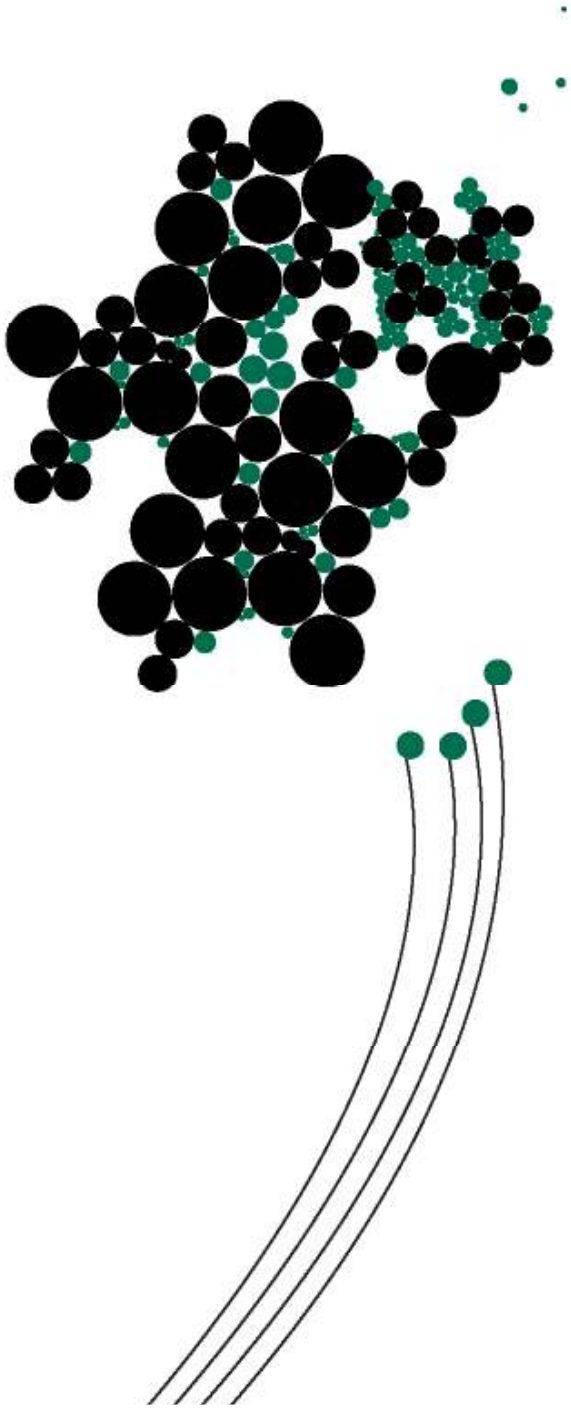
IMPACT



Biomass *Research at TCCB*

UNIVERSITY OF TWENTE.

Biomass Research at the University of Twente

- Since 1972 biomass research
- Now: 40 fte researcher (PHD, post-doc)
- Research disciplines:
  - Process Technology
  - Catalysis
  - Separations
  - Chemistry/Materials
  - Socioeconomics
- Funding: university board, subsidy agents (local, national, international), companies

Biomass Province Overijssel

- Biomass available
- Companies
  - Biomass collection
  - Technology owners
  - Biomass users
- Support by the Provincial Government
  - Initiating and financing a centre for Research and Innovation

btg-btl biomass-to-liquid

HoST BIO-ENERGY INSTALLATIONS

Twence® Afval en energie

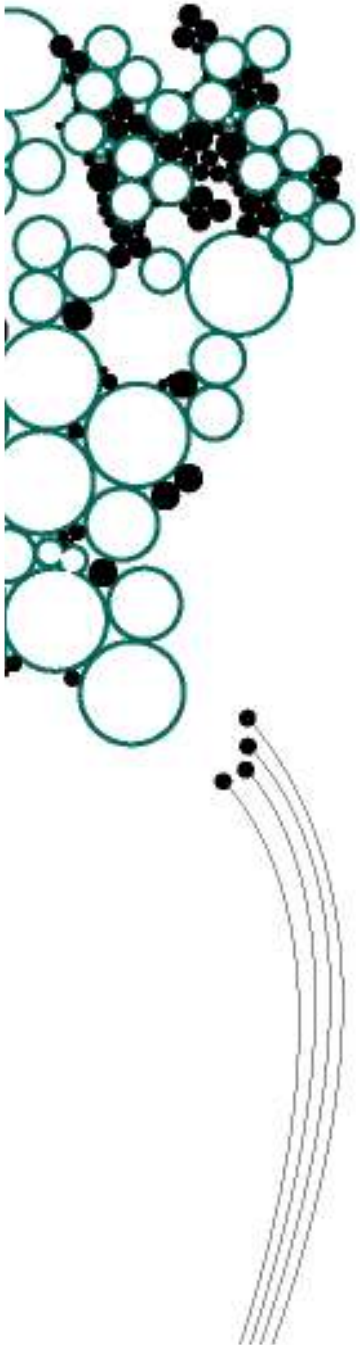
btg biomass technology group

bruins & kwast biomass management

TWENTE MILIEU

BE2.0

provincie Overijssel



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UNIVERSITY OF TWENTE.

Research

Biomass

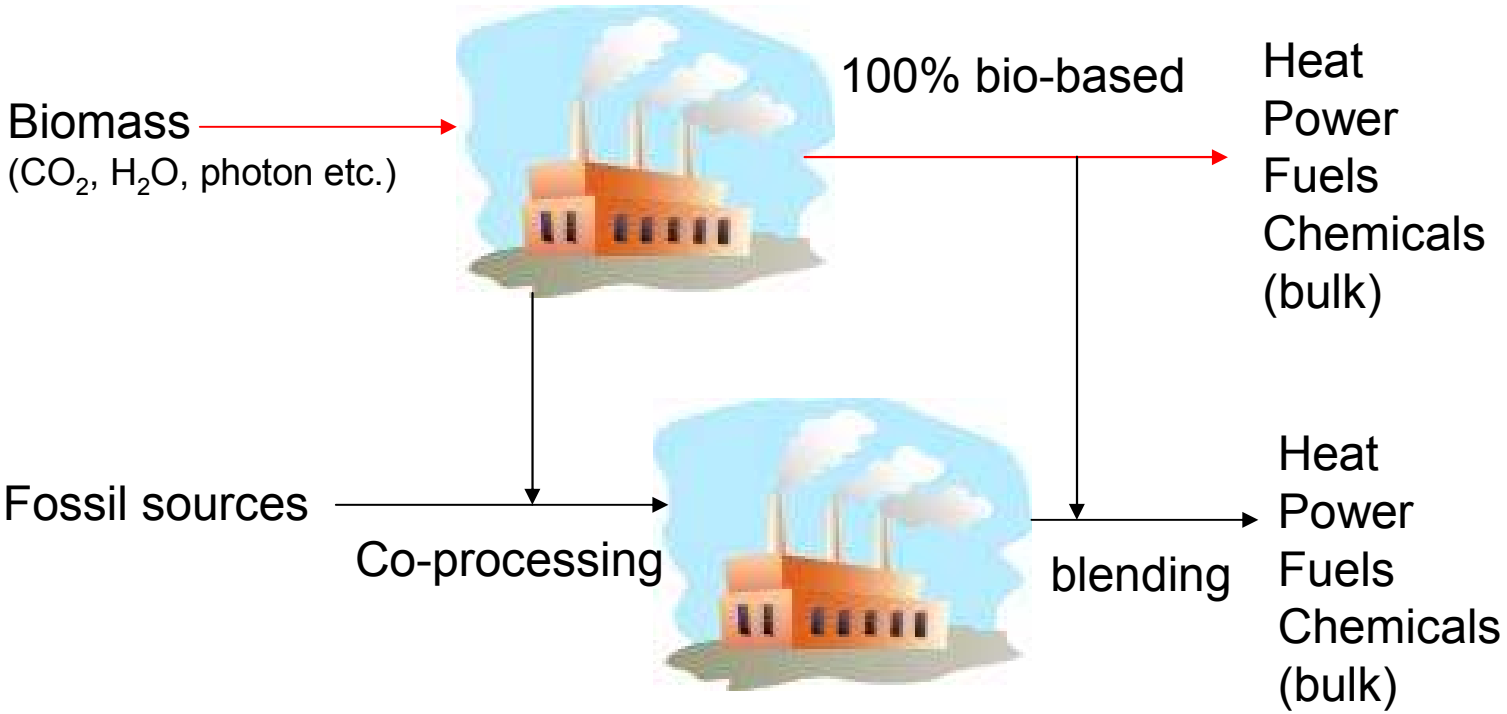
Thermo-chemical conversions
Catalytic Conversions
Biotechnological conversions
Separations
Non-technical aspects

CO_2 / C-source
Photons
Electrons

Heat
Power
Fuels
Chemicals

Fossil feeds

100% biobased or integrating with fossil industry



Feedstocks

1st generation

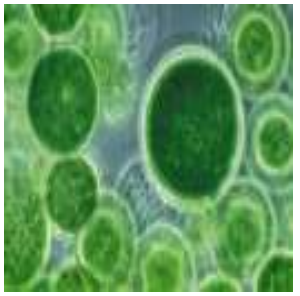
Sugar Cane

(Current Biofuels)

Forestry residues

2nd generation

Agricultural residues



Energy Crops

3rd generation

Photons
Electrons
CO_2
H_2O
C-source

(intermediate) products

Research Topics

- Primary Thermo-chemical / catalytic conversions
  - Liquefaction
  - Gasification
  - Torrefaction
- Upgrading (thermal/chemical/catalytic) of bio-gases and liquids to fuels and chemicals
- Algae production and refinery
- Separations (for fuels and chemicals production)
- E-Fuels
- Artificial photosynthesis (engineering part)

- P-recovery/recycling
- Affinity separations
- Desalination

Scales of Production and Processing

Current Conversion Scales

- Large Scale Central
  - Power plants: 0.5 – 2 GW
  - Refinery : 2 - 40 GW
    - 10% chemicals
    - 20% energy
    - 70% fuels
  - Chemical plants 0.1 – 2 GW

Biomass Production / Availability

- Farm (100 ha): 1.5 MW
- Sugar plantation: 0.5 – 2 GW
- Wood farming: 10MW – 1 GW
- Paper mill: 0.05 – 1 GW

(Small) Refineries and chemical plants fit on the largest farming complexes and paper mills → Co-processing

Small scale availability requires pretreatment and very efficient logistics

In 2050 Biomass is used for:

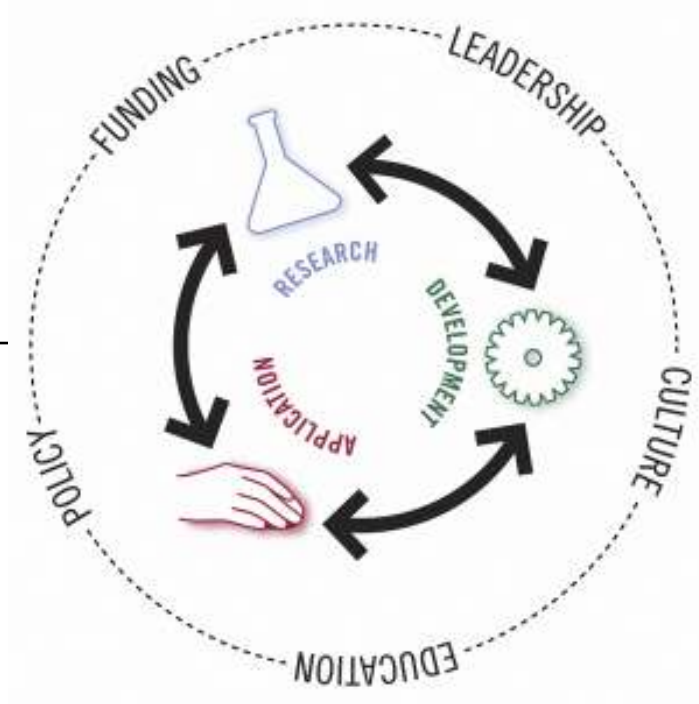
- Food
- Feed
- Dedicated liquid fuels
  - Long distance heavy transport

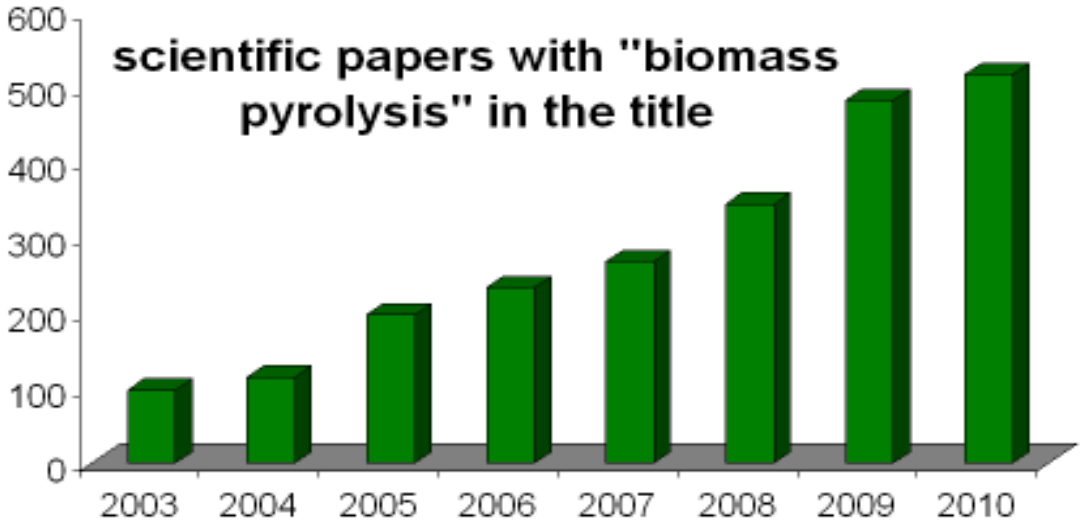
  (short distance → electric)
  - Aviation (jet fuel)
- Chemicals & Materials
  - Acids
  - Ethylene / propylene
  - aromatics
  - Plastics
  - Specialties….

Energy Storage Systems		
	MJ/L	MJ/kg
Gasoline	32	43
Methanol	17	21
Ethanol	22	28
Liquid hydrogen	8.4	120
Hydrogen 350 bar	2.8	120
Hydrogen hydride	13	6
Lead battery	0.24	0.12
Li-ion battery	1.2 - 2	0.84

Innovation Gap

Implementation needed to improve technology





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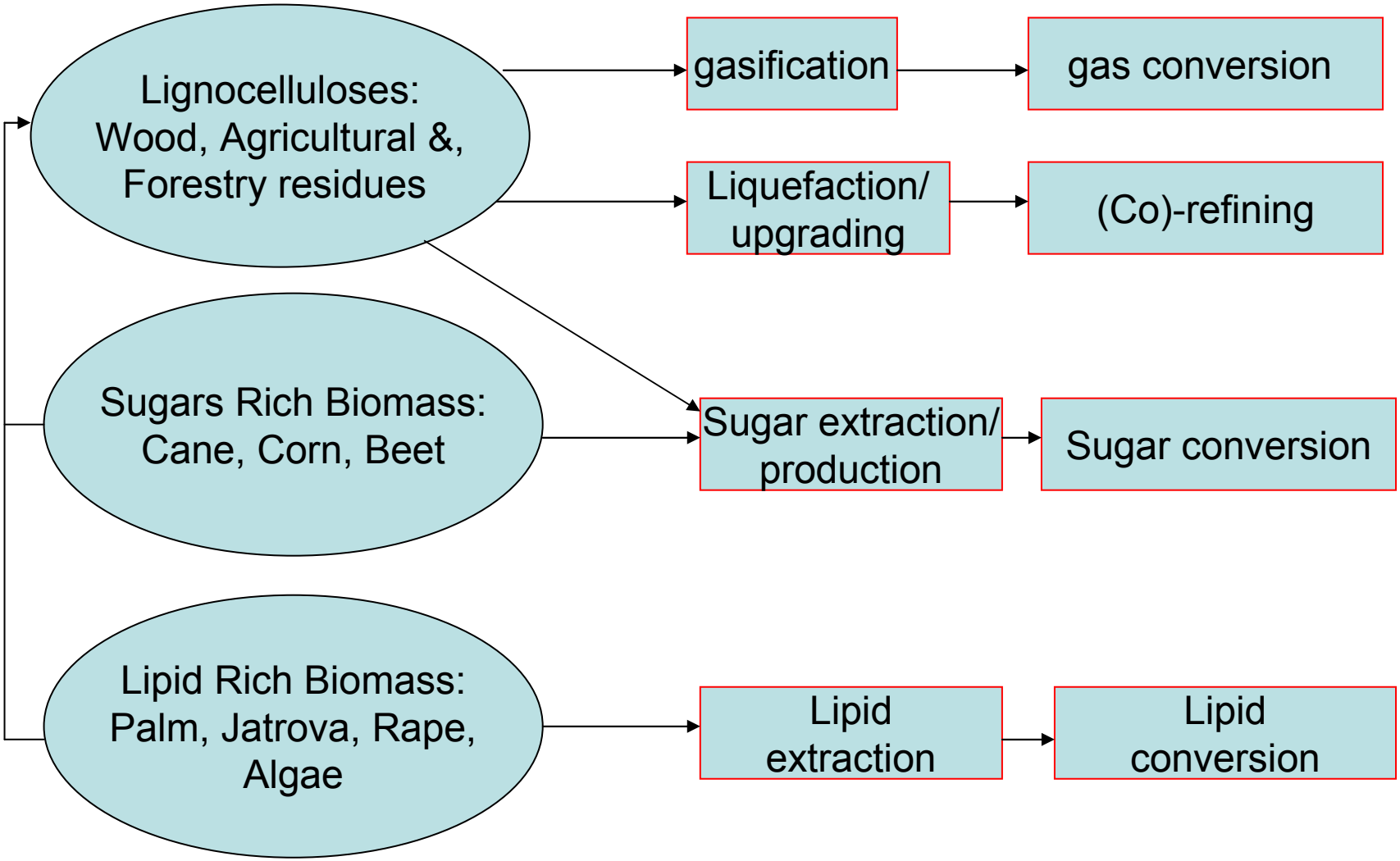
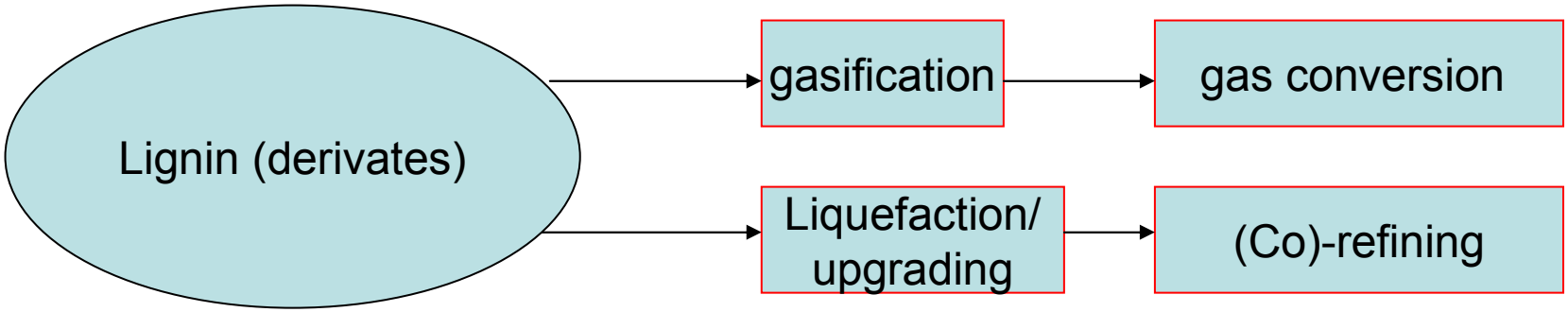
Number of commercial pyrolysis plants 2011

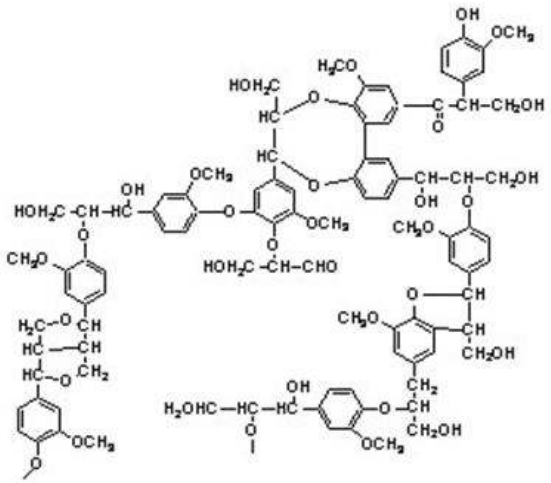
In a perfect world, strong technological concepts would always evolve into commercial reality. But that ideal is relatively rare#.

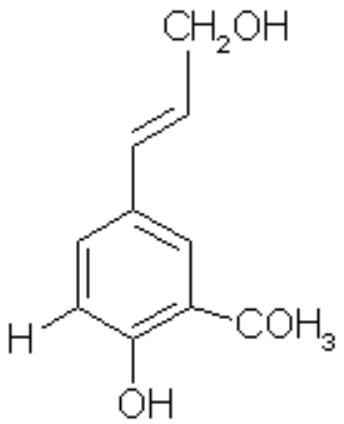
Processing Routes to Fuels & Chemicals



Processing Routes to Fuels & Chemicals (cont.)



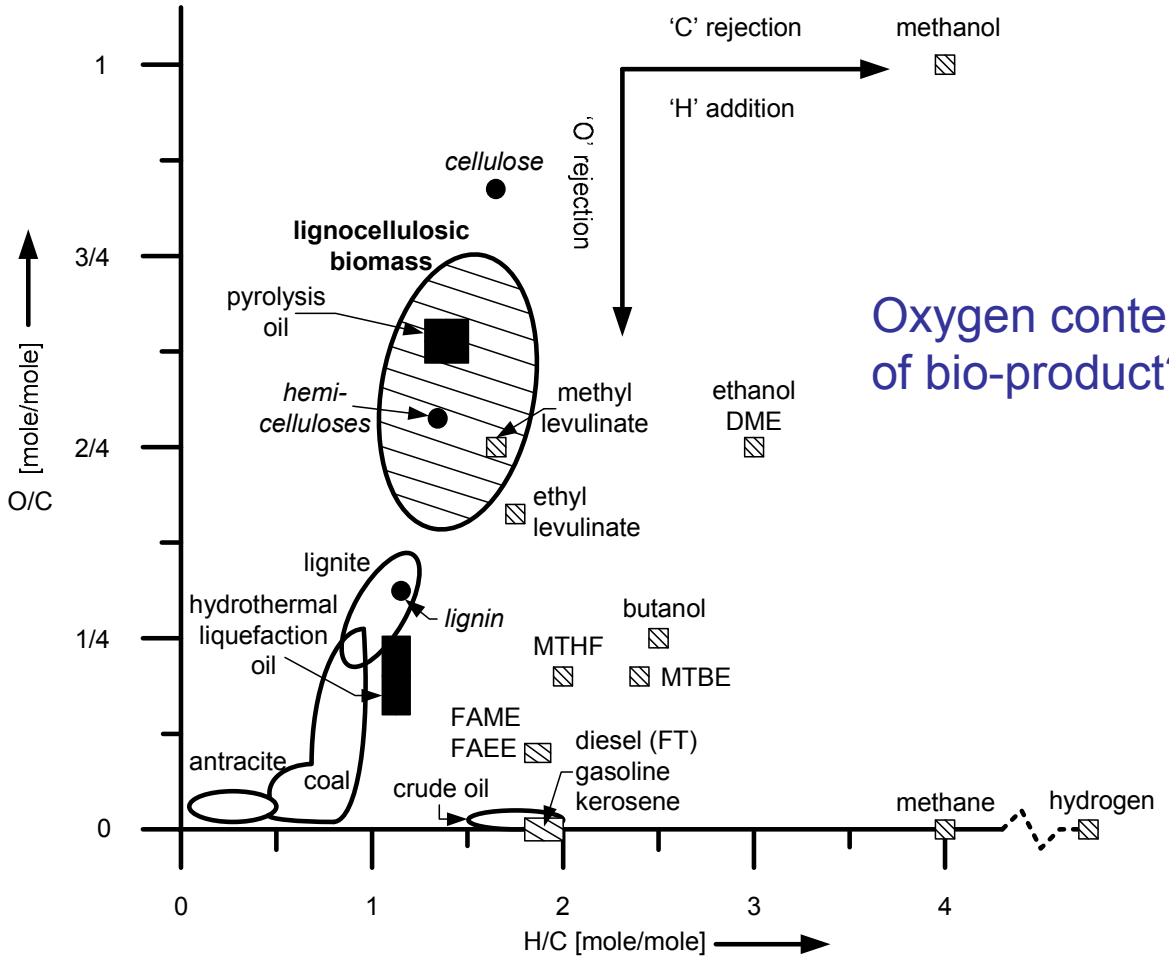




Lignin subunit: Coniferyl Alcohol

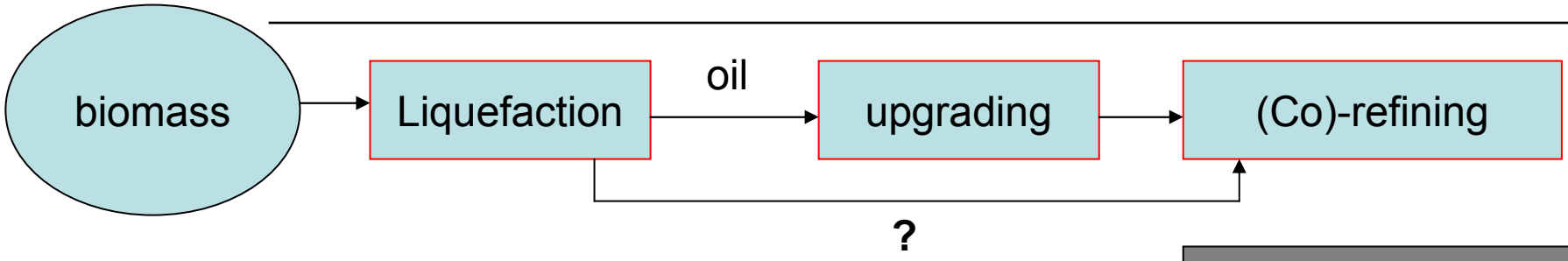
Chemicals
- Aromatics
- Propylene

What type of Fuels?



Oxygen content of bio-product?

Oil from Residues

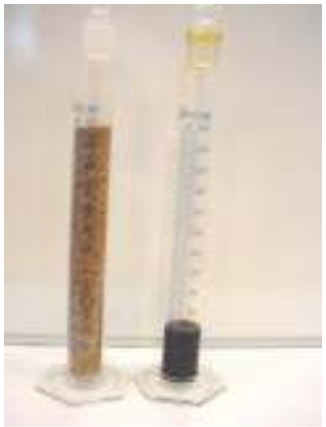


- Liquefaction (making biomass liquid)
  - Mimicking nature
  - Increased volumetric energy density (5x)
    - Transport easier and cheaper
  - Liquids easier to process
  - Enables refinery
  - Minerals (fertilizer) remain in a by-product (return to soil)
  - Enables decentralized biomass pretreatment
    nearby biomass production locations
  - Central refinery

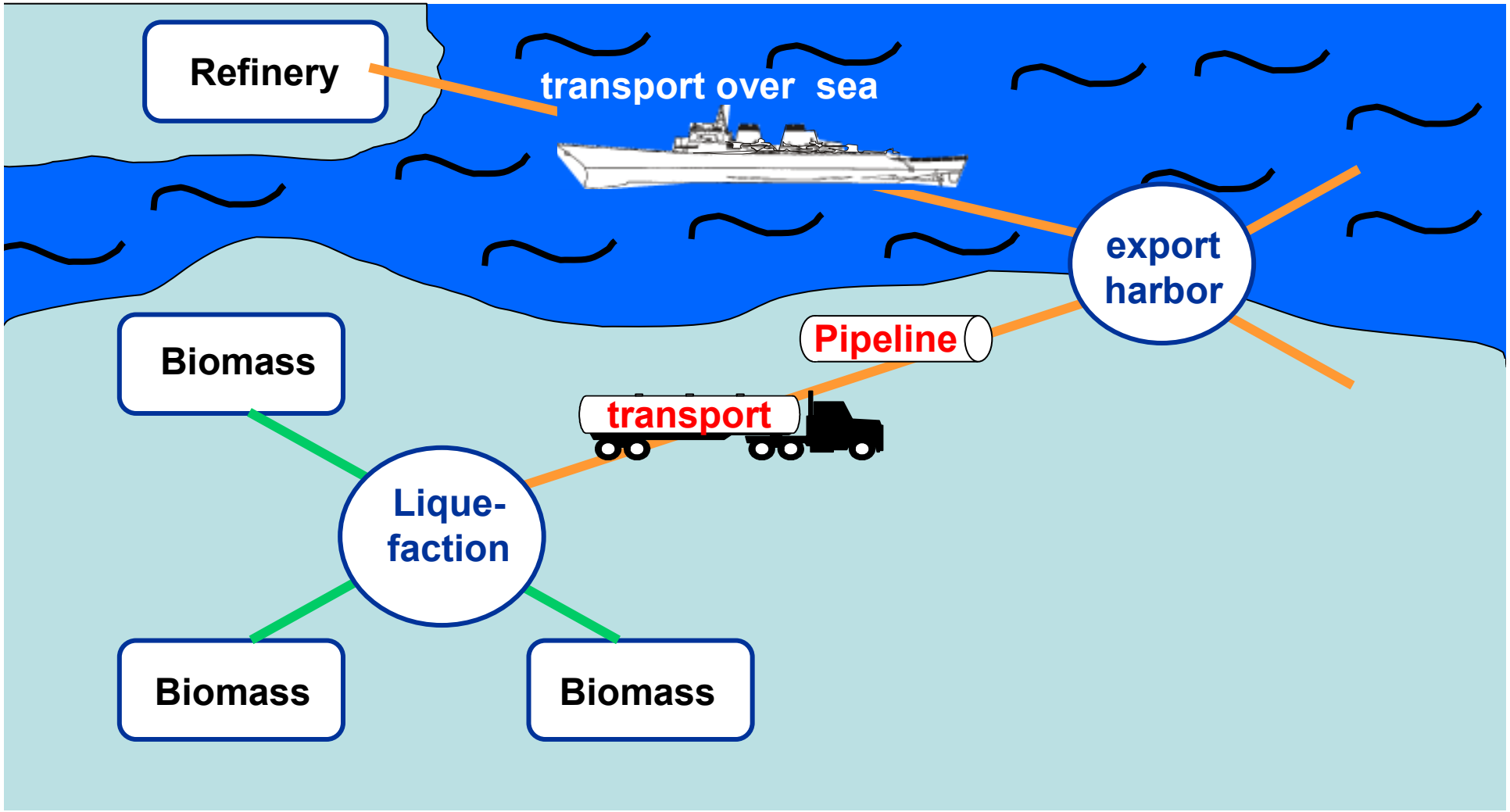
Oil is liquid biomass:

50 wt% C
6 wt% H
44 wt% O

1 MJ



Decentralized Pretreatment & Central Refining



Pyrolysis

1000 kg

Pretreatment

T = 500°C

p = 1 atm

650 kg vapors

Condensation

175 kg Gas

650 kg Oil

175 kg Char

- Research at UT since 1985
  - Process development
  - Oil quality
  - Oil applications
- Commercialization by companies (BTG)
  - 5 ton/hr Plant in 2012 in Hengelo (OV)

btg-btl
biomass-to-liquid

Pyrolysis Oil

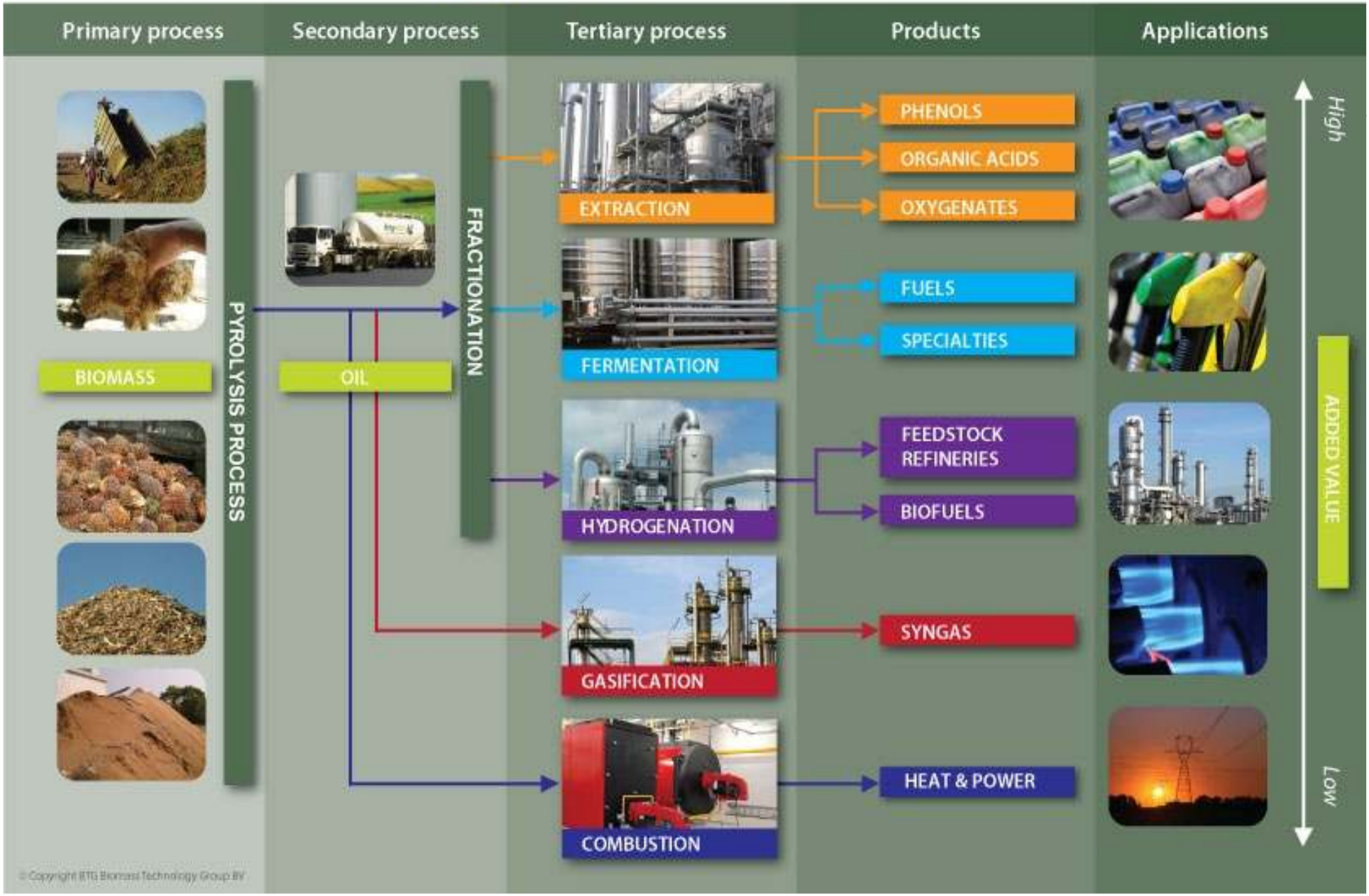
Physical Characteristics and Elemental Composition of Pyrolysis Oil, Hydrothermal Liquefaction Oil, and Fossil Heavy Fuel Oil

Characteristic	Pyrolysis Oil	Hydrothermal Liquefaction Oil	Heavy Fuel Oil
Water content (w%)	15-35	3-6	0.1
C (w%, dry)	50-64	65-82	85
H (w%, dry)	5.2-7	6-9	11.1
O (w%, dry)	35-40	6-20	1.0
N (w%, dry)	0.05-0.4	nd	0.3
S (w%, dry)	0.05-0.3	nd	2.3
Heating value (MJ/kg) (LHV)	16.5–19	25-35	40
Viscosity (cp at ~50°C)	40-150	$\sim 10^4$	180
pH	2.4	--	--
Total acidity number (TAN)	70-150	nd	--
Specific gravity	1.15-1.25	1.05-1.15	0.90
MW (g/mol)	600-700	500-1000	180-400

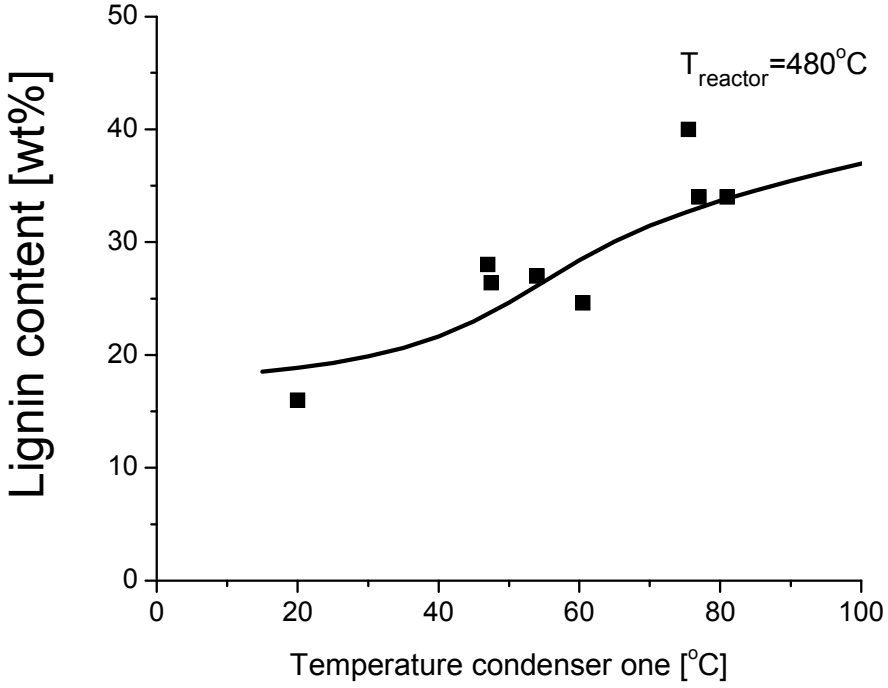
Upgrading is required!

bioliquids refinery

btg-btl
biomass-to-liquid



Lignin is present in pyrolysis oil (emulsion)

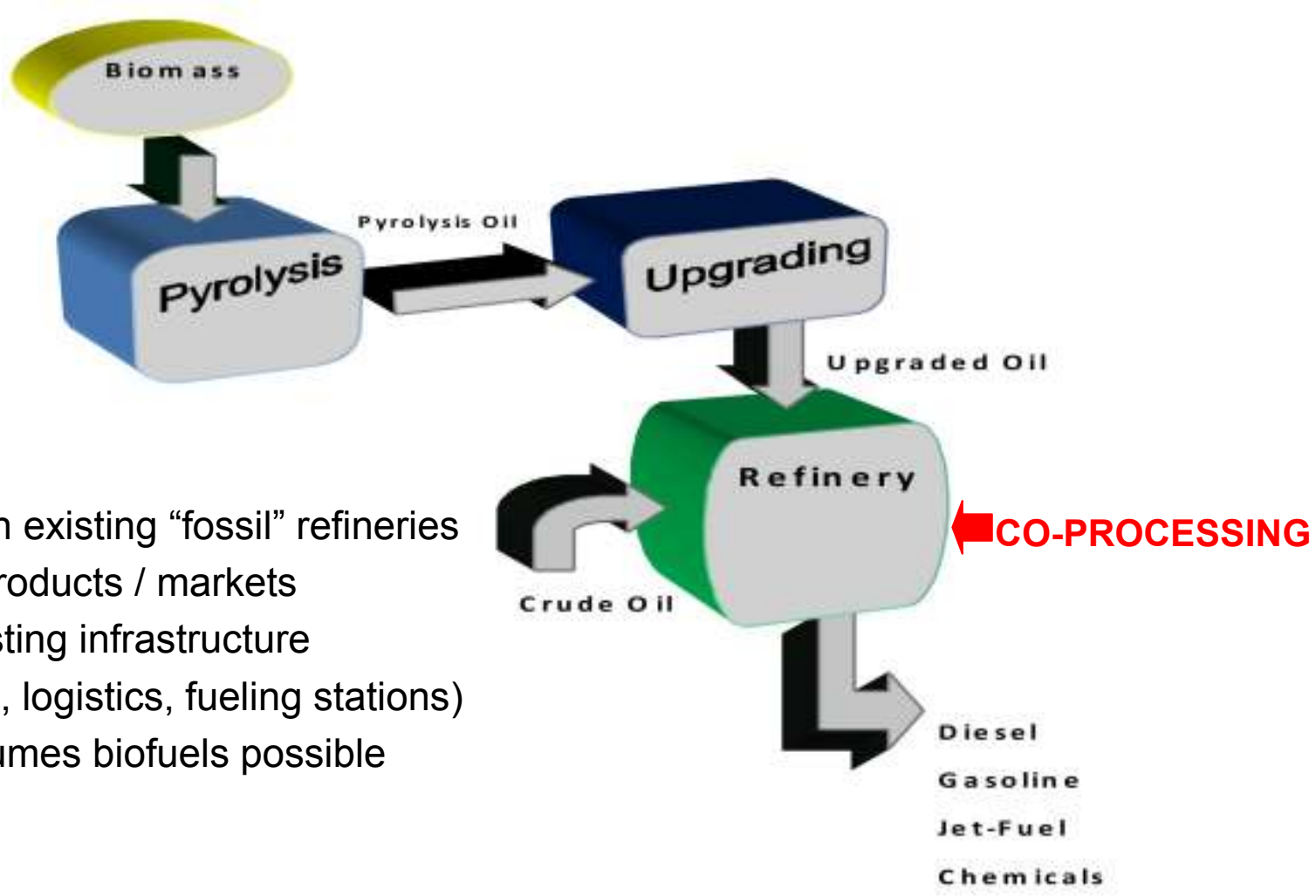


Pyrolysis: Process Development Units at UT

PyRos pilot plant – 30 kg/hr

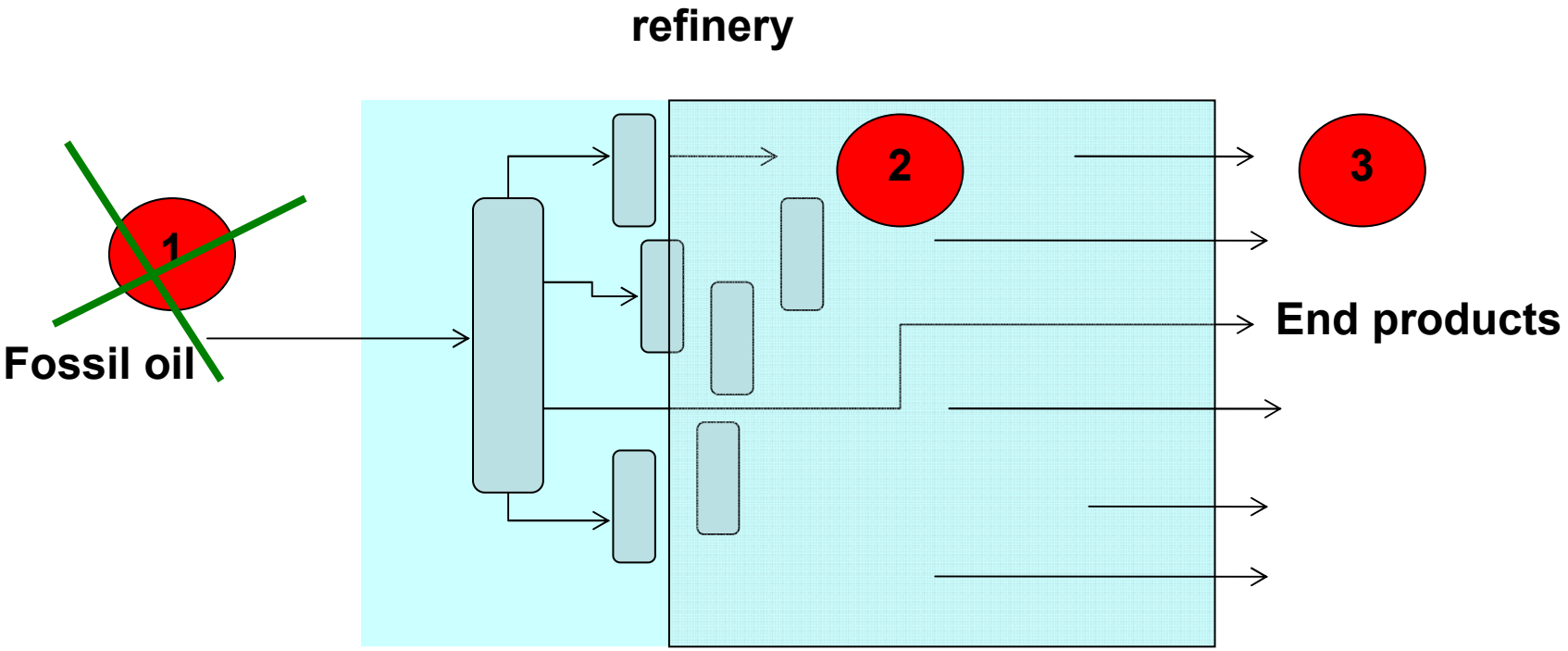
Fluid bed – 1 kg /hr

Co-Processing Pyrolysis Oil in Crude Oil Refineries

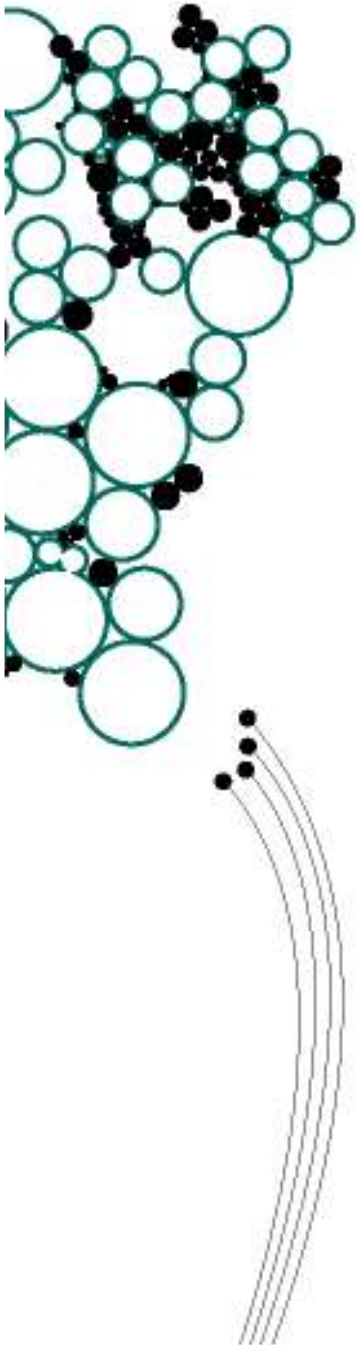


- Partnering with existing “fossil” refineries
  - Existing products / markets
  - Using existing infrastructure (refineries, logistics, fueling stations)
  - Large volumes biofuels possible

Co-processing options



- For 2 and 3 ‘upgrading’ of pyrolysis oil needed
- From 2-3: increase in upgrading severity needed
- Option 2 “Deoxygenation important”



FCC of Hydrotreated Pyrolysis Oil

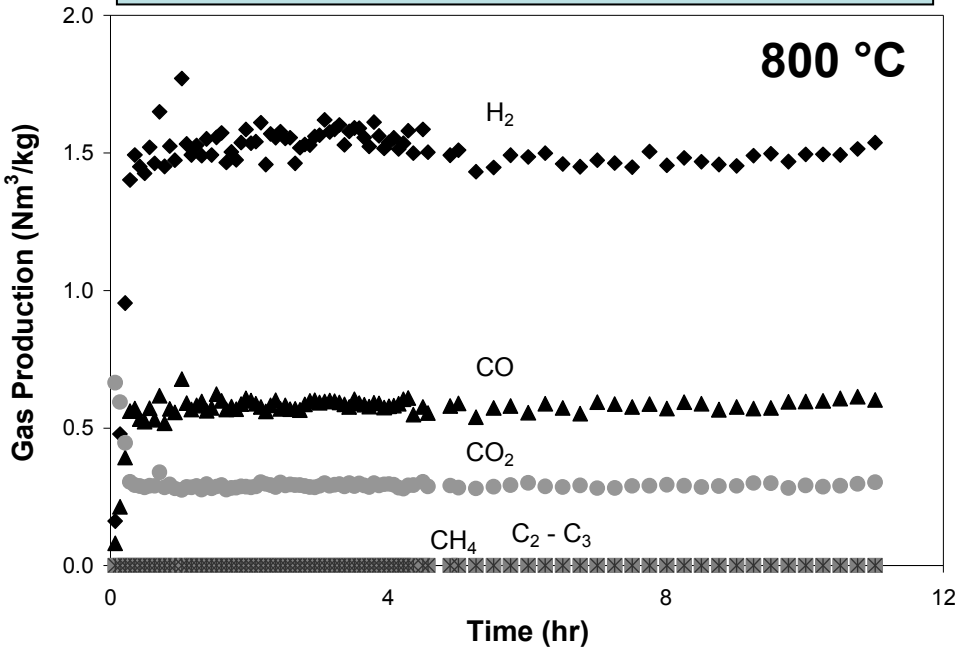
- Hydrotreating in autoclave (290 bar)
- MAT tests with 80/20 mixture of long residue and hydrotreated pyrolysis oil (lab-scale)
- Next stage → pilot testing

Hydrotreating temp °C		230	260	300	**330**	340
Oxygen content oil wt%		28	24.4	22.6	**15.5**	16.9
MAT FCC 20 wt% hydrotreated oil 80 wt% long residue						
	Long Residue					
Cat/oil raio	3.1	4.3	3.4	3.4	3.7	3.8
LPG yield	8.5	10.1	9.4	9.6	8.9	9.2
Gasoline yield	**44**	**40.2**	**41.7**	**43.4**	**43.5**	**43**
LCO yield	25.2	21.3	22.2	22.5	23.8	24
Dry gas	1.5	2.3	21.1	1.8	1.9	2
Coke yield	**5.9**	**7.2**	**6.6**	**5.2**	**5.5**	**5.8**
Other (HCO, Slurry Oil)	14.8	10.8	11	11.6	12.2	12
Water	0	7.9	6.7	5.7	3.9	3.9

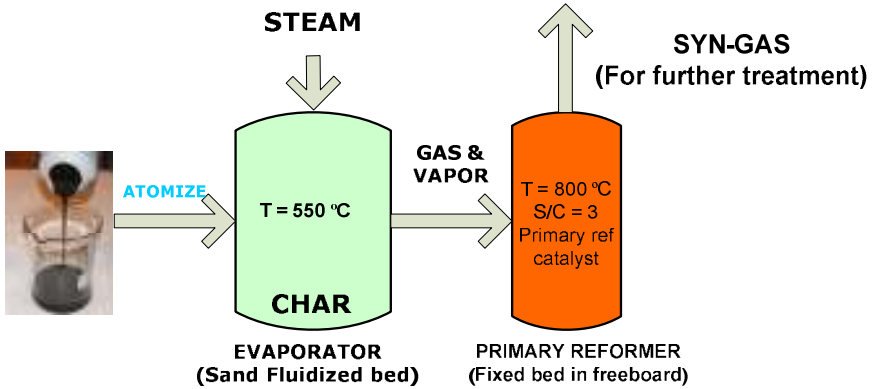
Gasification Route: Reforming

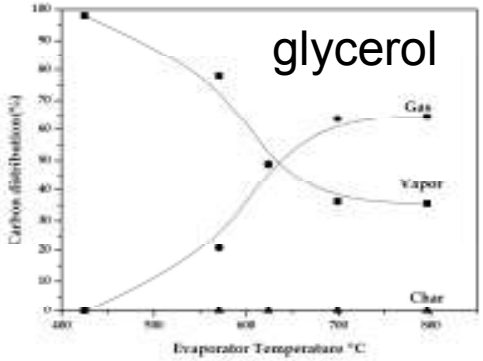
- Reforming of Biomass
- Biomass + H_2O → CO + H_2 (Ni)
  (CH_4 + H_2O → CO + $3H_2$)
- Allows smaller scale operation
  - Lower T
  - No oxygen needed
- R&D phase
  - Severe problems for solid biomass
  - Liquid biomass shows promising results

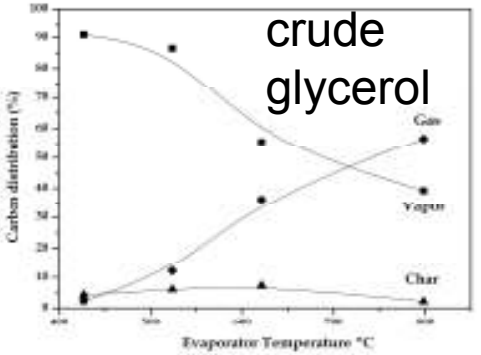
Catalytic reforming of pyrolysis oil over commercial Ni catalysts

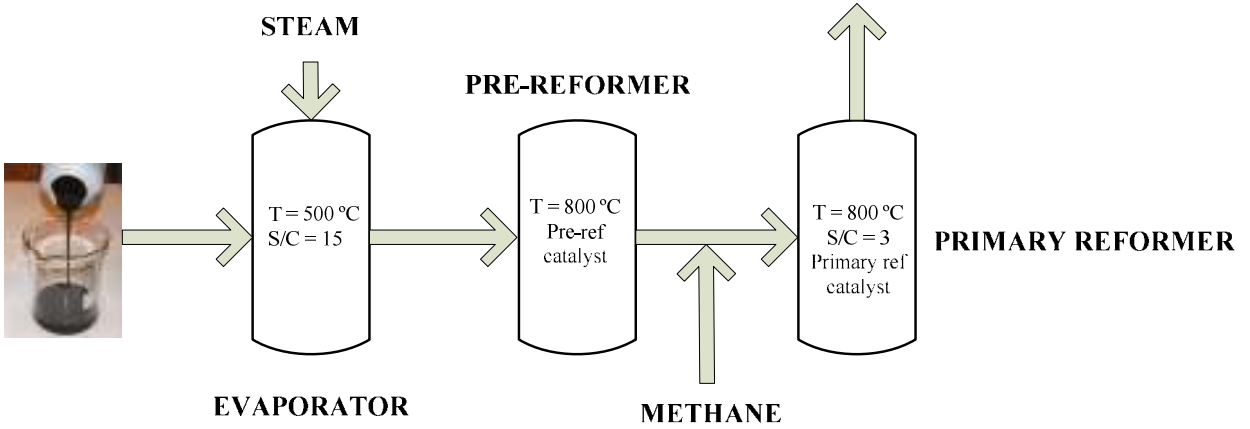


Hybrid Reforming

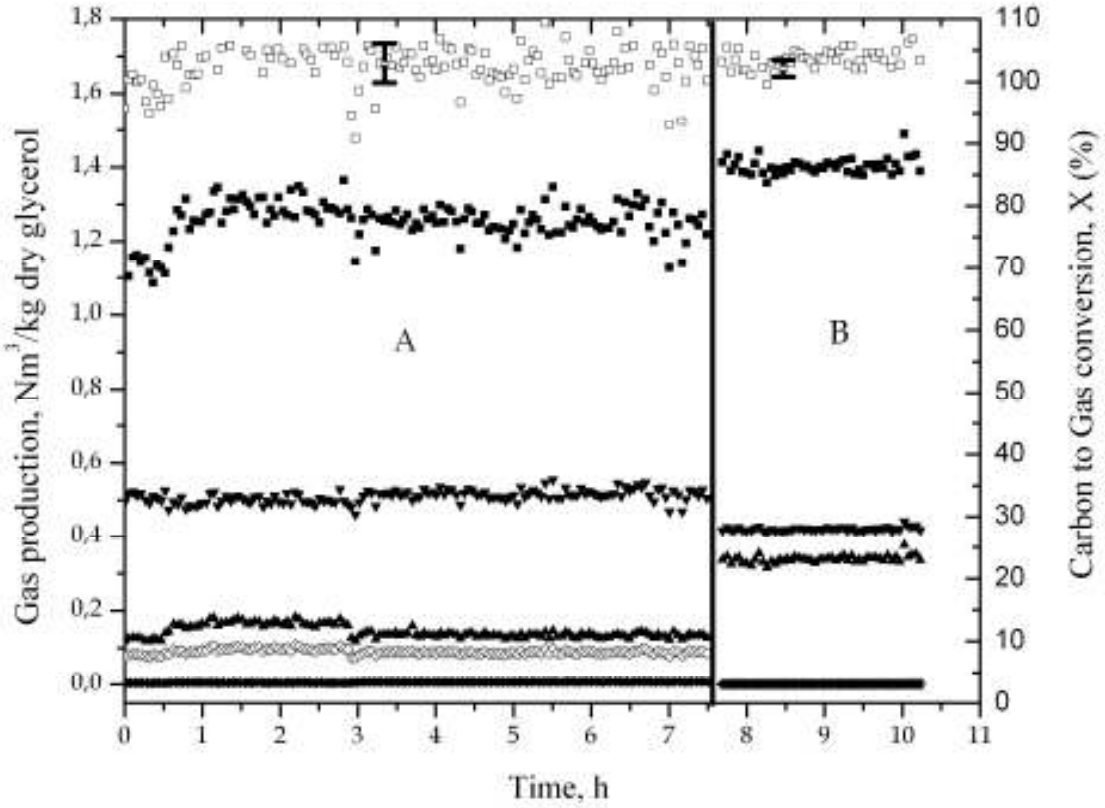






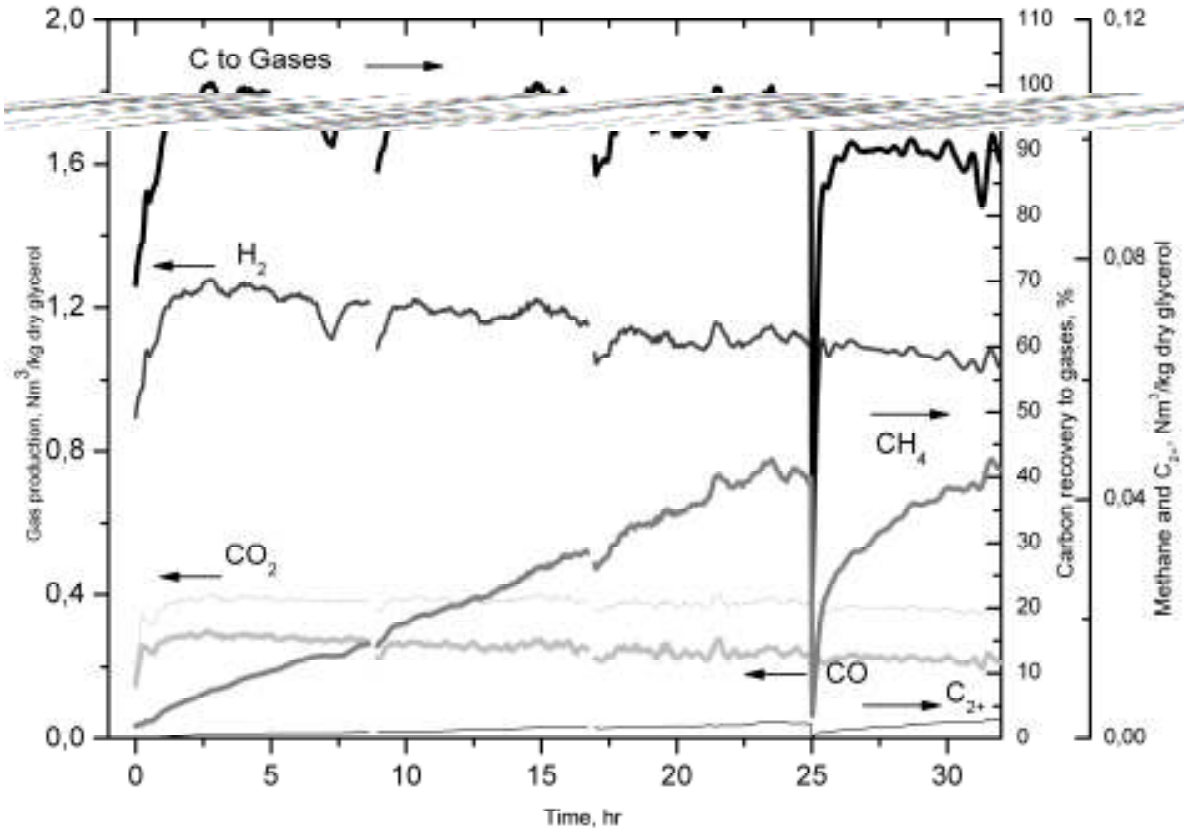


Glycerol as Feed

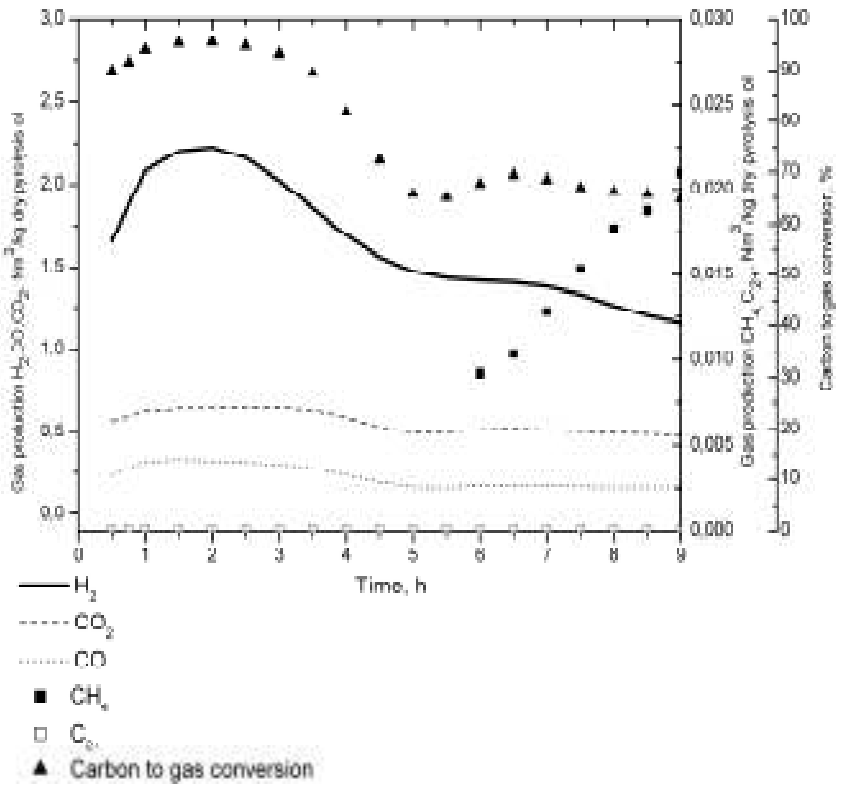


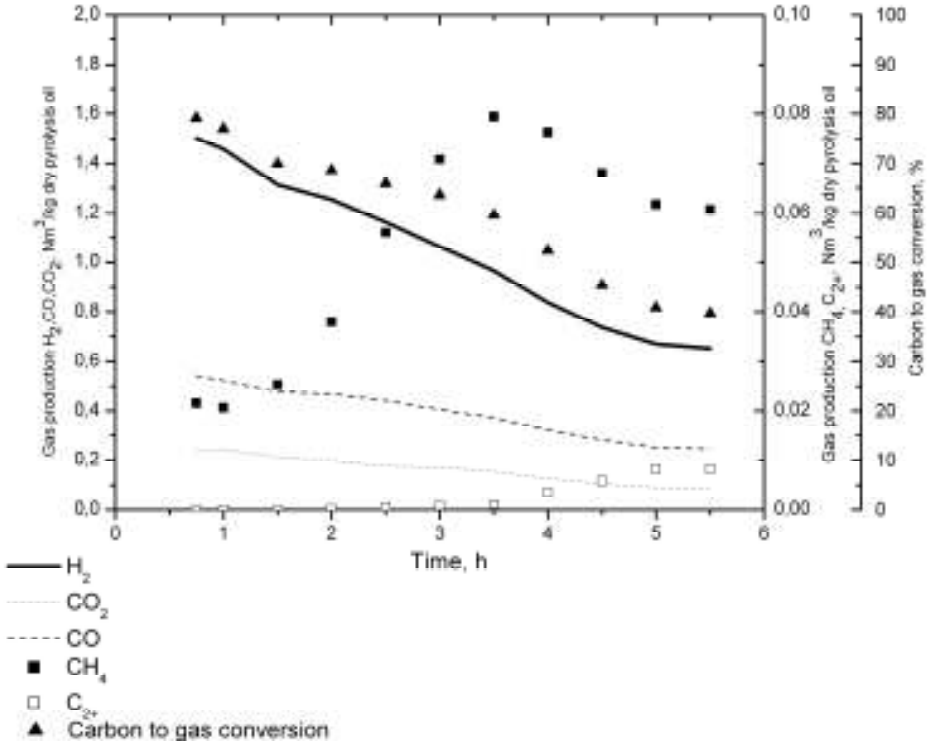
Pre-reforming and steam reforming of glycerol (62.5 wt%). (A) *S/C* **= 3,** ***T*cat = 588ºC and (B)** *S/C* **= 3,** ***T*cat = 787ºC. For all cases GC1HSV = 838 h-1**
□ Carbon to Gas conversion, ■ H2, ▼ CO2, ▲ CO, ◊ CH4

Crude Glycerol as Feed



Pyrolysis oil as Feed

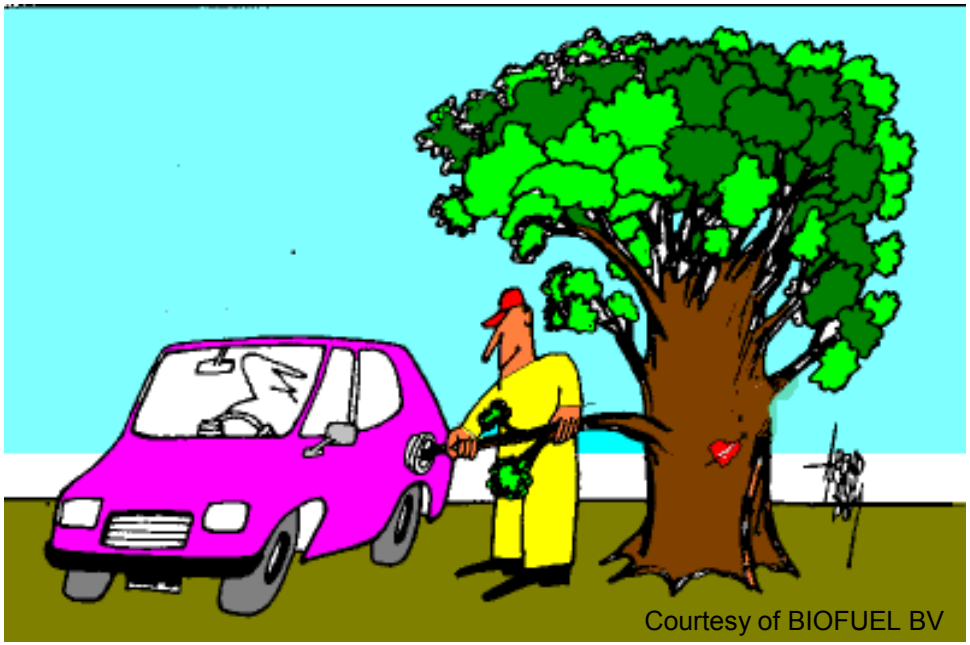




Concluding Remarks

- Large volumes of residues can be made available (and scales match with lower limit of fossil feed processing → co-processing)
- Liquid biofuels from forestry, agriculture and paper/pulp residues is the R&D – Demonstration stage (5-10 years for full scale commercial operation)
  - Liquefaction – Refining
  - Gasification – Gas conversion
- Winners (technology level and fuel type) cannot be identified yet, hence, multiple diverse approaches should be investigated.
- For quick introduction of large amounts of biofuels, it is essential to integrate and to partner-up with existing industries and markets.
- For a fast development trajectory it is essential to adapt the knowledge available for making fossil fuels to lignocellulose-based fuels.
  - Catalysis
  - Process Technology

Thanks for your attention!



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