Pyrolysis and gasification to provide a flexible pathway for advanced biofuel production

CONVERGE workshop

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Introduction - Advanced biofuels through pyrolysis & gasification

- Decentralized fast pyrolysis of biomass for FPBO production (25 MW_{th} ~ 40 kt dry/y)
  - ✓ Scale matches with typical biomass availability, e.g. sawmill or palm-oil residues (EFB)
  - ✓ Convert heterogeneous solid biomass into an uniform liquid bioenergy carrier
  - ✓ Increase energy density (on volumetric basis primarily)
- Transport of FPBO from multiple plants to central gasifier (>100 MW_{th})
  - ✓ Gasifier benefits from economy of scale
  - ✓ Liquid fuel allows easy pressurization & pressurized operation of the gasifier
  - ✓ FPBO contains <5% of inorganic elements present in biomass
    - ➢ Avoiding ash melting problems & Potentially allowing the use of a dedicated catalyst

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Introduction: Fast Pyrolysis of Biomass – Technology Status

- Commercialization through sister company BTG Bioliquids BV.
- Currently 3 plants in operation, cumulative FPBO production close to 100.000 m^3

Empyro – Hengelo (NL)

In operation since 2015
20 million litres FPBO/year
~25 MWth input
FPBO used to replace natural gas in a steam boiler

GFN – Lieksa (FI)

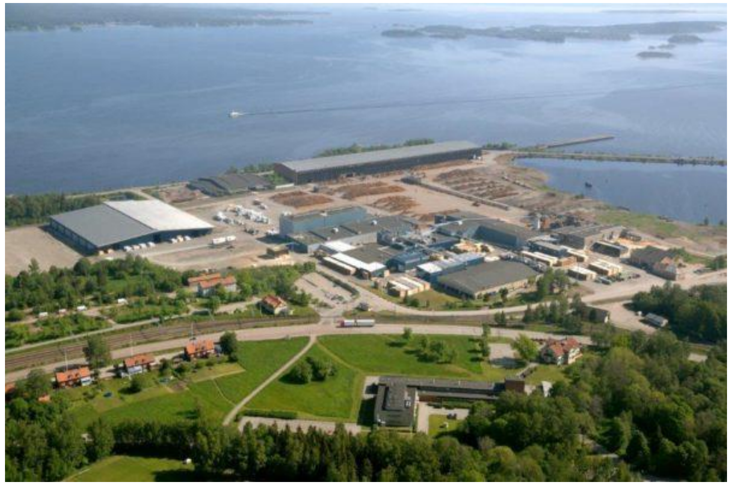
In operation since 2020
24 kton FPBO/year

FPBO for heating applications

Pyrocell – Gävle (SE)

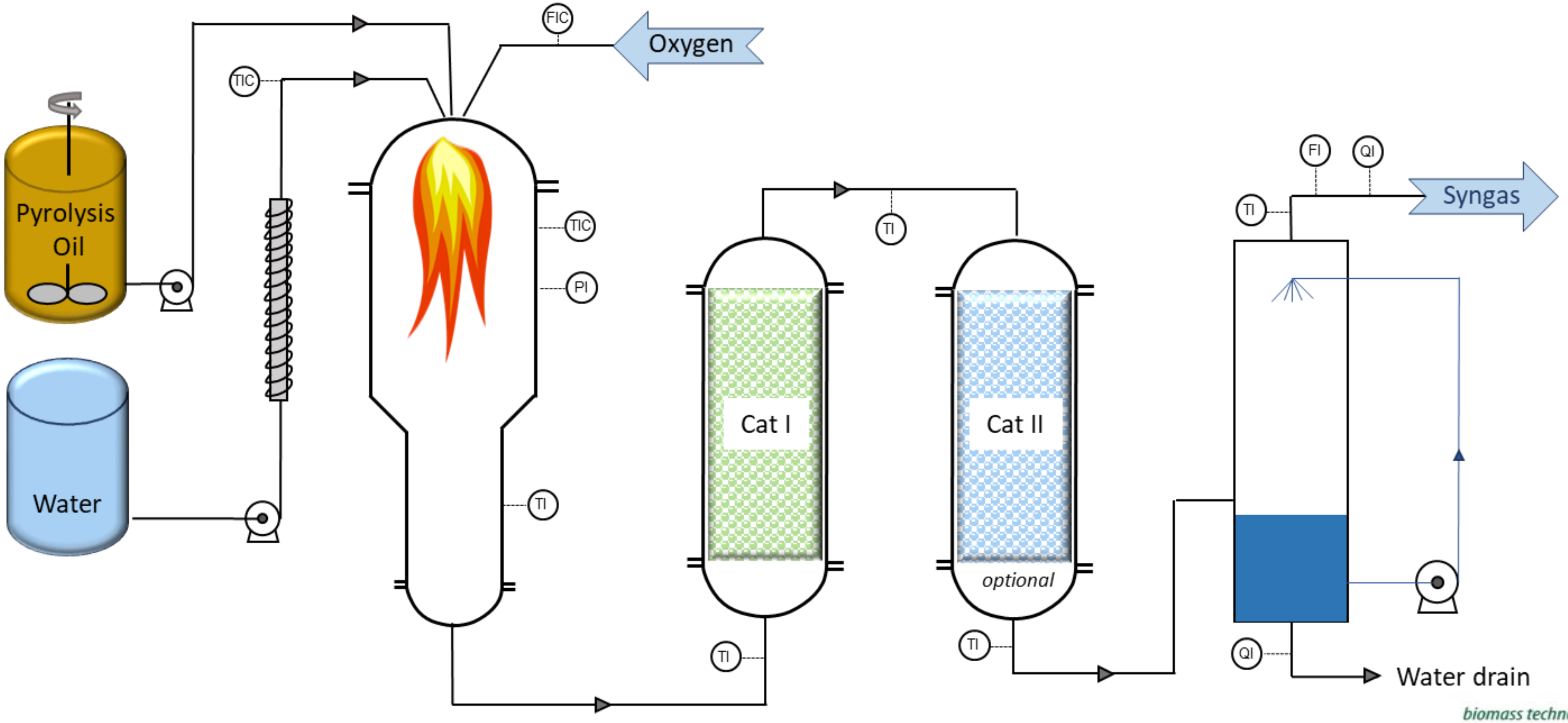
In operation since 2021
24 kton FPBO/year

FPBO used as co-feed in Preem refinery, biofuel production



Introduction - Autothermal catalytic reforming

- Oxygen blown, steam for H_2/CO_2 and temperature control, pressurized operation
- FPBO contains much less contaminants than biomass – use of catalyst feasible
- Lower operating temperature should increase energetic efficiency (compared to EF)



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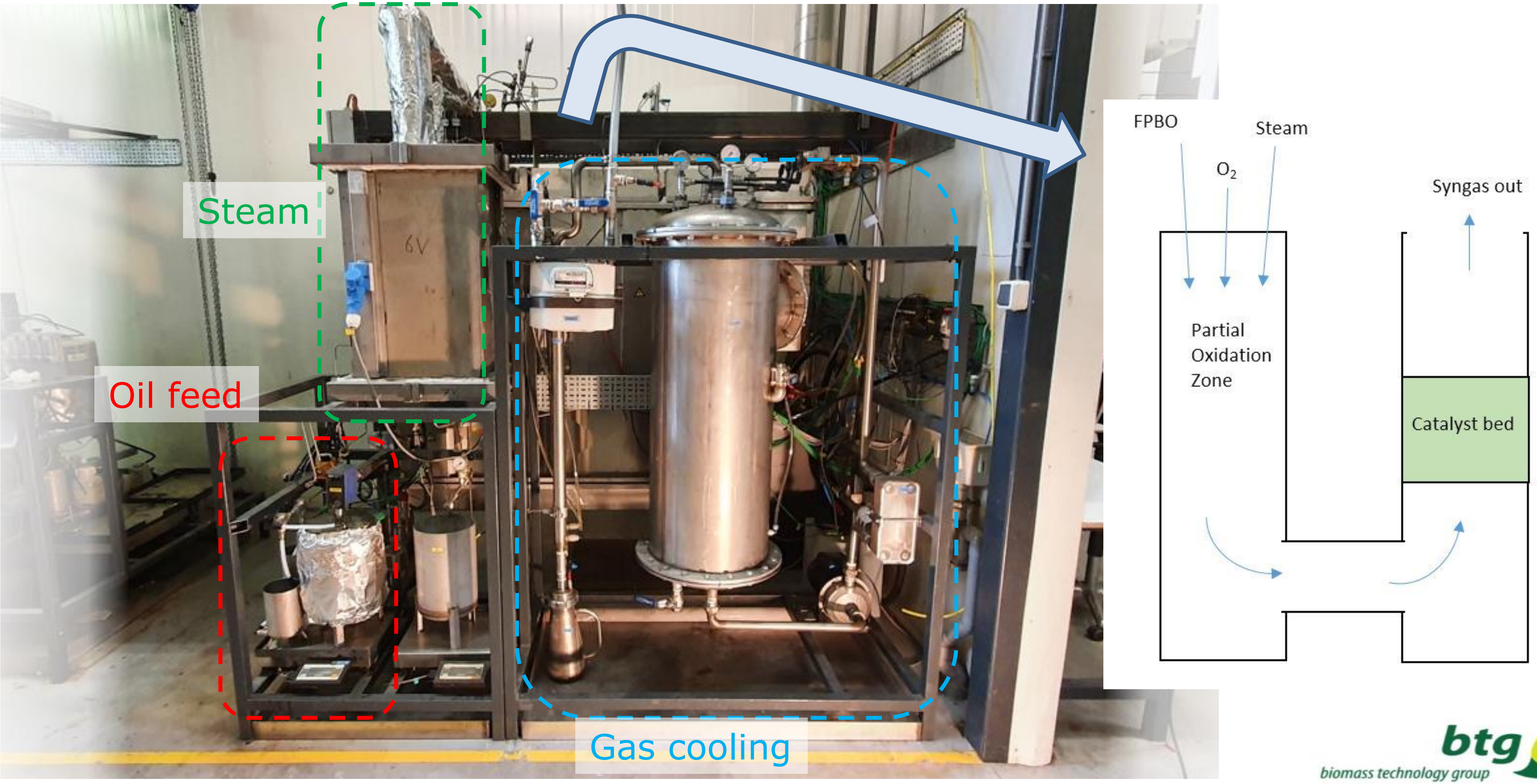
Materials & Methods - The autothermal catalytic reformer

- Design, construction and commissioning of a 10 kW gasifier



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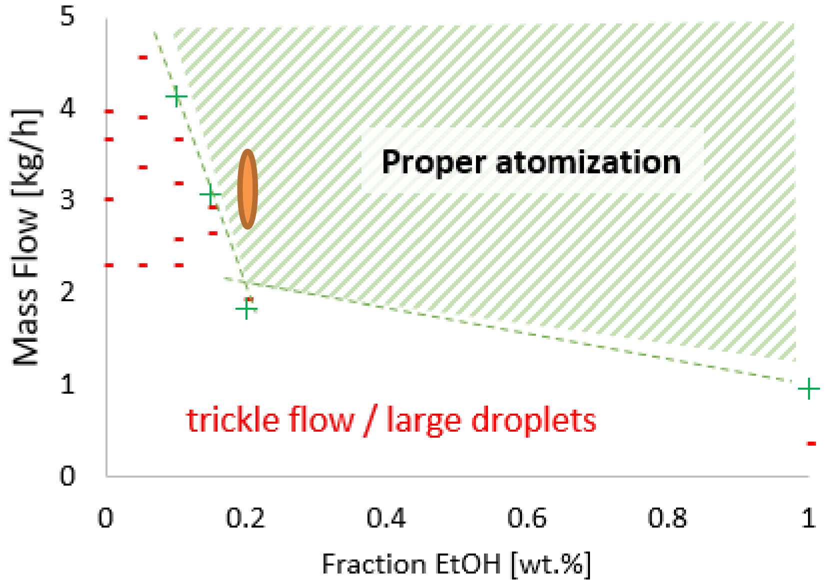
Materials & Methods – atomization of FPBO

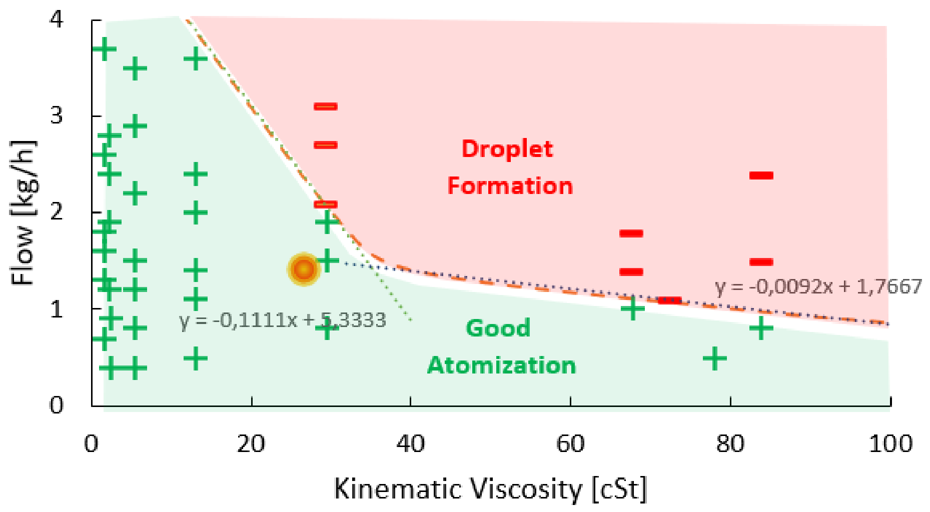
Pressurized atomization:

- Atomization based on kinetic energy diff.
- High liquid pressure 50-100 bar needed
- Fuel supply difficult to control, high capacity for proper atomization (3-4 kg/h)
- Ethanol required, 20 wt.% in FPBO
- $FPBO_{20}$ preheating to ~40 °C



Ultrasonic atomization:

- Atomization based on ultrasonic vibration
- Fuel supply pressure slightly above gasifier pressure
- Fuel supply easy to control, around 1 kg/h for proper operation
- **No ethanol required! pure FPBO**
- FPBO preheating to ~ 40 °C



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Materials & Methods – Catalytic reforming

- Packed bed catalytic reforming zone
- Commercially available reforming catalyst
  - ReforMax 330
  - 10-hole spoked weel
  - Potassium-promoted nickel based on Al_2O_3
  - Applied in natural gas / nafta reforming

- Excess of catalyst (best case start):
  - GHSV ~ 900 h^{-1} for pressurized atomization [m^3/h syngas / m^3 cat]
  - GHSV ~ 300 h^{-1} for ultrasonic atomization system [m^3/h syngas / m^3 cat]

Materials & Methods – FPBO composition

- Fast pyrolysis bio-oil (FPBO) from various biomass materials:

Ultrasonic ↓

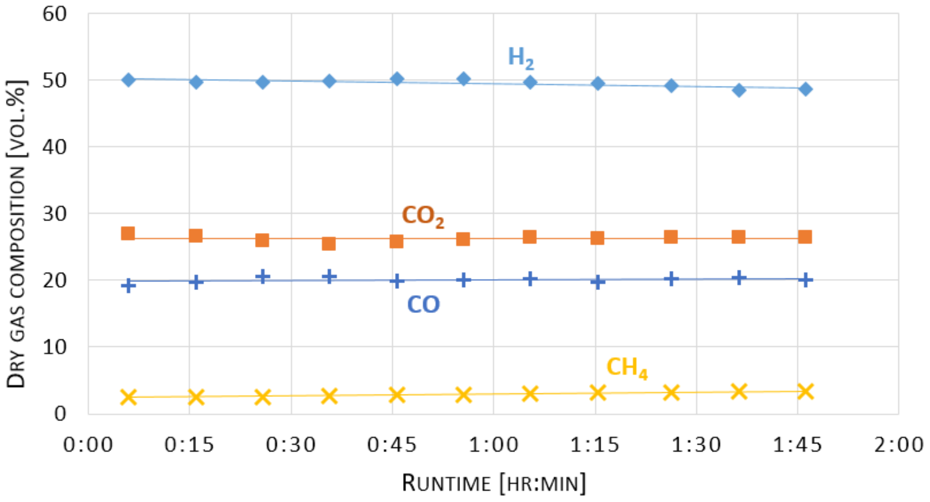
Biomass	Unit	Pine Wood	Arundo	Eucalyptus	Shorghum	Wood residue
FPBO Producer		BTG	VTT	VTT	VTT	GFN
Ethanol added	[wt.%]	20%	20%	20%	20%	0%
Elemental composition (a.r.)[A]						
Carbon	[wt.%]	44.5	43.4	45.8	42.9	44.4
Hydrogen	[wt.%]	7.5	8.9	8.5	8.4	7.1
Nitrogen	[wt.%]	0.3	0.4	0.3	0.7	0.3
Oxygen (diff)	[wt.%]	47.7	47.3	45.4	48.0	48.2
Water content	[wt.%]	22.3	22.9	19.8	25.6	19.5
LHV (a.r.)[B]	[MJ/kg]	16.8	18.0	18.7	17.1	16.3
Viscosity (40°C)	[cSt]	16.2	6.8	11.7	7.5	40
MCRT	[wt.%]	17	12.6	14.8	12.7	17.1

[A] = Elemental composition measured including ethanol *[B] = LHV calculated using the Milne correlation*

Results and discussion – Pressurized atomization

Steady state & Reproducibility

Pine wood FPBO with 20 wt.% bioethanol. ER 0.31, S/C 1.2

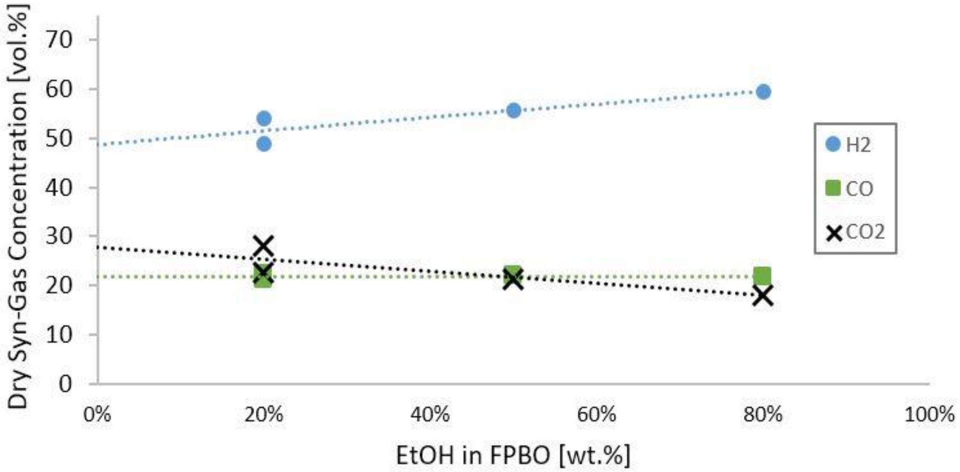


Stable operating conditions during run

- Minor decrease in H_2 production (50.0 to 48.6%)
- Increase in CH_4 production (2.5 to 3.3%)

Influence of ethanol

Variable EtOH content, ER ~0.3 & S/C ~1.4



Ethanol LHV and H-cont. higher than FPBO

- Increase in H_2 production
- Decrease in CO_2 production
- Carbon to Gas ratio higher (not shown in graph)

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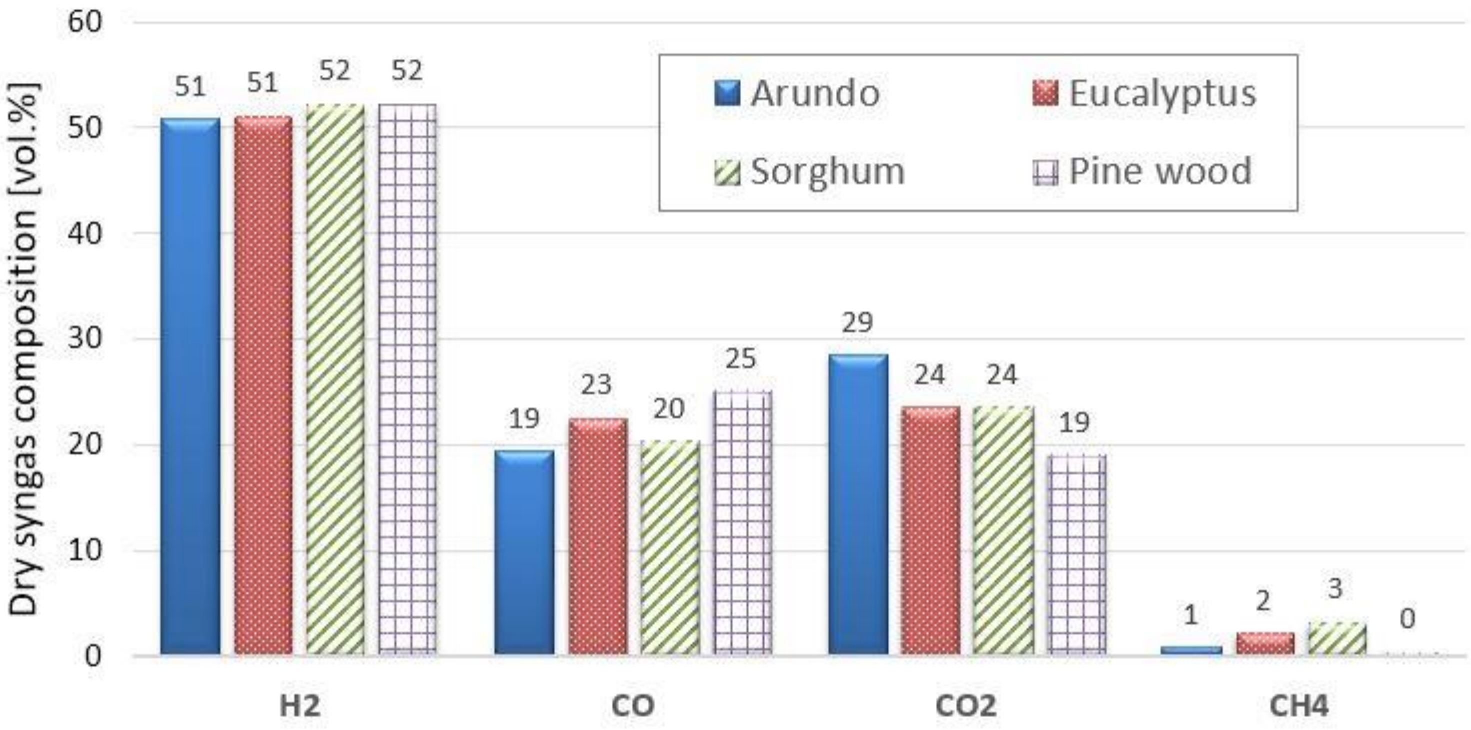
Results and discussion - Influence of various pyrolysis oils

- Dry syngas compostion:



Operating conditions:

- Pressurized atomization
- Temperature ~ 900 °C
- Temp catalyst ~ 800 °C
- ER ~ 0.3
- S/C ~ 1.4
- 20 wt.% EtOH in FPBO

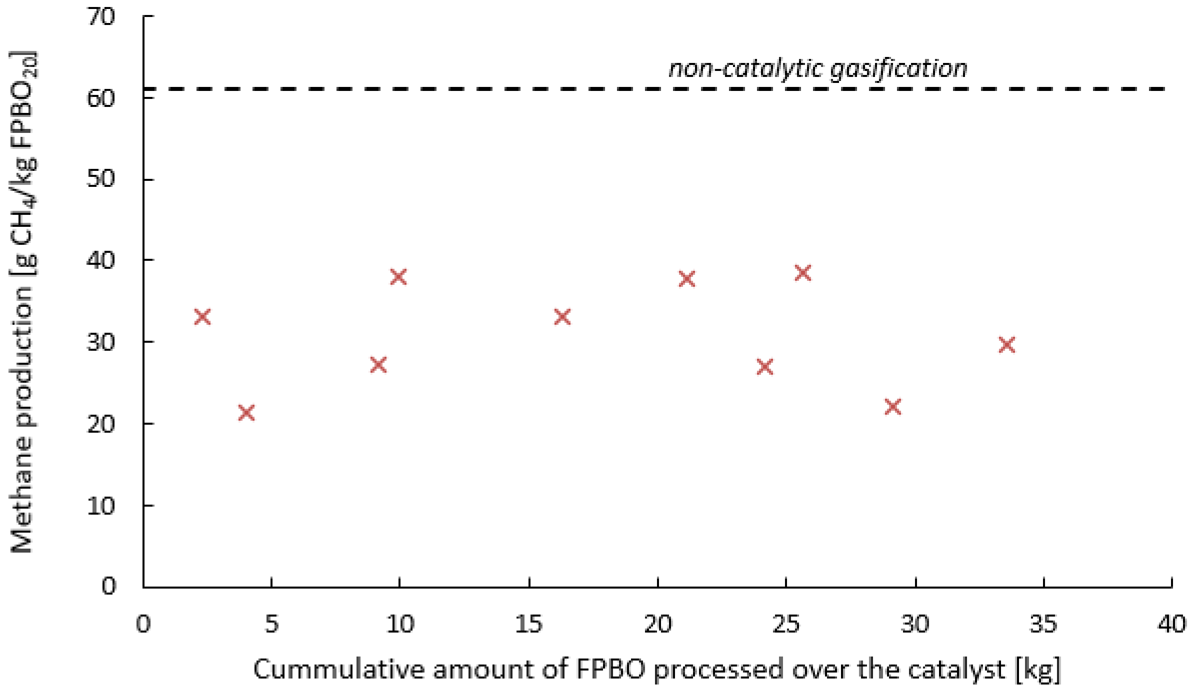
✓ Minor variation in gas composition for different FPBO's

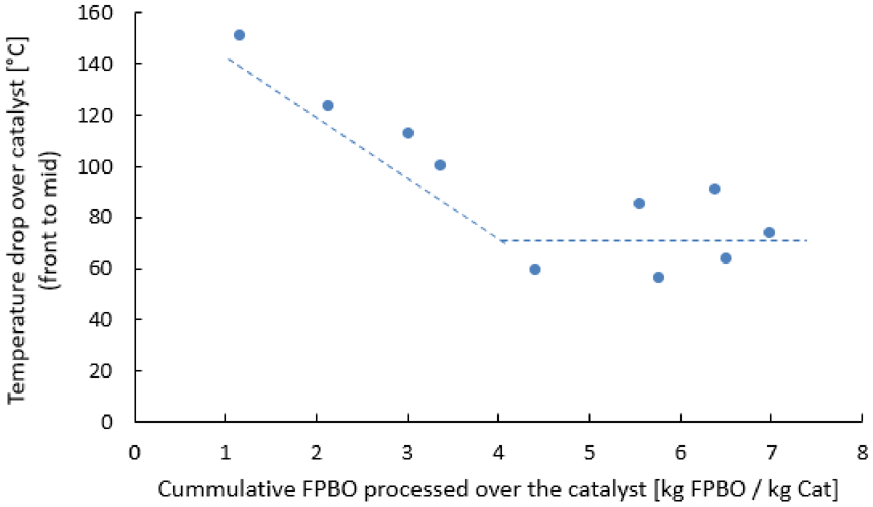
✓ Carbon conversion 90-95%

✓ Dry syngas ~ 1.7 Nm^3/kg FPBO

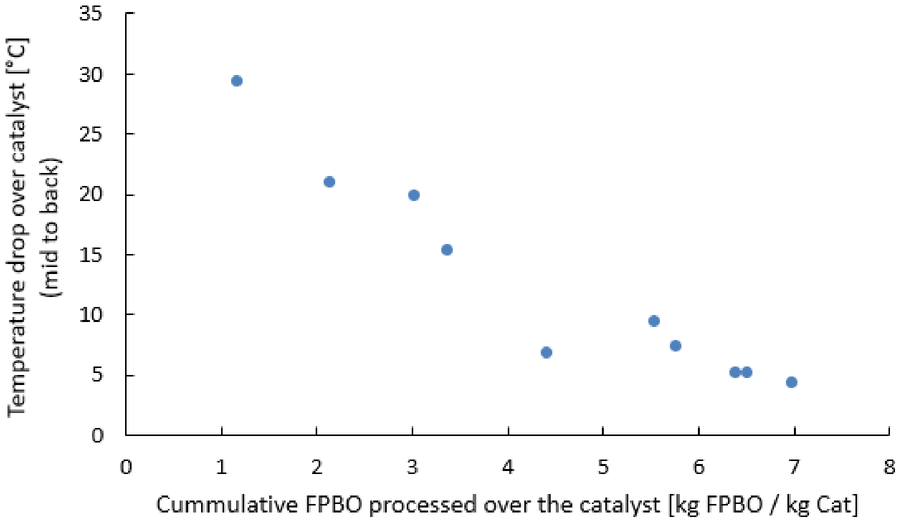
Results & Discussion - Deactivation of the catalyst

- Measurements with the pressurized atomisation & $FPBO_{20}$.
- Methane production (conversion) as indicator



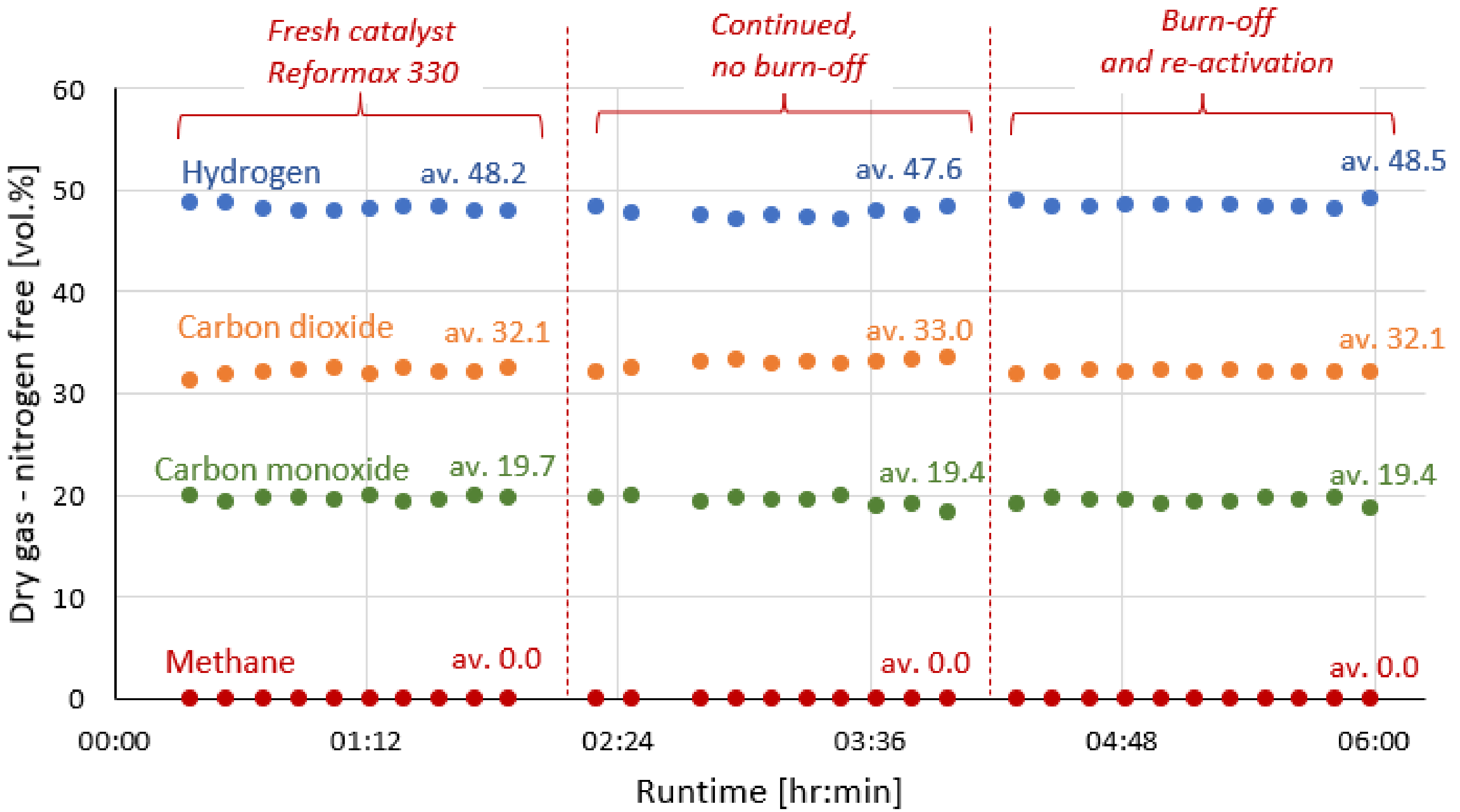


- However, temperature drop shows deactivation
- More than only methane reforming, C2 – $C20^{+}$
- Tar analysis performed; reproducibility difficult for now



3. Results & Discussion – Ultrasonic atomization

- Pure FPBO (GFN), triplicate test



Operating conditions:

- Ultrasonic atomization
- Temperature ~ 900 °C
- Temp catalyst ~ 800 °C
- ER ~ 0.38
- S/C ~ 1.3

✓ Very stable gas composition, no deactivation so far

✓ Carbon conversion ~ 95%

✓ Dry syngas ~ 1.7 Nm^3/kg FPBO

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Conclusion & Outlook

Experimental setup performs very well:

- √ Fuel flexible
- √ Reproducible tests, good balance closure
- √ Gas composition approaches thermodynamic equilibrium

Concept works:

- √ Synthesis gas composition virtually independent of biomass feedstock
- √ Use of FPBOs from different resources in same gasifier should be no problem

Future work:

- → Atomization requires improvement: Carbon to Gas 90-95%, needs to go (close) to 100%
- → Pressurized gasification desired for subsequent syngas conversion processes
- → Catalytic activity requires detailed investigation
- → Overall chain evaluation; syngas composition & quality versus product choice

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