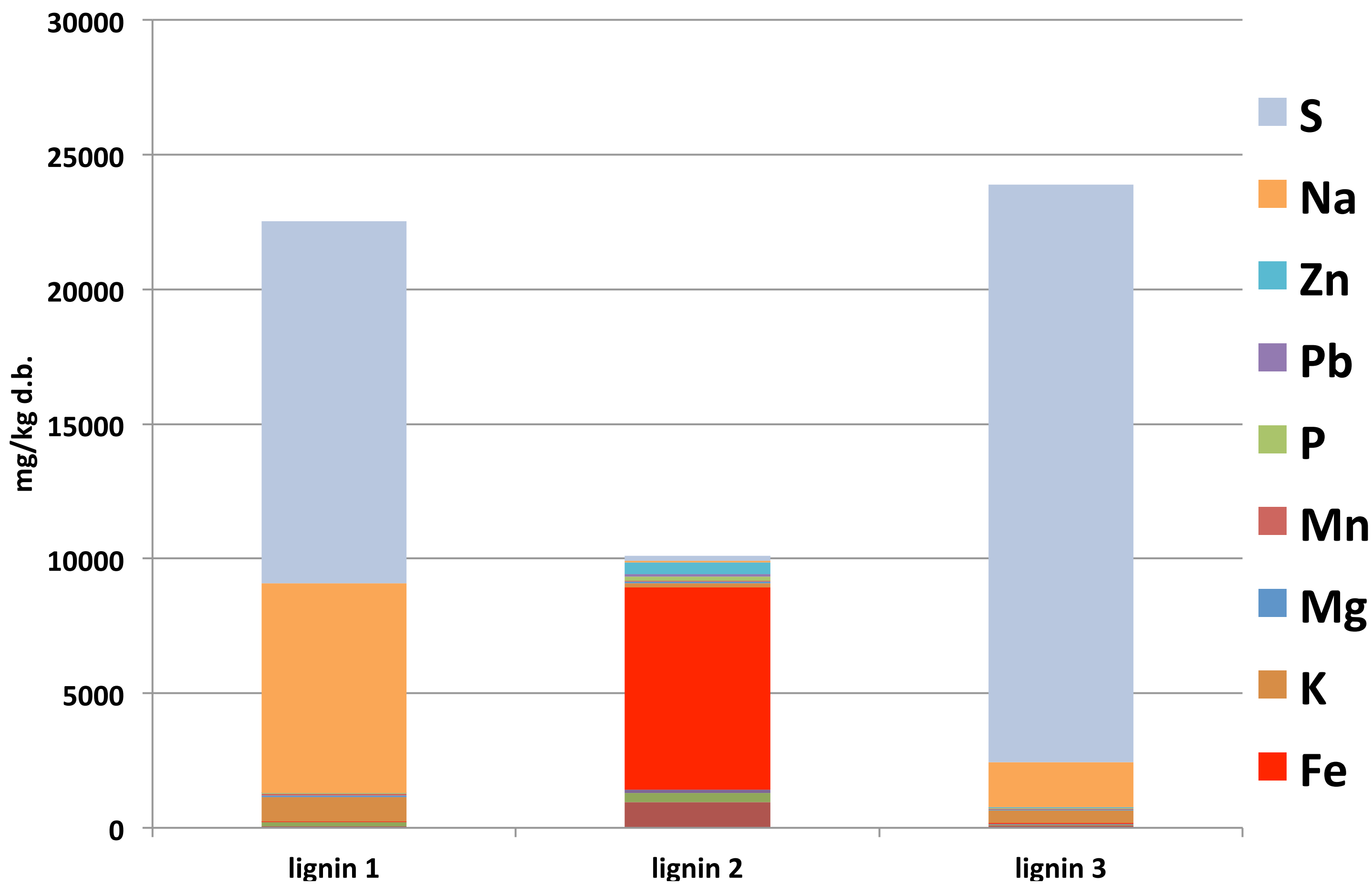
- The energy island often is the single largest investment
  - Usually a CHP unit
- Biomass residues from production processes are burnt in the energy island at significant quantities
  - Lignin typically 15-25% of total biomass composition
- Residues properties can vary substantially
- Technology providers are often not willing to guarantee performance of their boiler




*Source: Final report, EET project K01116, 2007*

# Residues for heat and power

## Large differences in (inorganics) composition




*From: Beis et al. (2010), Bioresources 5(3), 1408-1424*

# Residues for heat and power

## Technical challenges

*Physical properties*

- High water content
- Fibrous/tenacious/bulky
- Finely dispersed/viscous

Residues

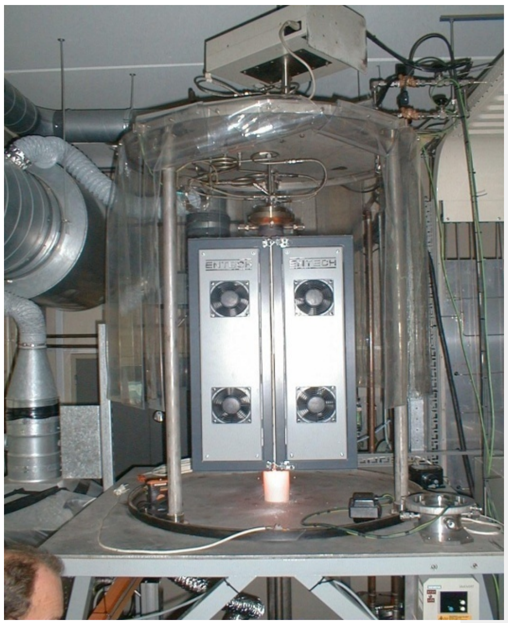
- (earth-)Alkali (Na, K, Ca)
- $NH_3$ / Cl / S
- Si and Al (sand or clays)
- Microbiological content
- Highly biodegradable

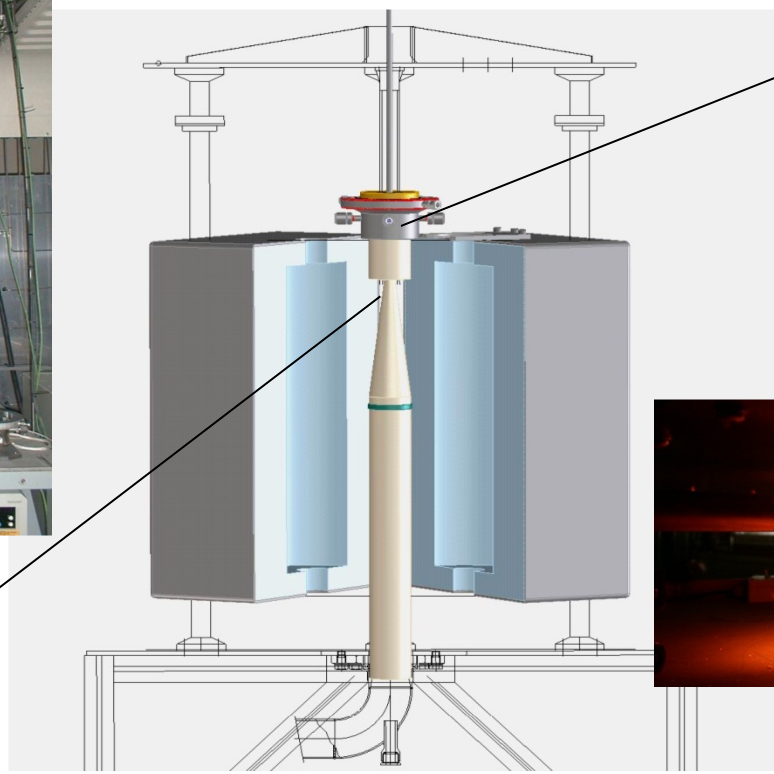
*Thermo- and Bio-chemical properties*

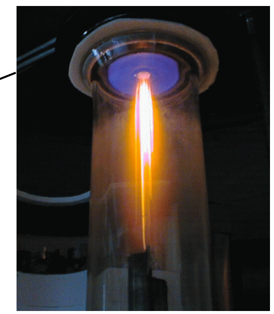
- Energy density
- Pressing/evaporation
- Pumping/conveying
- (intra-process) Storage
- Size reduction (grinding)
- Slagging/fouling
- Corrosion
- Mineral residues utilisation
- Microbiological risk
- Emissions to air and water

# Lab-scale Combustion Simulators (LCS)

## Mimic pulverised-fuel and liquid fuel combustion conditions







Staged gas burner: high heating rate + proper gas atmosphere

Special reactor design: 1-2s residence times with only limited total reactor length

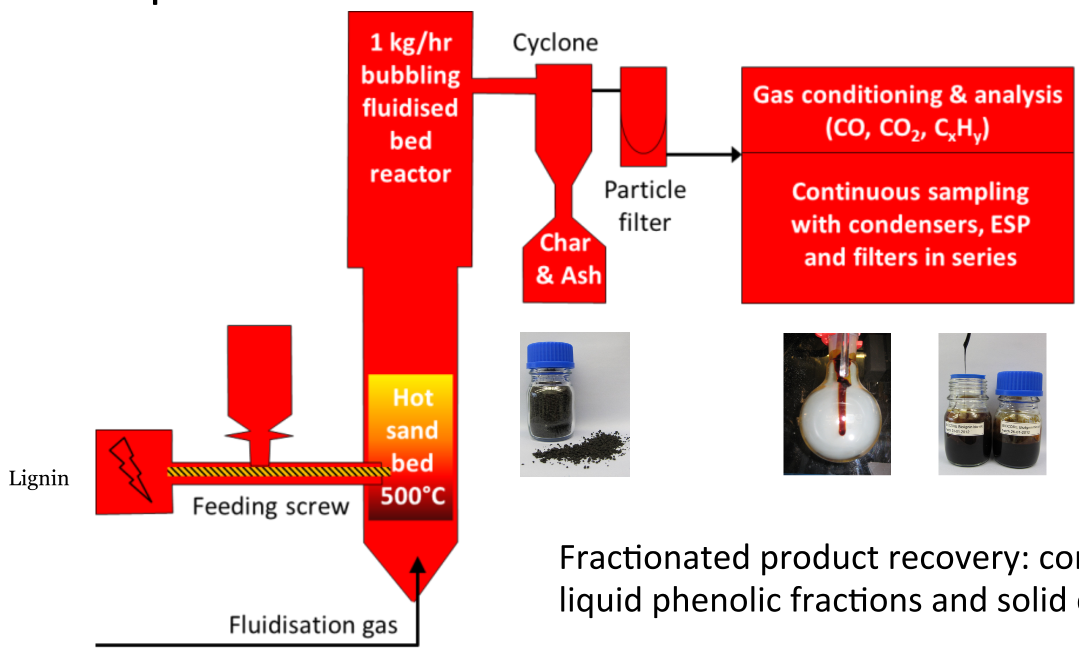
Fouling probe

Particle sampling probe

# LIBRA – pyrolysis-based lignin biorefinery

- LIBRA involves:
  - Conditioning of lignin to prepare it for conversion by pyrolysis
  - Feeding the conditioned lignin into a bubbling fluidized bed pyrolyser via appropriate feeding protocols
  - Pyrolysis of lignin into gaseous and solid products
  - Recovery of products by fractionated condensation of pyrolysis vapors and active removal of solid char
  - Primary product upgrading (filtration, distillation, etc.)

- LIBRA lab-scale development

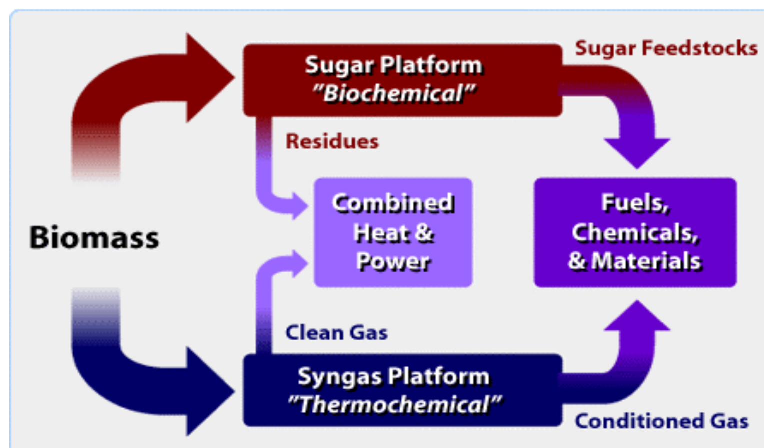



Fractionated product recovery: combustible off-gas, liquid phenolic fractions and solid char

# Syngas platform – gasification

- Gasification converts biomass into gaseous fuel
- Large feedstock flexibility (e.g. woody biomass, agricultural residues, but also wastes and waste-derived fuel)
- Opens the door to existing energy systems:
  - Boilers
  - Engines
  - Turbines
  - Chemistry
  - Fuels
  - Refineries
  - Steel industry

Biorefinery Concept

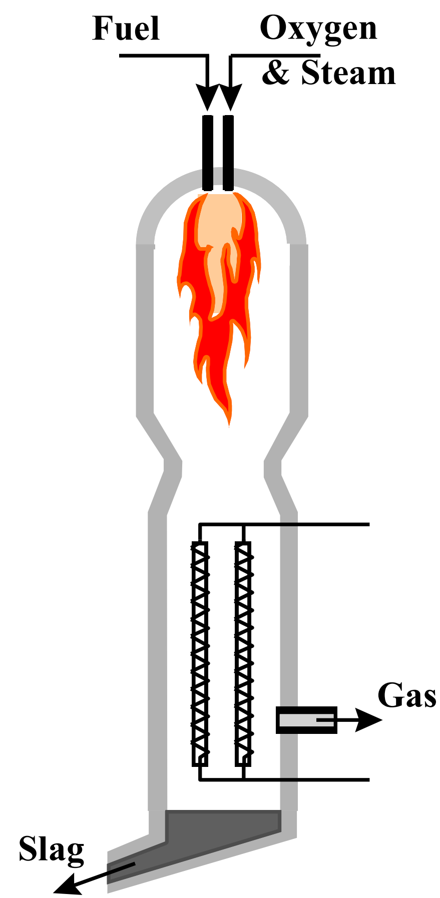



*National Renewable Energy Laboratory (NREL)*

# Entrained-flow gasification of biomass

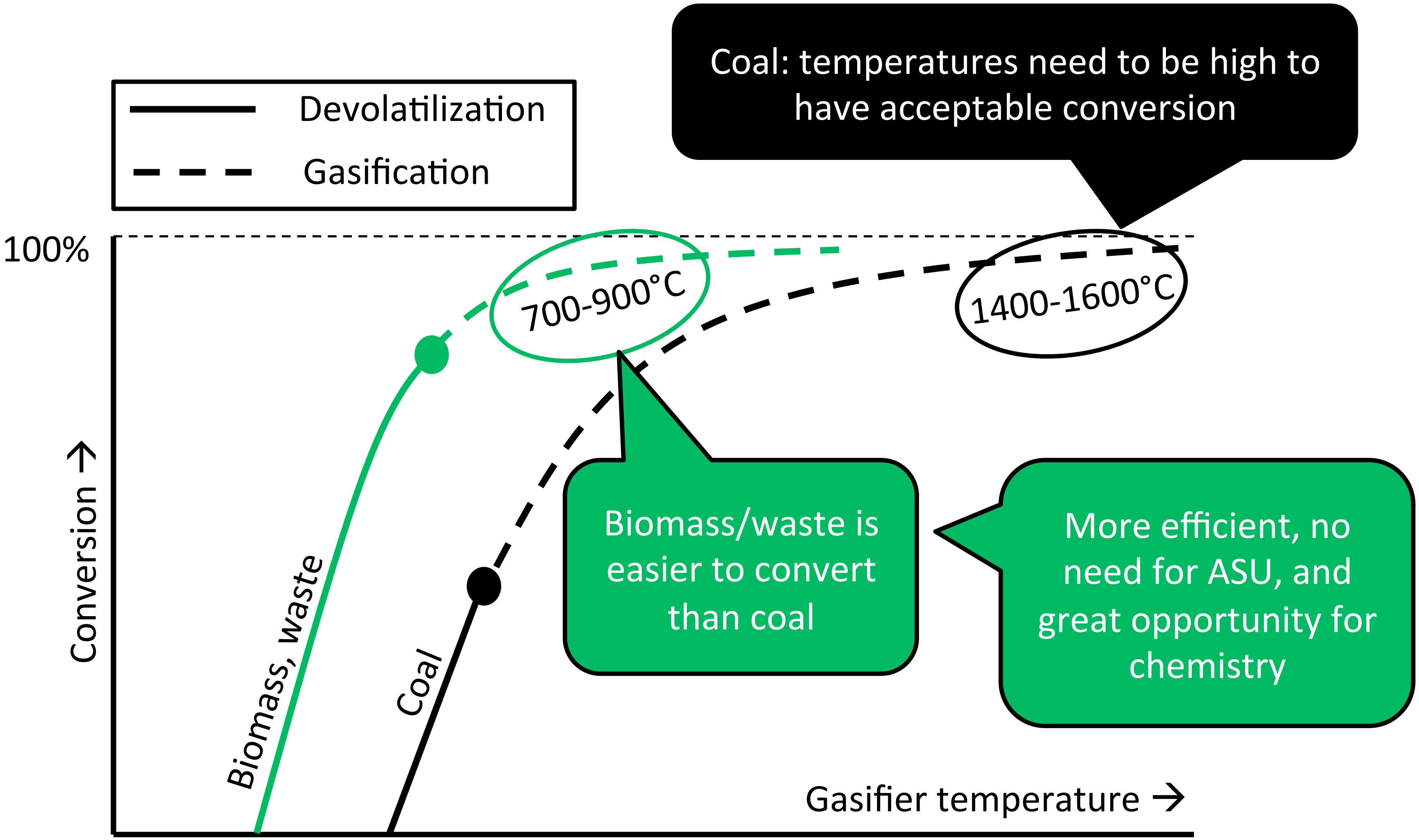
## Produce syngas as chemical feedstock

- Pressurized operation, steam/oxygen blown
- Typical 1300°C
- Syngas (mainly $H_2$ , CO), no tars and other hydrocarbons
- Inorganic material melts, becomes slag
- Complete fuel conversion
- Scale > 100 $MW_{th}$
- Pulverized fuel required (~ 50 micrometer) or liquid or slurry; biomass needs pretreatment: torrefaction or liquefaction (e.g. pyrolysis)
- Complex design (membrane wall)
- Examples: Shell, Siemens, Chemrec (Black Liquor), a.o.



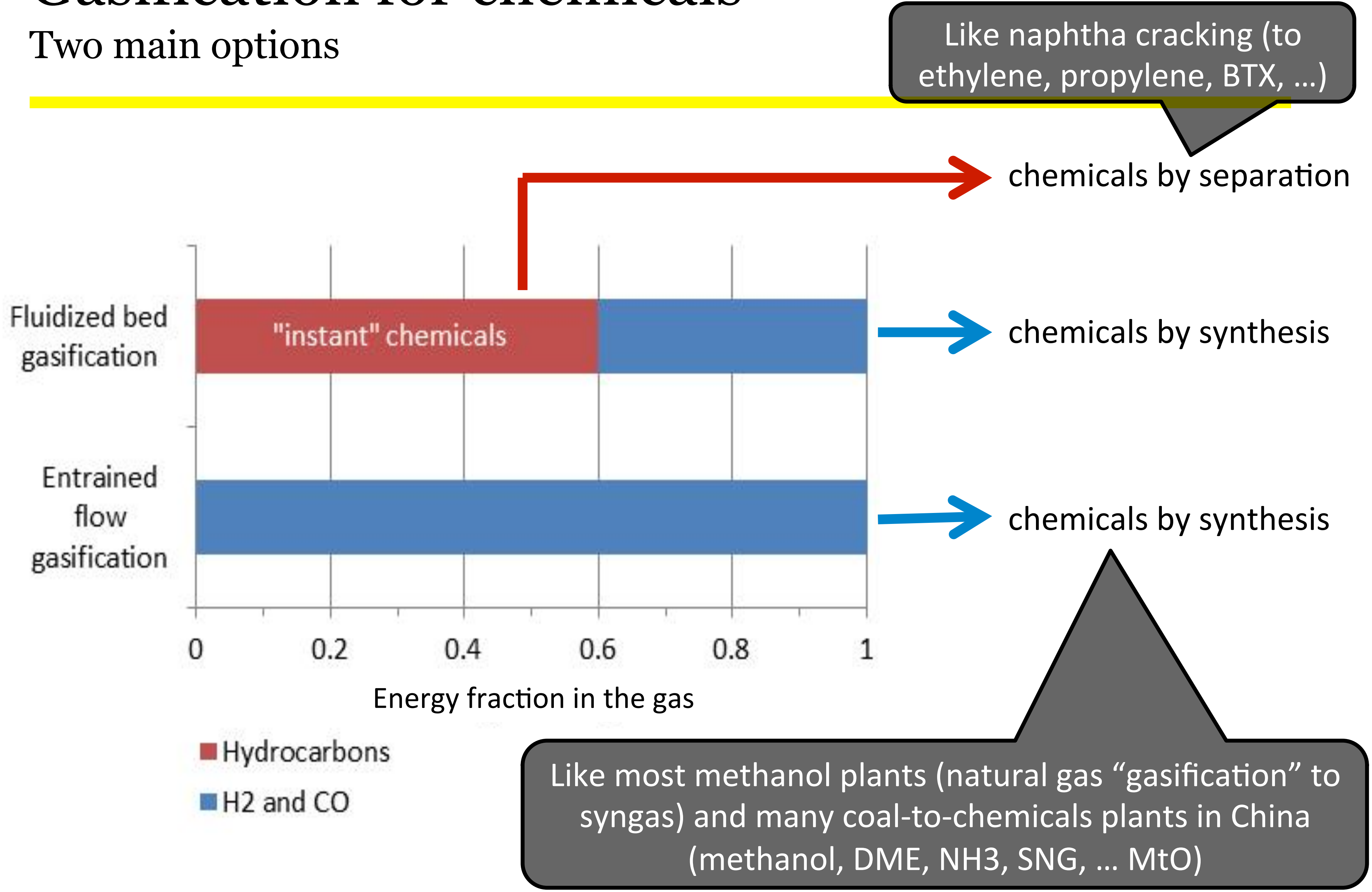
# Conversion vs. temperature

## Biomass and waste do not need severe conditions



# Gasification for chemicals

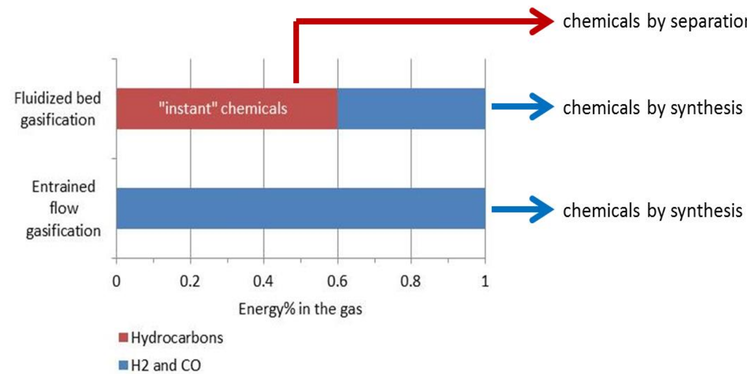
## Two main options



# Gasification for chemicals (2)

## Two main options

- Chemicals by synthesis:
  - H2 + CO (syngas) → chemicals like methanol, ammonia, SNG, diesel
  - Mature and available technology
  - Syngas-to-chemicals ~80% energy efficient

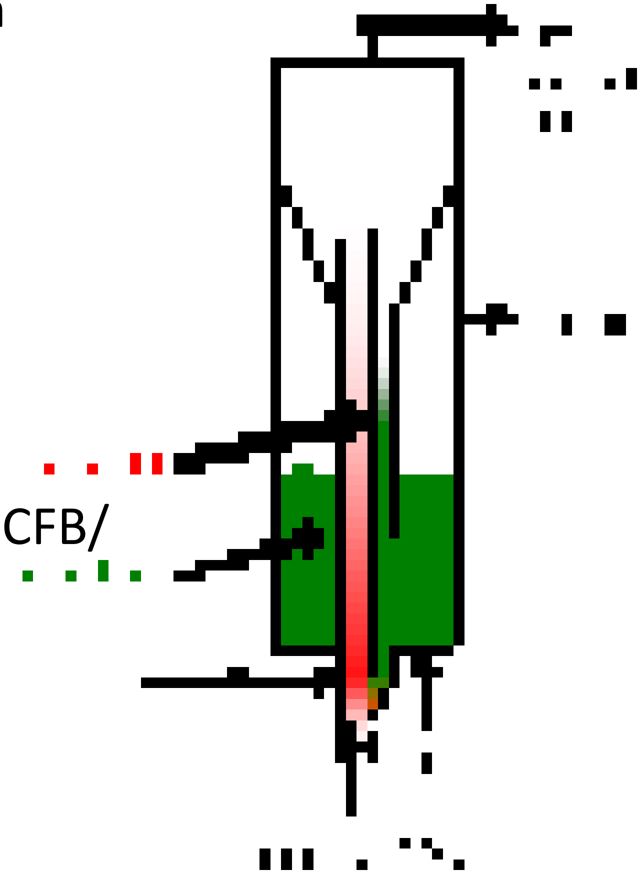



- Chemicals by separation:
  - Separate already existing molecules from gas
  - Requires mild gasifier conditions (< 1000 °C) to keep hydrocarbons alive
  - Concerns mainly benzene, ethylene, methane
  - Matches very well with biomass/waste: low temperature suffices
  - Double energy benefit: not broken down in gasifier and not having to synthesize from syngas
  - But may also include H2 and CO2

# Indirect fluidized-bed gasification

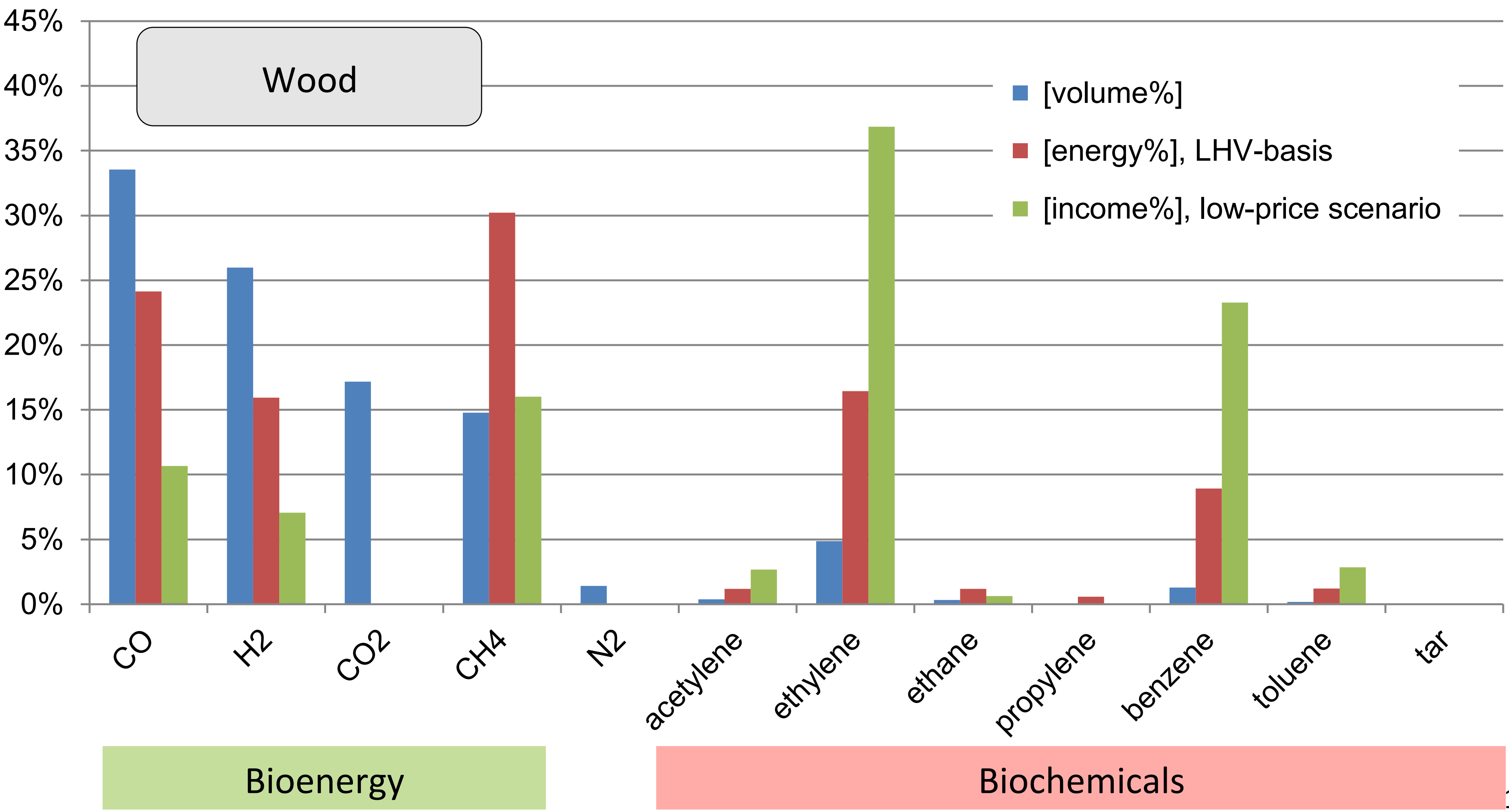
## Coupled fluidized-bed reactors

- Energy production and energy consumption processes in separate reactors
- Char serves as fuel for combustion reactor
- Complete conversion
- Air-blown, yet essentially $N_2$-free gas
- 5-200 $MW_{th}$
- Medium tar (10-50 $g/Nm^3$)
- Examples: Batelle/Rentech/SilvaGas (US), FICFB/ Repotec (A), ECN/MILENA (NL)



# Biomass indirect gasification

## Gas composition: small concentrations, high value

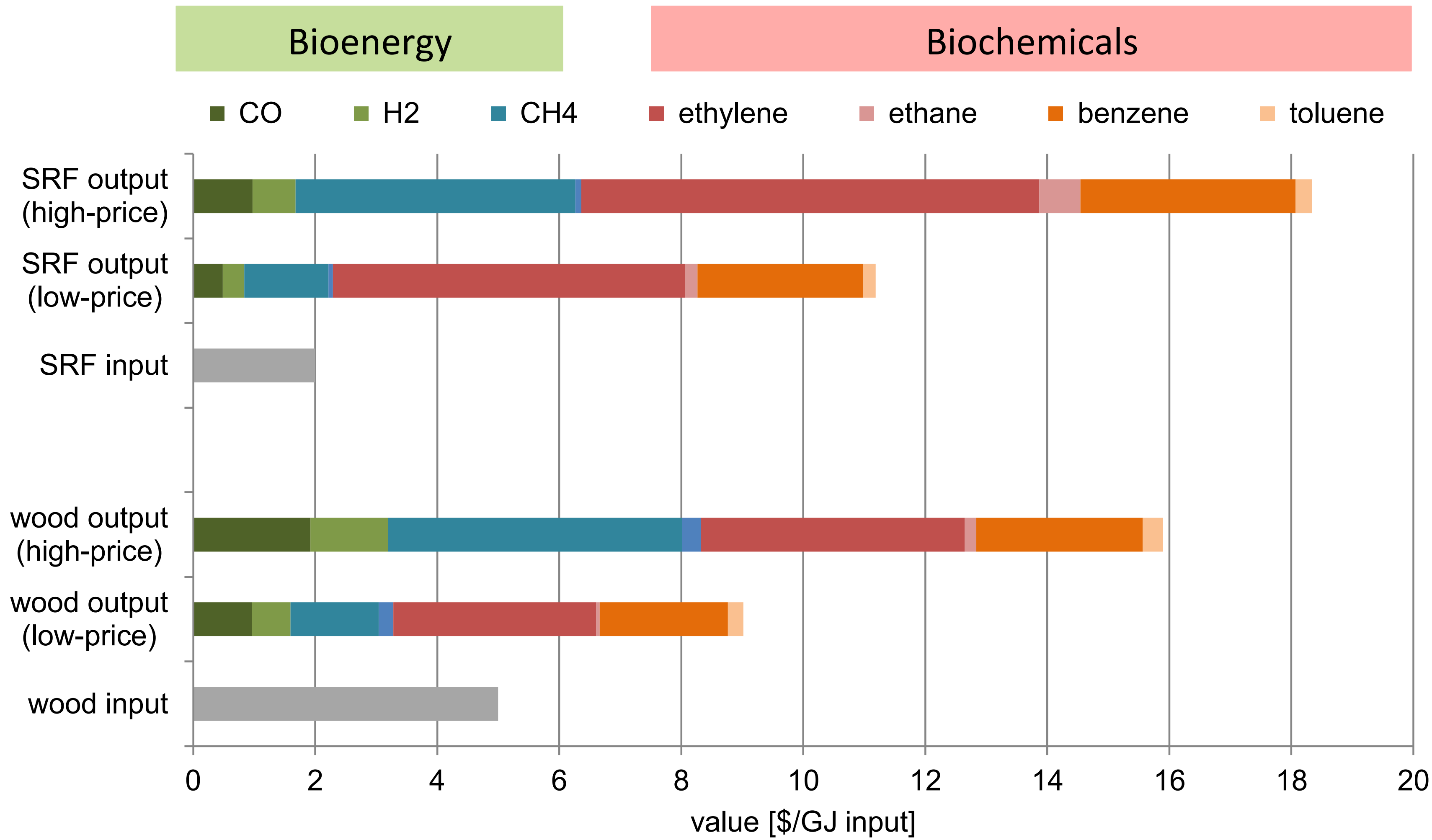


# Biomass indirect gasification economics

ECN

## Impact of feedstock cost and chemicals co-production

(low-price = based on fossil prices; high-price = 100% premium on syngas, 200% premium on methane, 30% premium on biochemicals)




*SRF = Solid Recovered Fuel = standardised paper-plastic residue*

# Gasification-based biorefinery

## “harvesting the chemicals”

Biomass gasification is the basis of a bio-refinery, similar to the biochemical (sugar-based) approach:

- A sequence of harvesting “instant chemicals” and syngas-based products
- But with the ability to convert all kind of (contaminated) low-quality feedstock to high-value chemicals
- Alternative feedstock: residues from biochemical bio-refineries, often low-value lignins and humins
- Chemicals fit current petro-chemistry

- So, biomass gasification becomes a way of producing chemicals, rather than only being a pre-treatment to produce an easy-to-use gaseous fuel from a difficult-to-use solid fuel
- Biomass gasification offers a new way of producing green chemicals

# Example: (ECN) Green Gas production

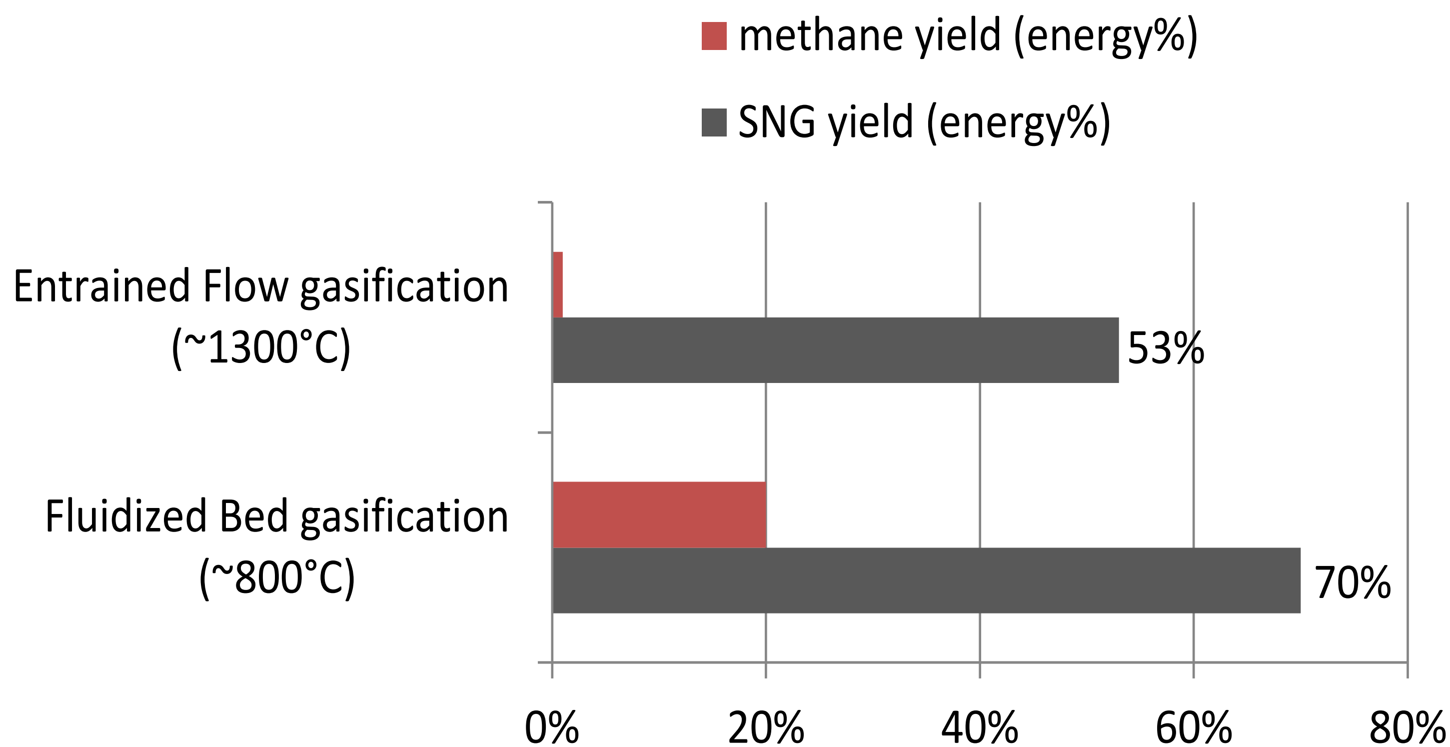
Green Gas = bio-SNG = Renewable Natural Gas = bio-Methane

For power
For (high-T) heat
For chemistry
For transport

Using existing infra
Including gas storage
With quality system
And security of supply

# Gasification: not too hot

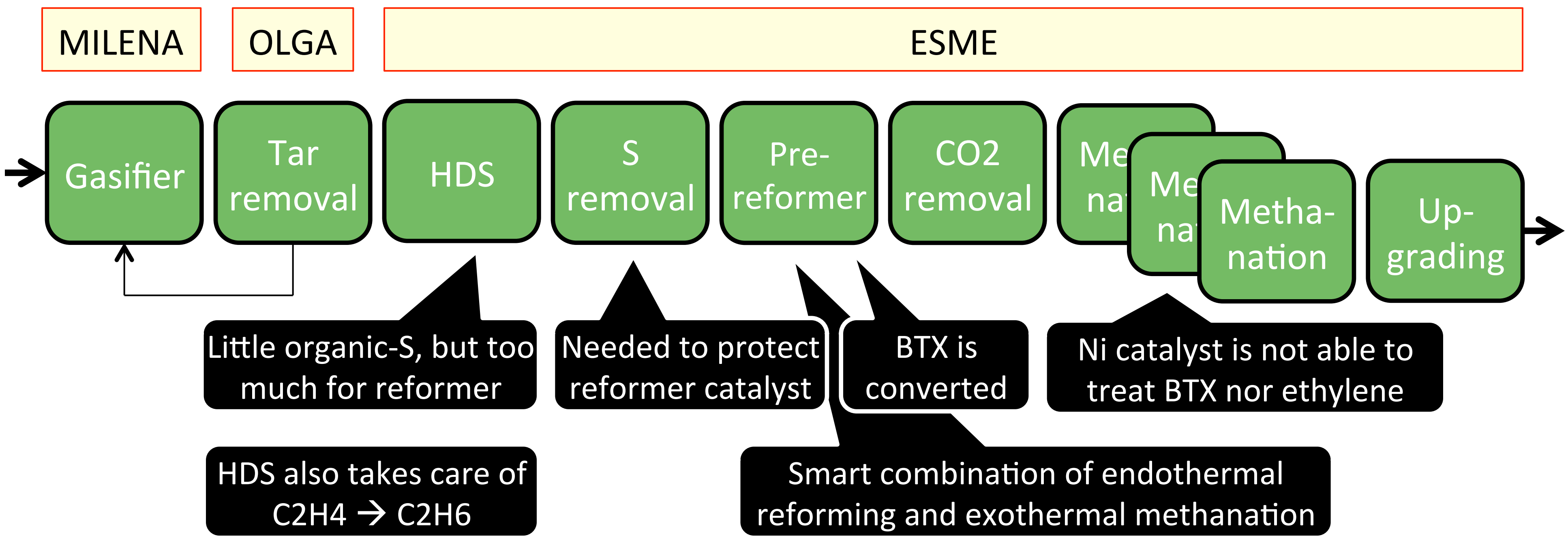
## Instant methane is good for efficiency




*Source: C. M. van der Meijden et.al., Biomass and Bioenergy 34, pp 302-311, 2010*

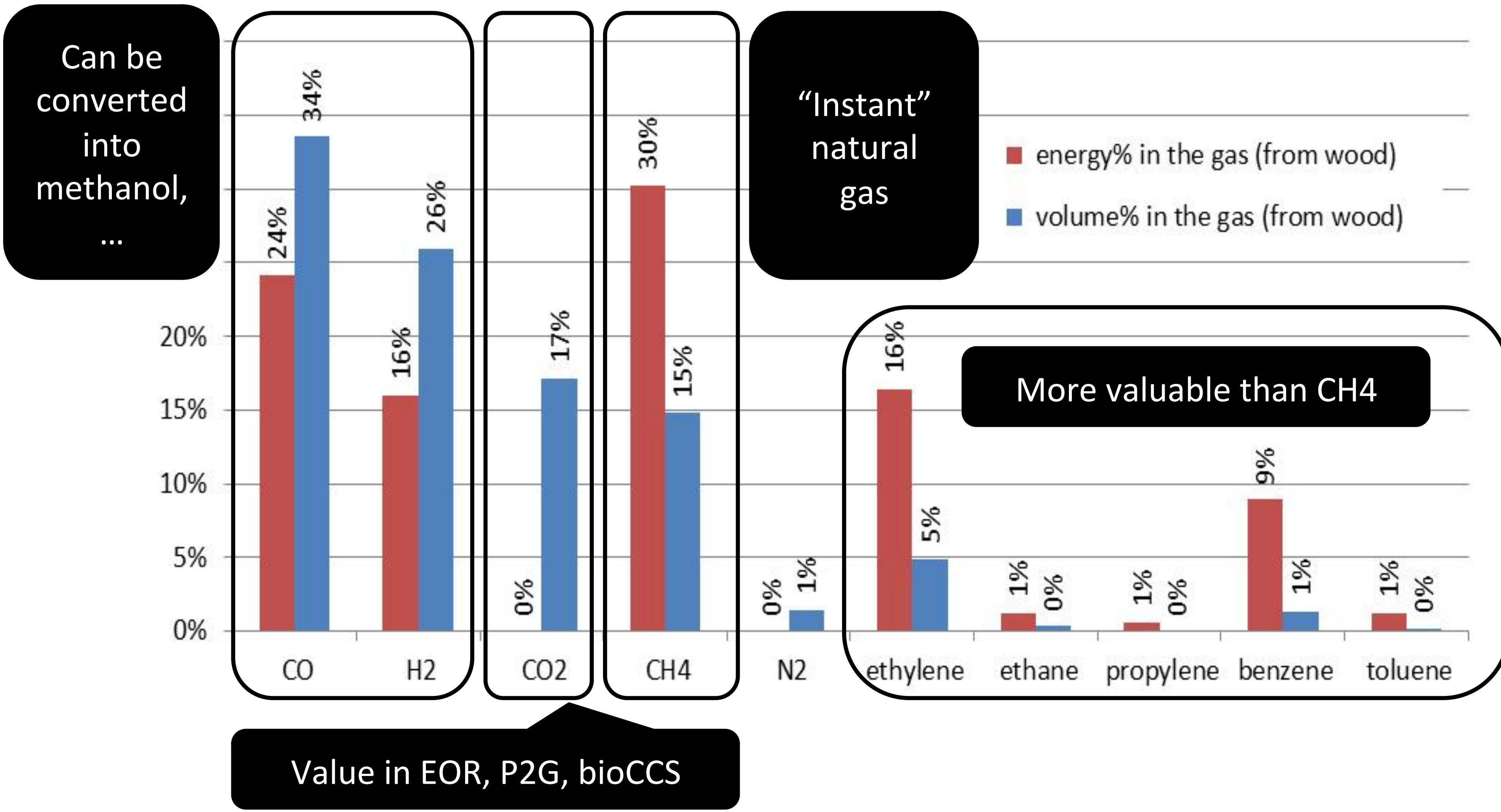
# ECN Green Gas process

## Base case: everything converted into methane




*Gasifier: Fluidized Bed Gasifier operating at ~800°C*
*HDS: HydroDeSulphurization (converting organic S molecules into $H_2S$)*
*BTX: Benzene, Toluene, Xylene (~90%/9%/1% in case of fluidized bed gasification at ~800°C)*

# … but the Green Gas business case can be further improved!



# Gasification-based green gas production

## Potential cost reductions

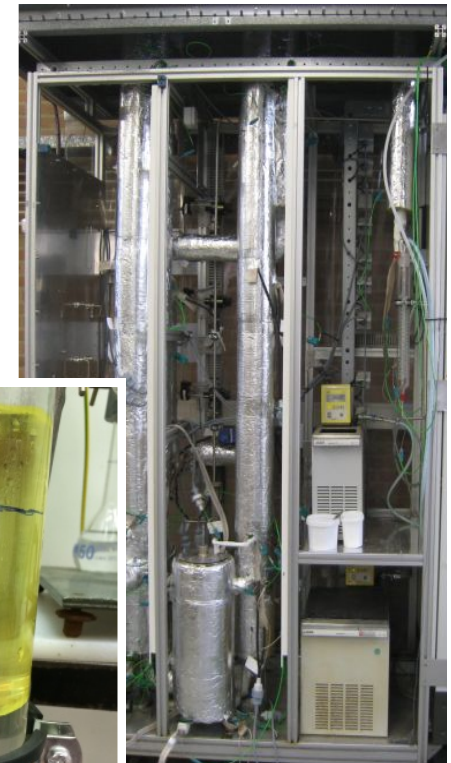
- Bio-BTX co-production
- Bio-ethylene co-production (either separated or converted into aromatics)
- Bio-$CO_2$ capture and storage
- And more:
  - $H_2$/CO for bio-chemicals
  - Increasing bio-BTX yield
  - Increasing bio-ethylene yield
  - Accommodate excess (renewable) $H_2$ to make methane and solve the renewable power intermittency issue (P2G)

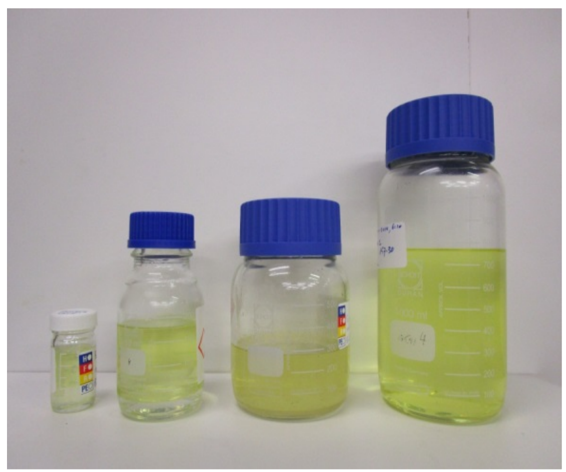
Green Gas can become cheaper than natural gas!

# ECN BTX separation process

## Benzene, toluene, xylenes

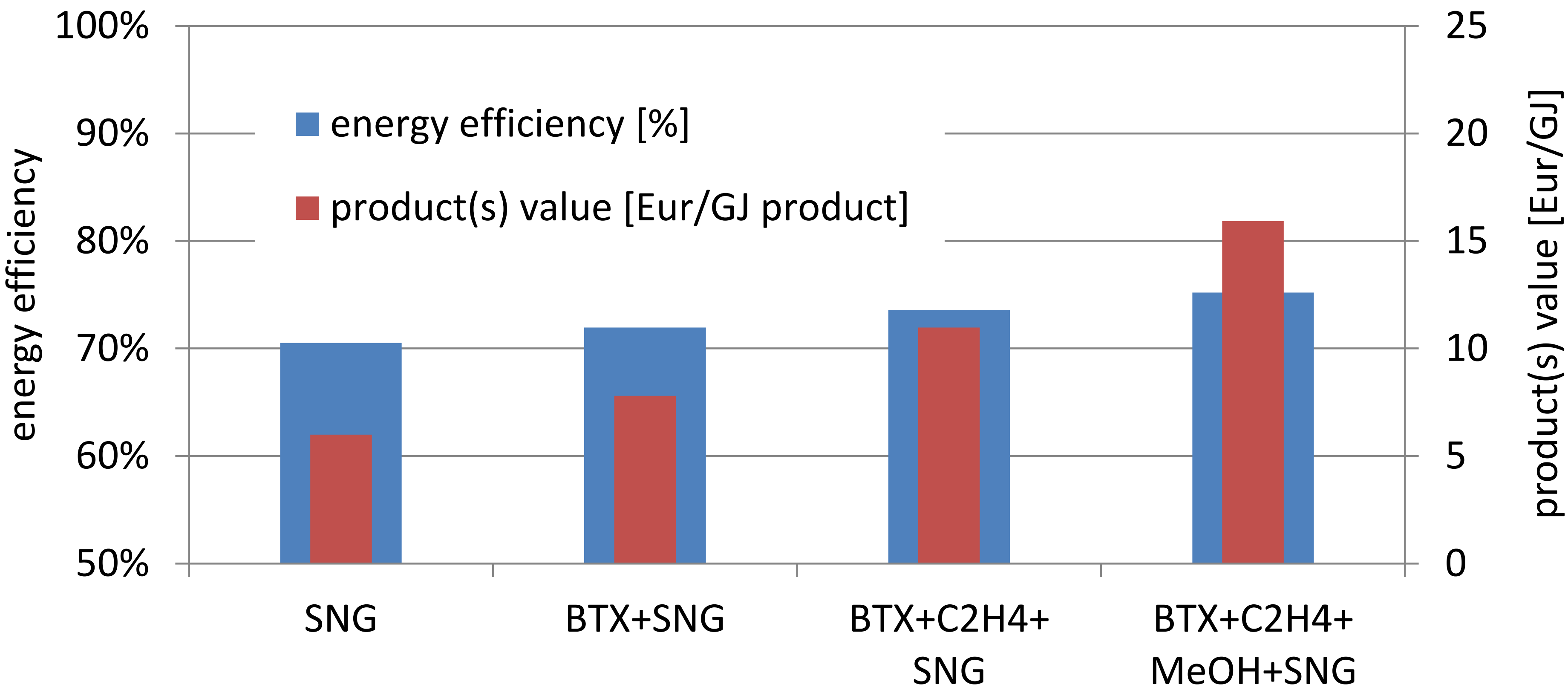
- First step after OLGA tar removal
- Liquid BTX product: first liter in 2014
- >95% separation
- B/T/X = 90/9/1
- Simplifies downstream process to SNG



# Co-production has potential

In view of product prices, energy efficiency and process complexity




SNG: Synthetic Natural Gas; BTX: mainly benzene; C2H4: ethylene; MeOH: methanol

# Summary

- A clear split between (the development of) biochemical and thermochemical biorefinery concepts leads to suboptimal solutions – join forces
- The energy island of a biorefinery is a major part of the total investment and biorefinery residues utilisation for CHP is not straightforward
- Other thermochemical conversion options (gasification, pyrolysis) may create higher added value from biorefinery residues
- Proper (mild) gasification technologies allow for attractive co-production schemes including chemicals co-production by separation
- Example: Green Gas can become cheaper than natural gas

# Thank you for your attention!

Publications: www.ecn.nl/publications
Fuel composition database: www.phyllis.nl
Tar dew point calculator: www.thersites.nl
IEA bioenergy/gasification: www.ieatask33.org
Milena indirect gasifier: www.milenatechnology.com
OLGA: www.olgatechnology.com / www.renewableenergy.nl
SNG: www.bioSNG.com / www.bioCNG.com
BTX: www.bioBTX.com

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