



TNO innovation
for life

SUPPORTING THE DEVELOPMENT OF GASIFICATION BASED VALUE CHAINS

IR. B.J. VREUGDENHIL

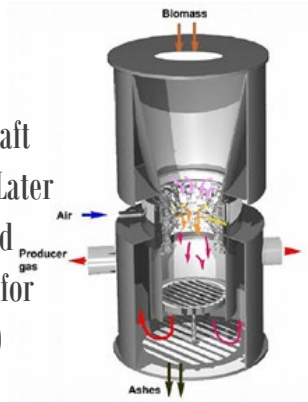
› GASIFICATION IS VERSATILE



› LONG HISTORY IN GASIFICATION / CLEANING /UPGRADING

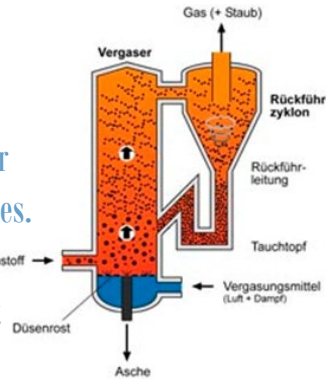
1980

300 kW_{th} Downdraft gasifier on coal. Later modified for wood operations. Used for gas cleaning R&D



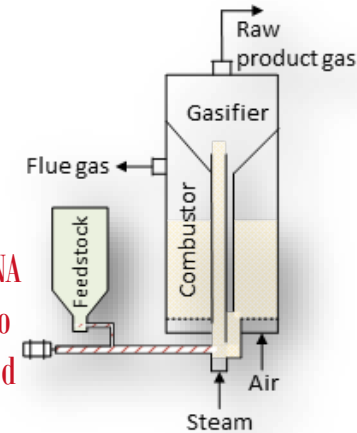
1995

500 kW_{th} CFB gasifier, used for various biomasses. Technology licensed to HoSt



2004

Start of indirect gasification MILENA 25 kW_{th}. Scaled to 800 kW_{th} and used for SNG development



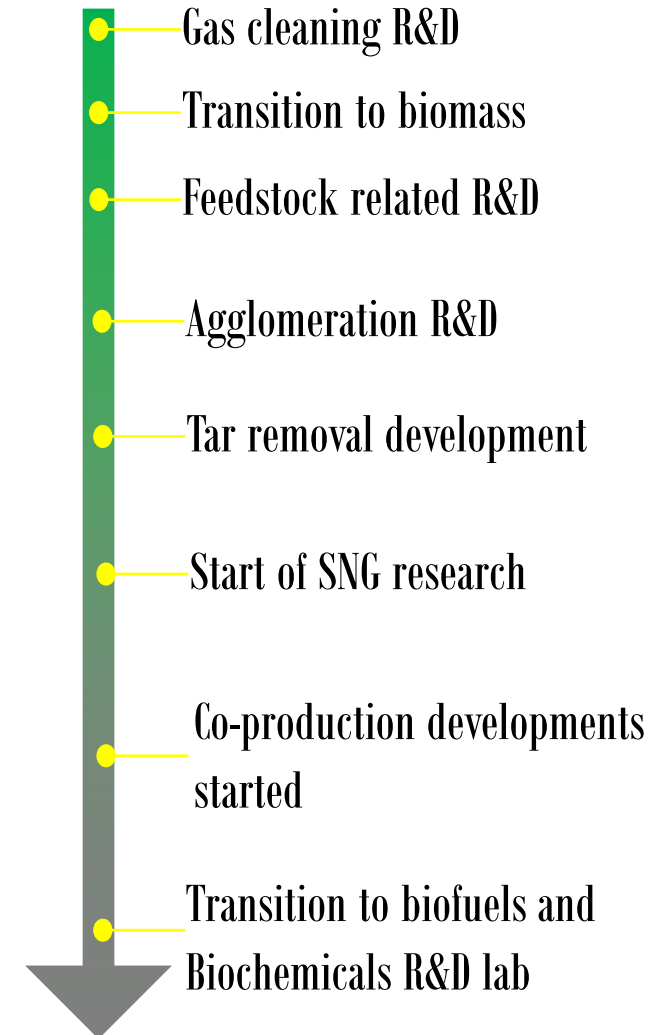
2020

New biofuel lab Gasification, cleaning, co-production (BTX), synthesis (MeOH, FT, DME and SNG)



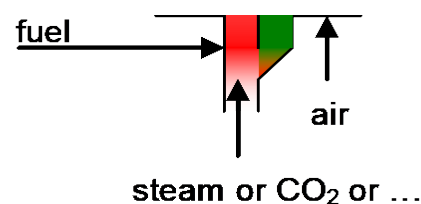
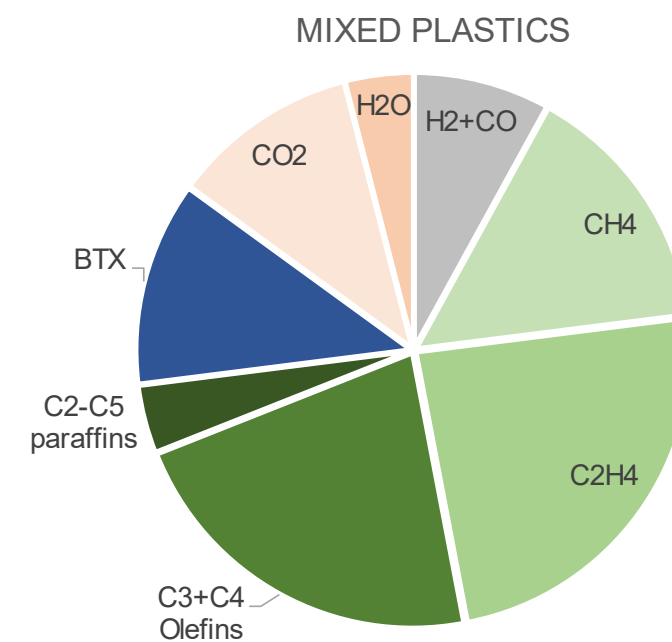
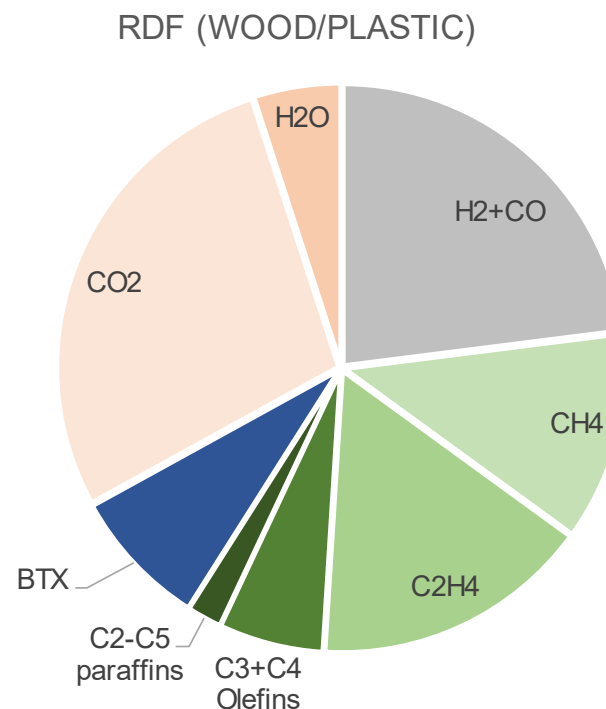
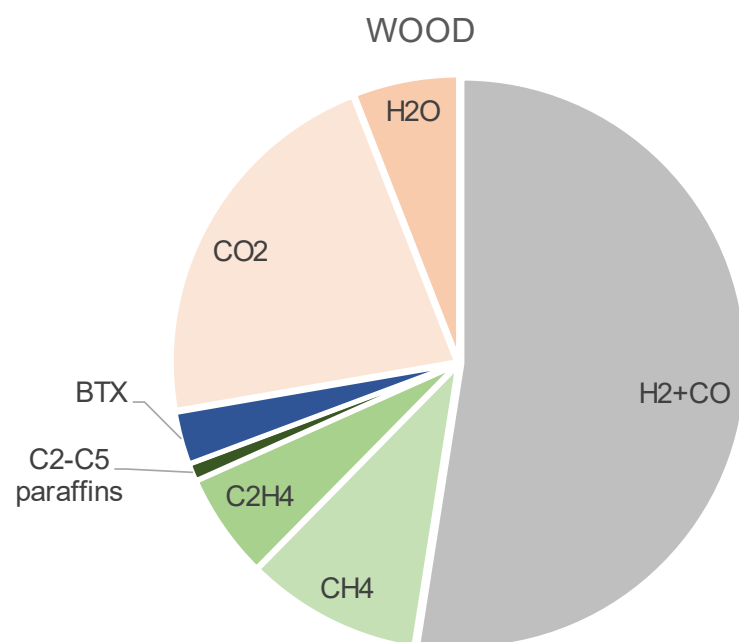
› GASIFICATION RELATED MILESTONES

1980	Downdraft coal gasifier 300 kW _{th}
1990	Downdraft gasifier modified for wood
1996	CFB gasifier 500 kW _{th} → Licensed to HoSt in 2002
1998	BFB gasifier 5 kW _{th}
2000	OLGA tar removal system build → License to Dahlman in 2006
2004	Indirect gasifier 25 kW _{th} MILENA → License to Thermax (2012) and Dahlman (2013)
2008	Indirect gasifier scaled up to 800 kW _{th}
2012	Co-production schemes developed (BTX recovery)
2013	SNG system developed and proven at ECN
2020	Sustainable Biofuels Technology laboratory opened → biofuels and biochemicals research facility



› GASIFICATION

A PLATFORM TECHNOLOGY FOR ENERGY AND CHEMICALS



OVERVIEW 500-HOUR BIO-SNG TEST

Availability

- MILENA: ~90%
- MILENA + OLGA + ESME ~ 85%

MILENA

OLGA

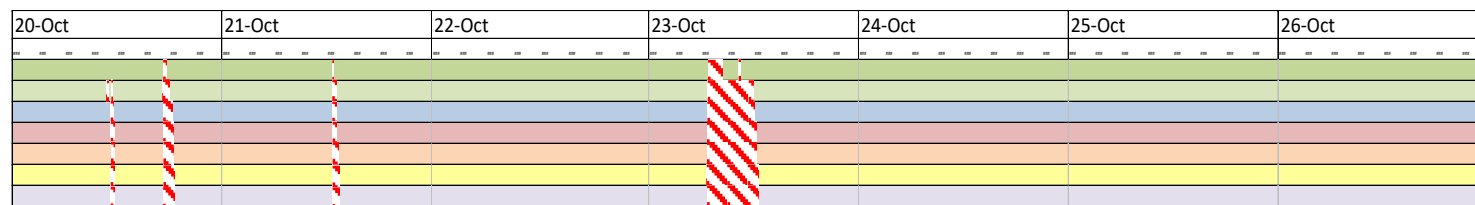
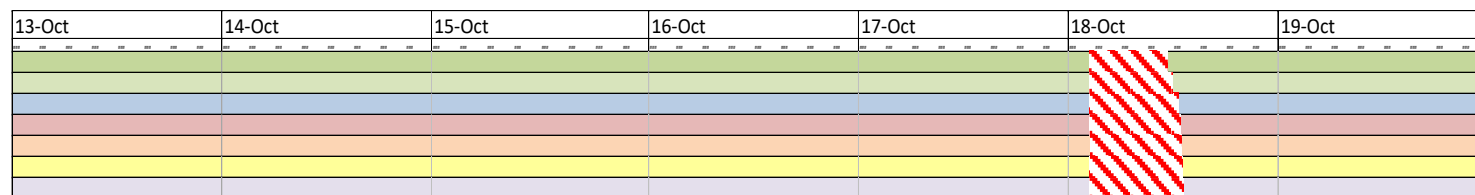
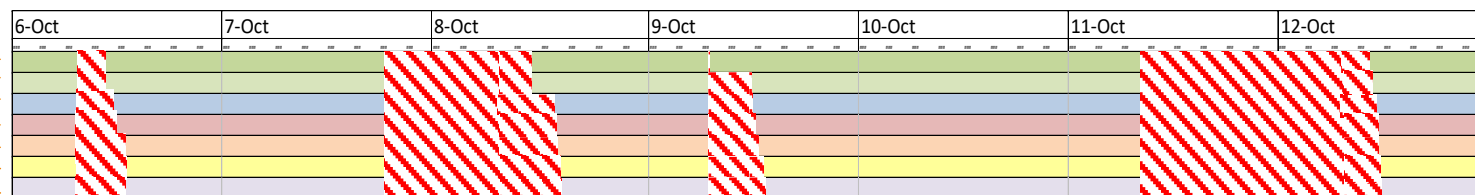
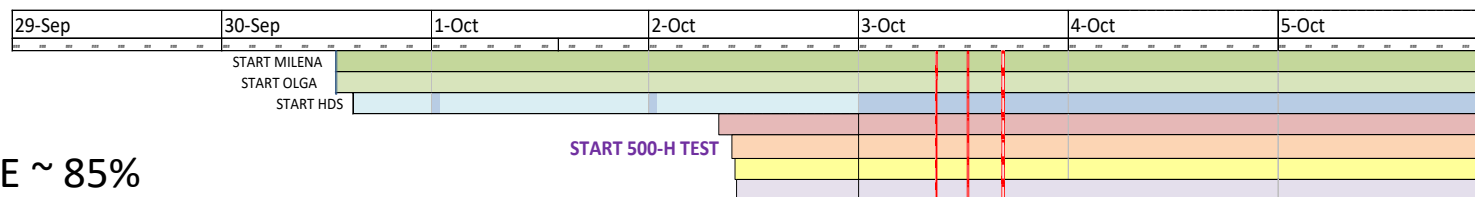
HDS

H₂S removal

Pre-reformer

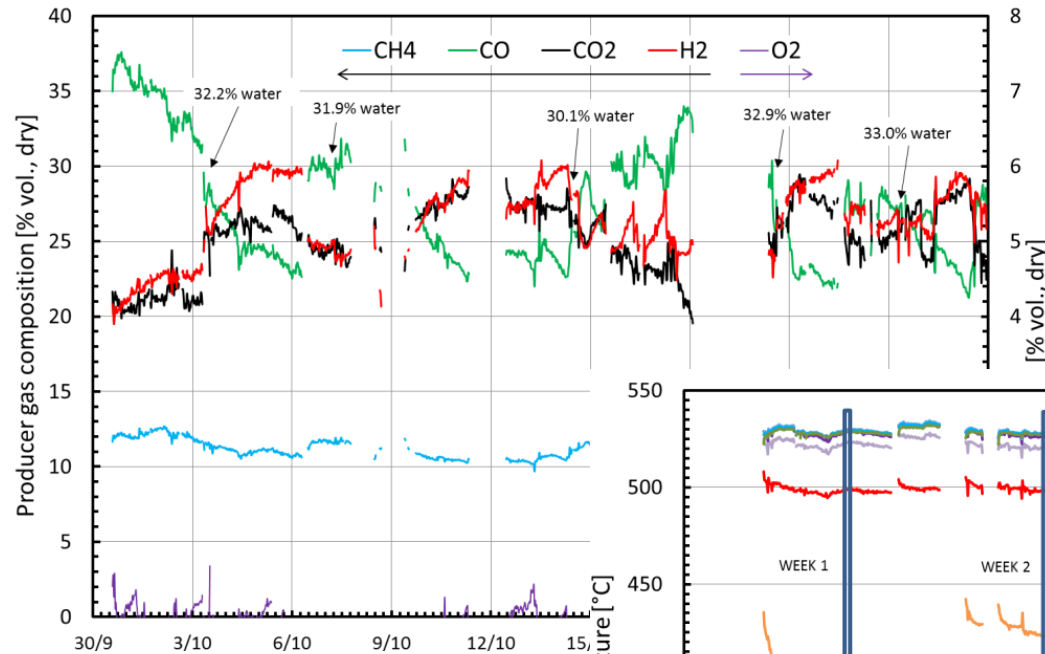
Methanation 1

Methanation 2

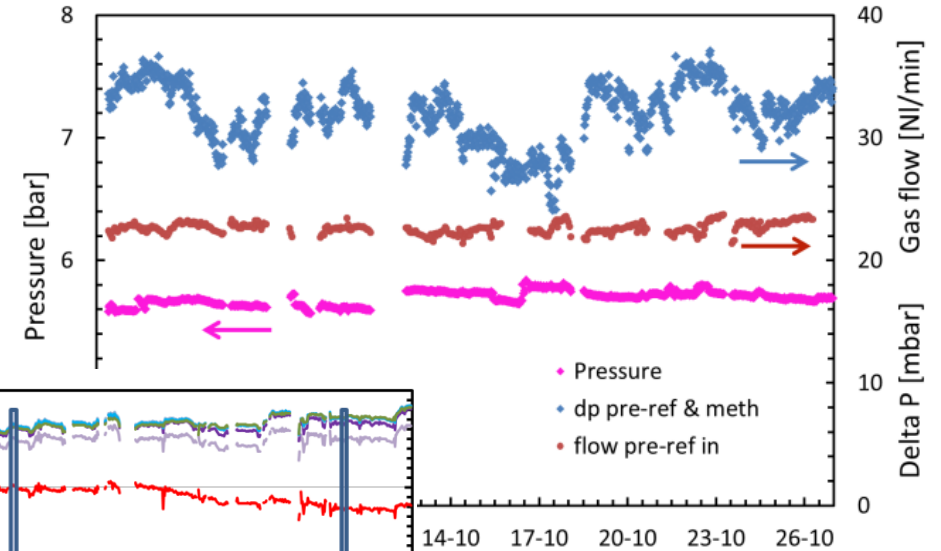


END 500-H TEST SNG

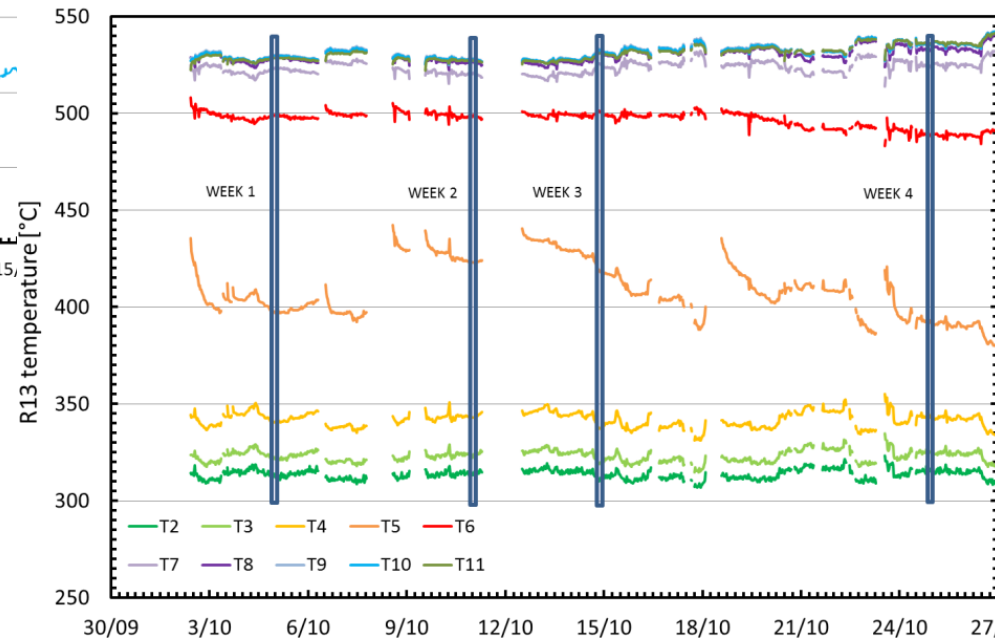
› SOME RESULTS OF THE 500 HOUR TEST



MILENA
gas



ESME **pressure**,
flow and **pressure**
drop



Pre-reformer
temperatures

› BIO-BTX PRODUCT

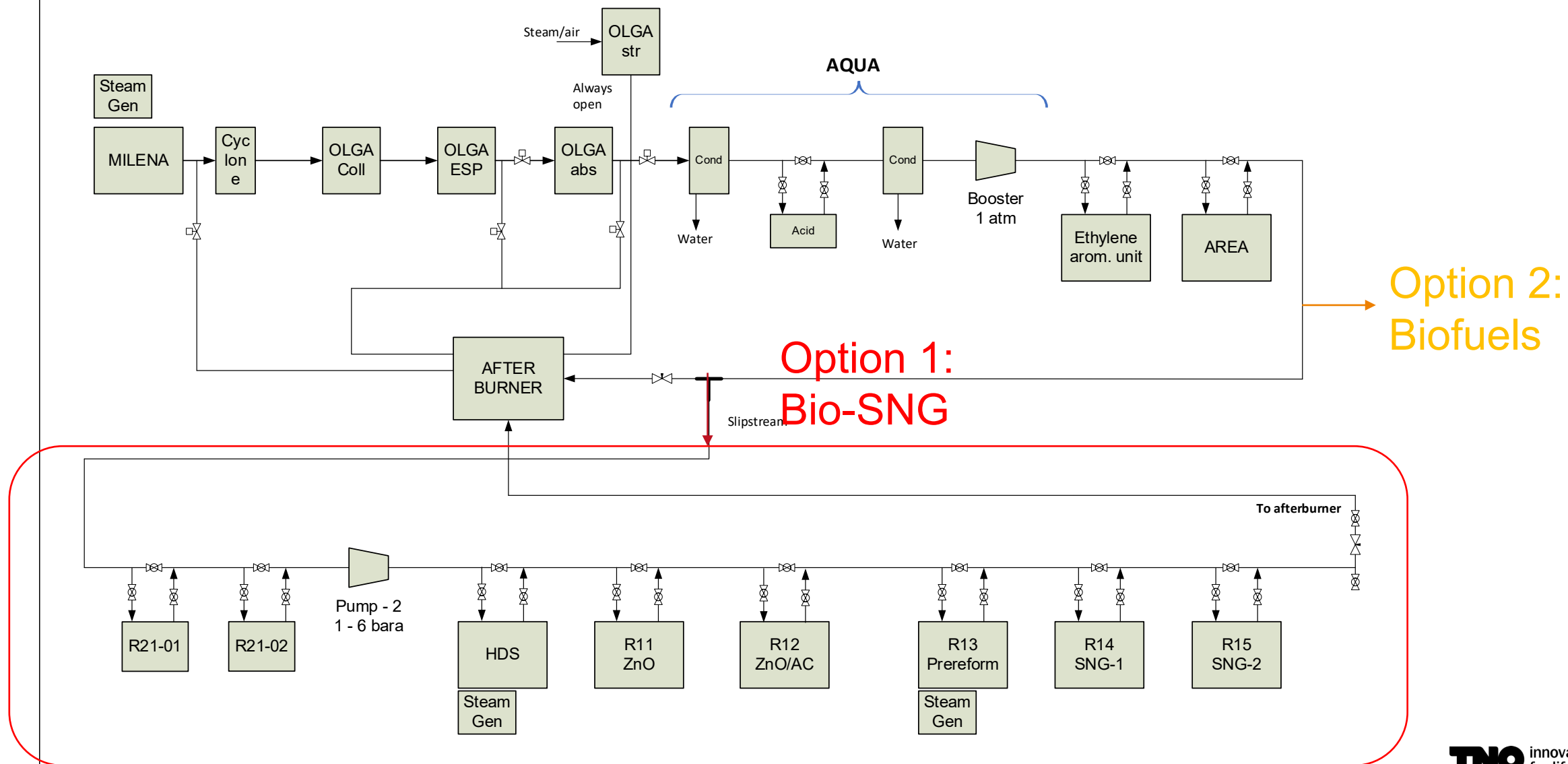
- Bio-BTX sample composition, main constituents, some examples:

BTX samples		Beech wood	Paper rejects	RDF (Qlyte)
Benzene	[wt%]	85.5	74.1	59.2
Toluene	[wt%]	8.9	10.7	14.9
Ethylbenzene	[wt%]	0.2	1.0	1.4
m/p-Xylene	[wt%]	0.2	0.4	0.7
o-Xylene+Styrene	[wt%]	1.5	4.7	6.5
Total S-organics (thiophenes)	[mg/kg]	1602	1782	2712



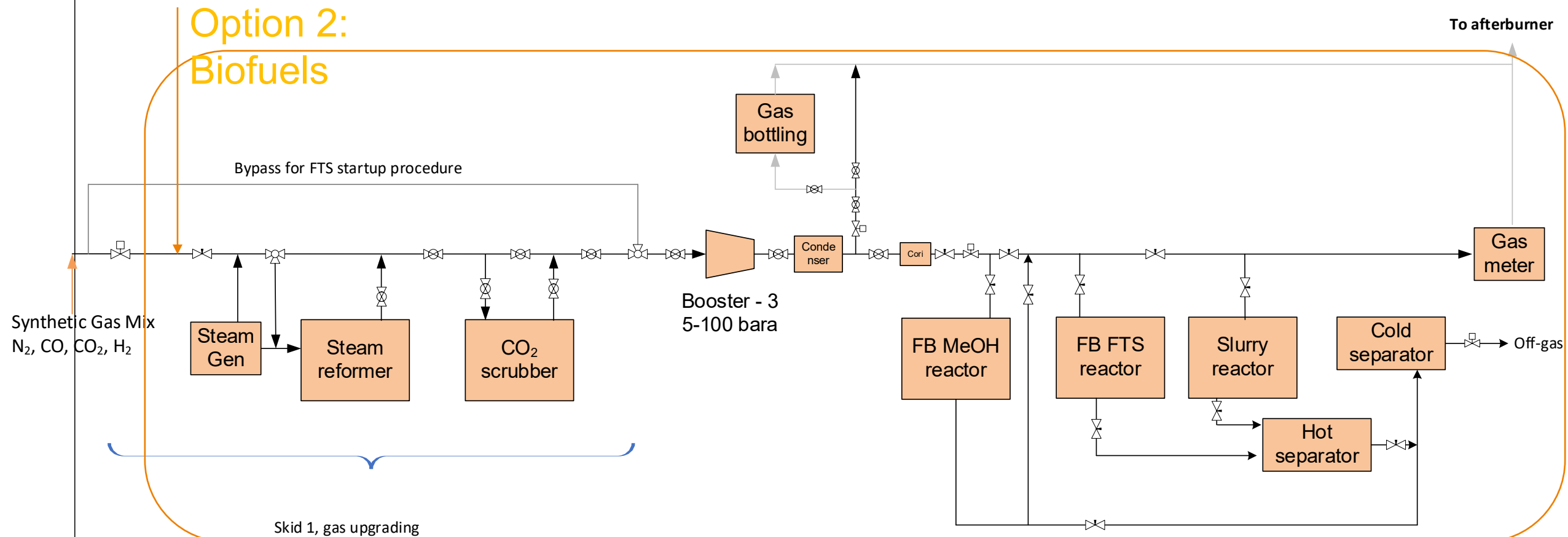
- Much S impurities (mostly thiophenes present) due to similar physical properties to benzene
 - Post/pre-treatment of BTX required.

› SBT LAB, BIO-SNG PRODUCTION

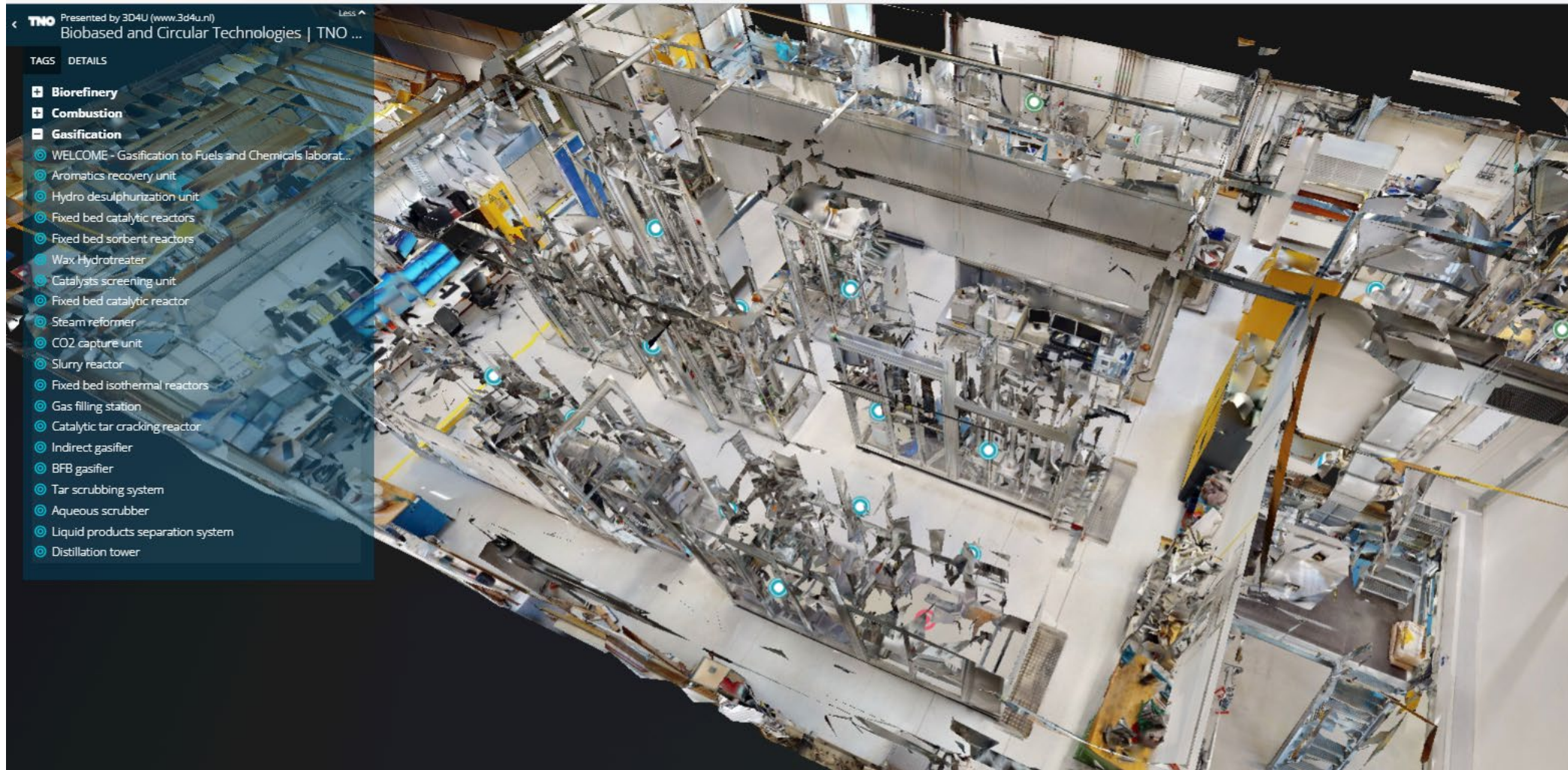


› SBT LAB, BIOFUELS PRODUCTION

Option 2: Biofuels



EXTENSIVE BIOFUELS AND CHEMICALS LAB

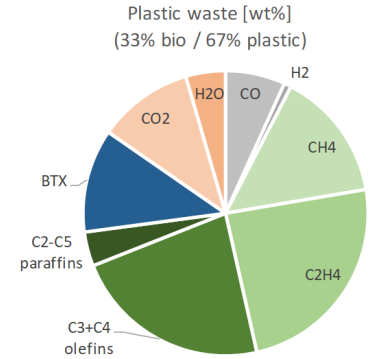


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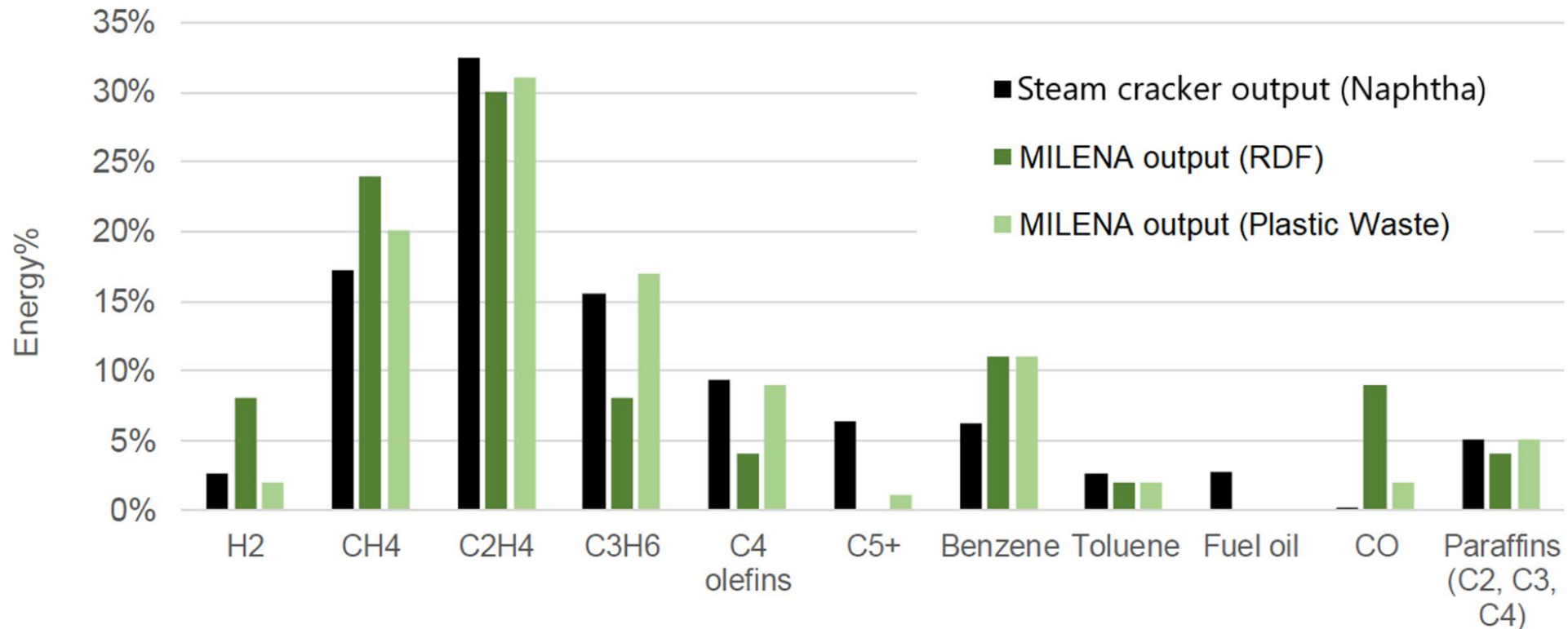
For password contact berend.vreugdenhil@tno.nl

MOVING TOWARDS WASTE

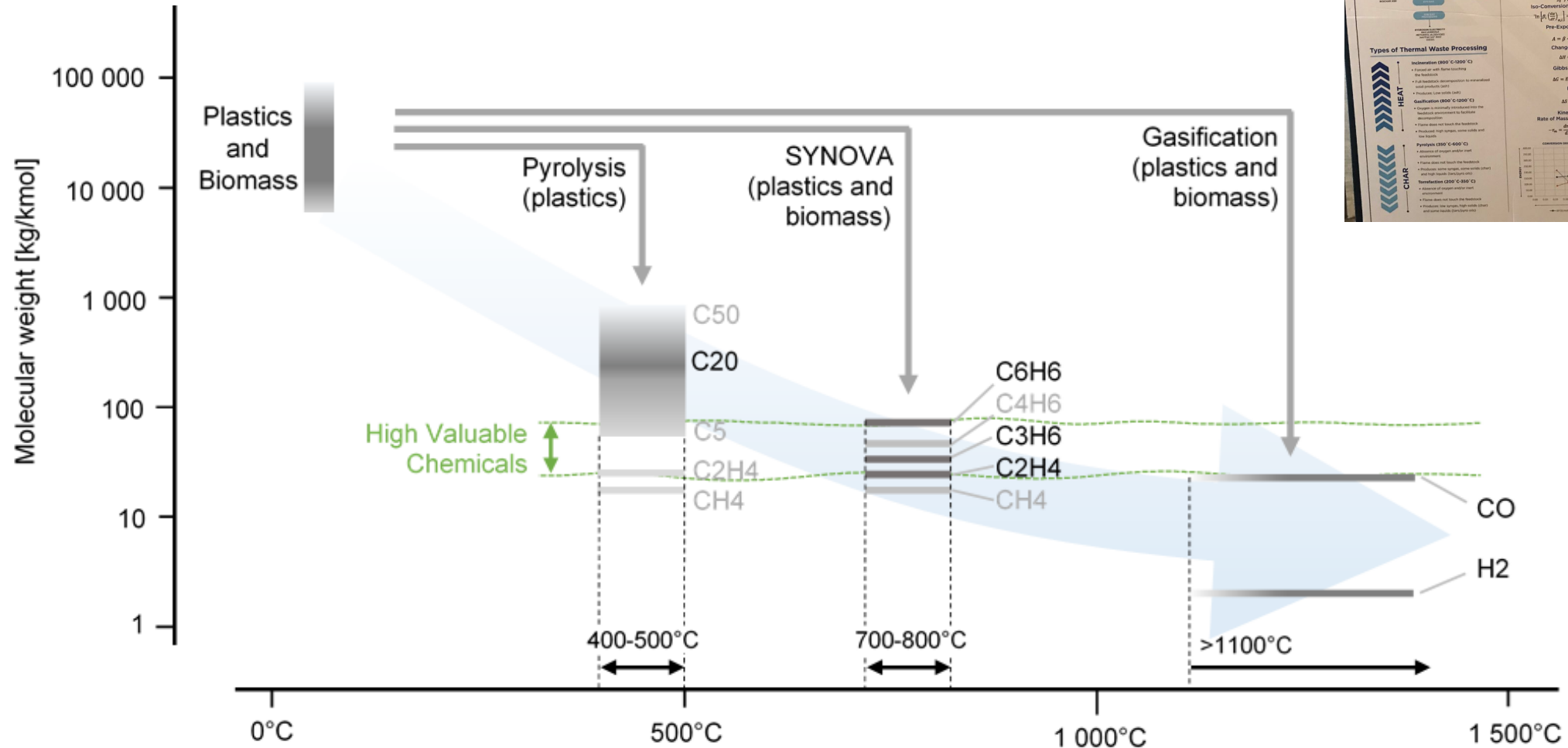
› THERMAL CRACKING OF WASTE FROM 100% BIOLOGICAL → ~70% FOSSIL BASED



Valorisation options for instance at a naphtha cracker



SYNOVA'S SOLUTION



BURNS & MCDONNELL

IS THERMAL ENERGY WASTE PROCESSING THE NEXT STEP IN WASTE TREATMENT?

What is Thermal Waste Processing?

- Utilizing thermal energy to break down feedstocks into new forms for processing into value-added products
- Feedstocks: WPC → volatile + Char
- Application of heat to treat and decompose waste materials through different approaches

Kinetic and Thermodynamic Foundation

Degree of Conversion: $\alpha = \frac{m_0 - m_t}{m_0 - m_{\infty}} \times 100\%$

First Order Reaction Kinetic Equation: $\frac{d\alpha}{dt} = k(1 - \alpha)$

Arrhenius Equation: $\ln k = \ln A - \frac{E_a}{RT}$

Heating Rate: $\beta = \frac{dT}{dt}$

General Equation: $\alpha(t) = 1 - \frac{1}{f(\beta)} \int_0^t \frac{1}{T^2} e^{-\frac{E_a}{RT}} dT$

iso-Conventional Method Equation: $\ln \left[\beta \left(\frac{dT}{dt} \right) \right] = \ln f(\alpha) - \frac{E_a}{R} \left(\frac{1}{T} - \frac{1}{T_0} \right)$

Pre-Exponential Factor: $A = \beta \cdot E_a \cdot e^{\frac{E_a}{RT_0}}$

Change in Enthalpy: $\Delta H = E_a - RT_0$

Gibbs Free Energy: $\Delta G = \Delta H - T\Delta S$

Entropy: $\Delta S = \frac{\Delta H}{T}$

Kinetic Equation: $\frac{d\alpha}{dt} = k_0(e^{-\frac{E_a}{RT}} - \alpha)$

Types of Thermal Waste Processing

- Incineration (800°C-1200°C)**
 - Control air with flame control by the reaction
 - Full oxidation decomposition to inorganic and simple gas
 - Products are ash and gas
- Gasification (800°C-1200°C)**
 - Organic is partially oxidized into the feedstock converted to hydrocarbon decomposition
 - Products: high tar, some ash, and the gas
- Pyrolysis (300°C-600°C)**
 - Thermal decomposition without oxidation
 - Products: some gas, some ash (char), and high value hydrocarbon
- Transformation (200°C-300°C)**
 - Thermal decomposition without oxidation
 - Products: low tar, high value (char) and high value hydrocarbon

Emerging Opportunities — Feedstock

Feedstocks without a viable disposal pathway

- Agricultural waste**
 - Aspenic digestate
 - Manures
 - Hay shells
- Woody biomass and wastes**
 - Forest clean
 - Orchard trimmings
- End of life batteries**
 - Cobalt
- Residential and industrial waste streams**
 - End of the plastics
 - Plastic solid waste
 - Plastic Types 3-7
 - Consumer plastics
 - Flexible packing
 - Plastic beverage caps
 - Plastic film
 - Stycoform

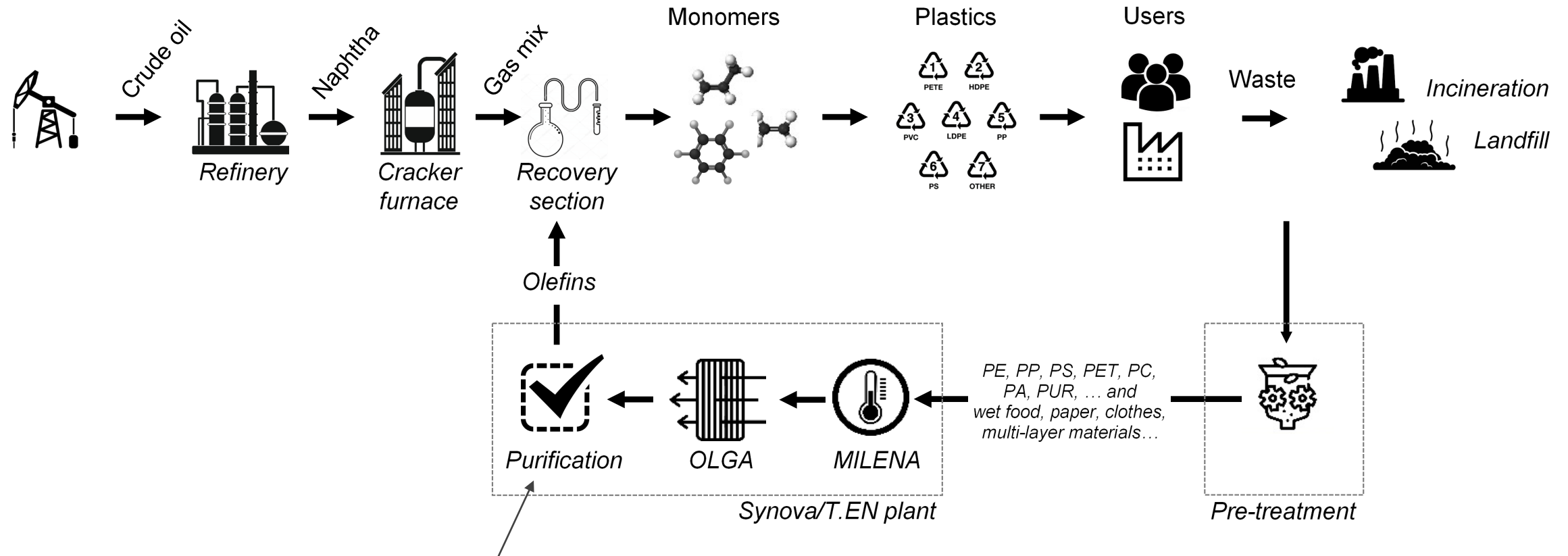
Emerging Opportunities — Feedstock

- Fossil fuel utilization wastewater
- Production of renewable power, heat, fuels, chemicals from syn gas
- Conversion of otherwise disposed of carbon into a valuable product or material
- Syn gas conversion into carbon-negative fuels
- Sustainable aviation fuel (SAF)
- Electro
- Carbonized waste biomass

What Will It Take to Get There?

- State and federal incentives
- Long-term planning
- Economic syn-gas conditioning technologies
- Pathways for thermal liquids conversion/char
- Syn-gas conversion technologies
- Reach beyond QLV methane reforming and
- Feedstock groups
- Solid byproducts (biochar) market development

SYNOVA/T.EN's SOLUTION REPLACING THE CRACKER FURNACE



› WHAT DOES IT BRING US....

MILENA APPLICATIONS IN THE MARKET

NEED TO KNOW

PRESS RELEASE

Trinseo Chemical Recycling Plant on Track



Trinseo's plant will be dedicated to recycled polystyrene (rPS), meeting increased demand for the material. PS is one of the most widely-used plastics.

Feb 08, 2022

SUPPLY CHAIN

Synova and Technip Energies Enter into Strategic Partnership



The agreement aims to commercialize Synova's advanced plastic waste-to-olefins technology in conjunction with Technip Energies' steam-cracking expertise.

Clare Goldsberry | Mar 17, 2021

› CONCLUSION

- TNO HAS DEVELOPED AN SNG VALUE CHAIN
- TNO SUCCESSFULLY DEVELOPED CO-PRODUCTION SCHEMES
- TNO HAS EXTENSIVE BIOFUELS CAPABILITIES
- TNO SUCCESSFULLY DEVELOPED INDIRECT GASIFICATION AS RECYCLING TECHNOLOGY





› **THANK YOU FOR
YOUR TIME**

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