# Co-production of green, high-quality $H_2$ and bio-SNG using electrochemical hydrogen compression

A.J. Grootjes
G. Aranda Almansa
C.M. van der Meijden
P.J. Bouwman **(Hyet)**
L.F.J.M. Raymakers **(Hyet)**

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EUBCE 2016
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HyET Hydrogen Efficiency Technologies

ECN
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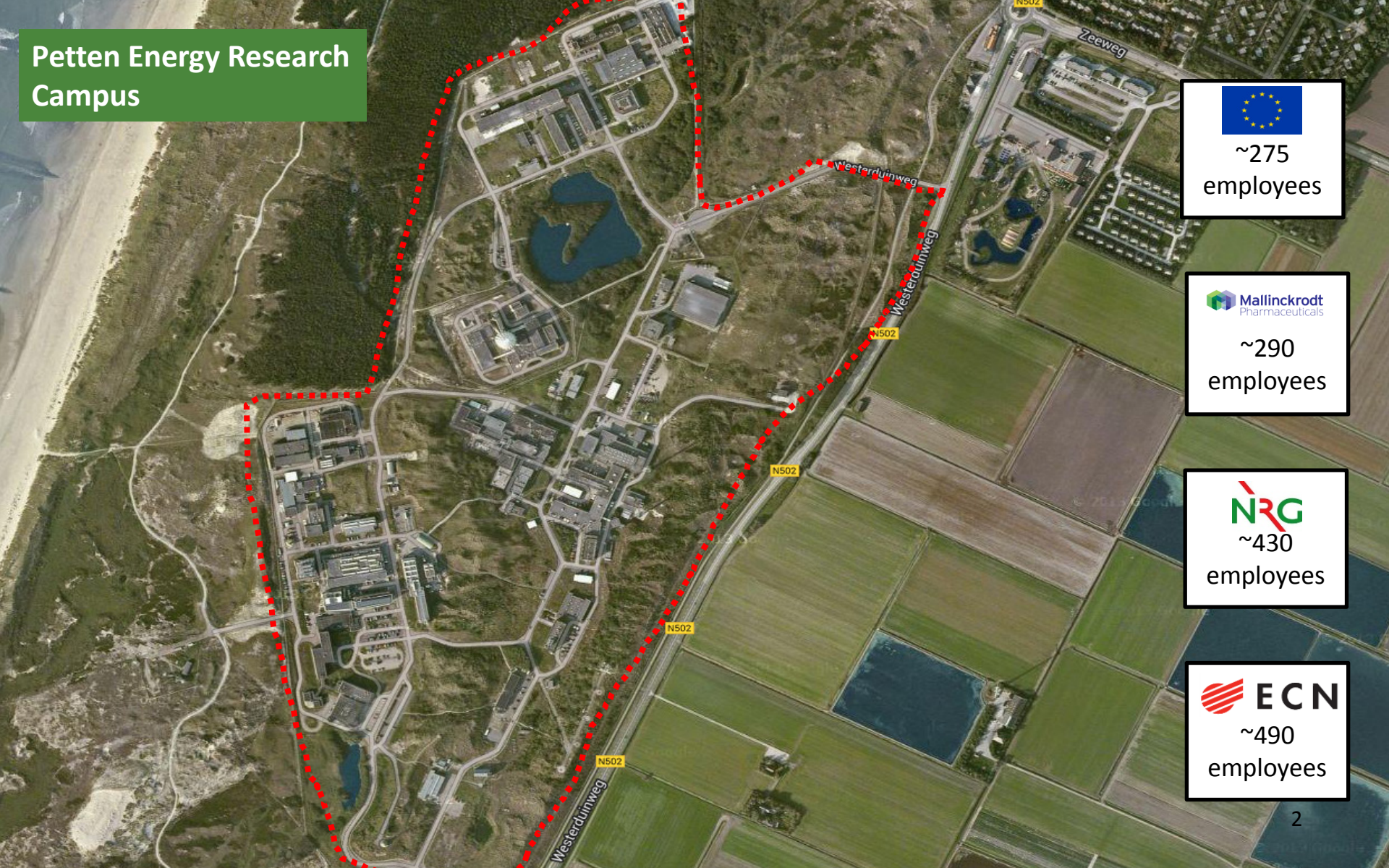
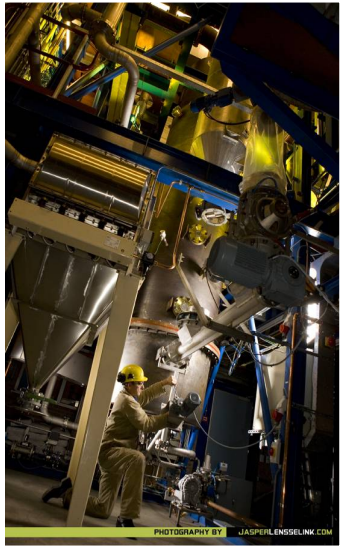
www.ecn.nl


Petten Energy Research Campus
Zeeweg
Westerduinweg
N502
~275 employees
Mallinckrodt Pharmaceuticals
~290 employees
NRG
~430 employees
ECN
~490 employees

# MILENA-OLGA-ESME invented by ECN

Efficient green gas production through gasification technology

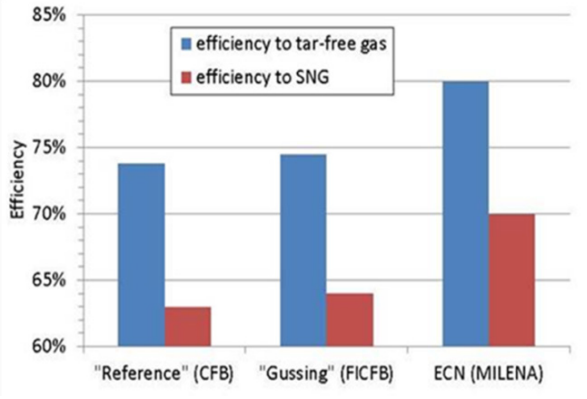

**MILENA**

**OLGA**

**ESME**

# Advantages of ECN Green Gas technology

- More energy efficient than other SNG technologies
  - 70% (10% higher than nearest competitor)
- Suited for agricultural and forestry residues
- Patented technology
- Unique leading knowledge position
- Scalable to very large power (400+ MW)
- Supported by a strong Green Gas Consortium
- 4 MWth biomass-to-SNG plant in Alkmaar (NL)

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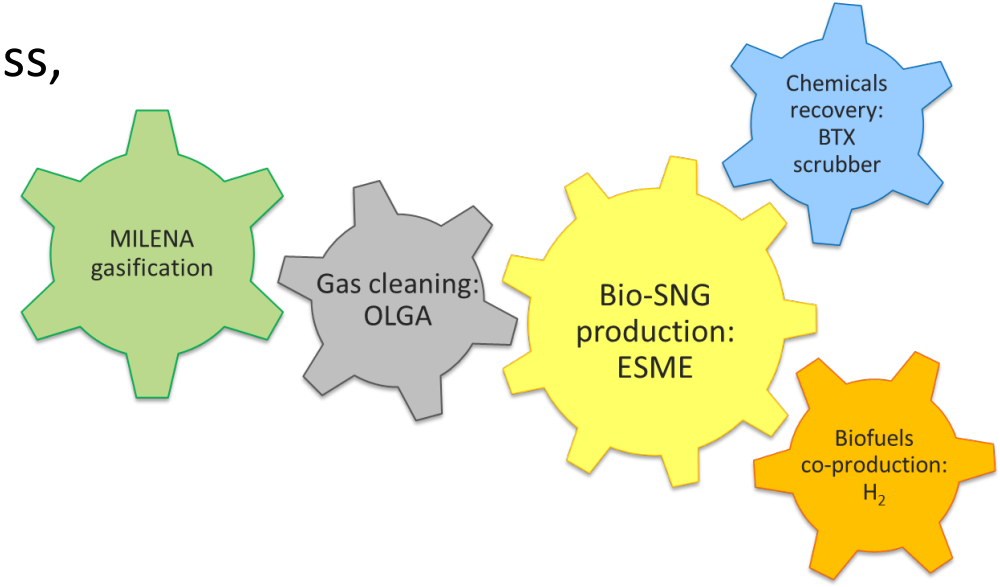
# $H_2$ + bio-SNG co-production

- MILENA/OLGA/ESME attractive technologies bio-SNG production
- Without subsidy bio-SNG needs valorization of co-products
- High efficient co-production routes are possible (poster 3CV.2.32)

- Short term: green $H_2$ for glass, steel and petrochemical industry
- Future: Green transport

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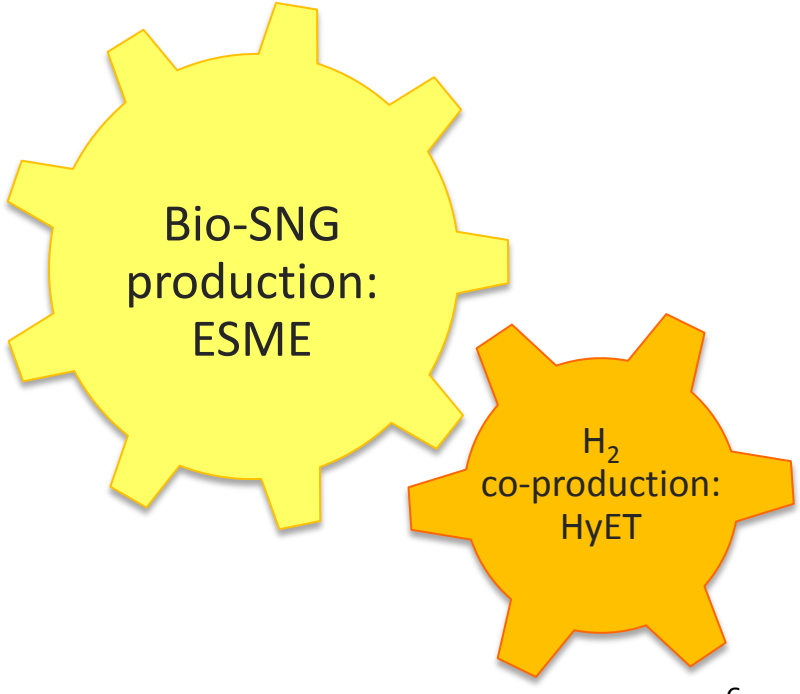
# A smart idea: co-production of bio-SNG + $H_2$

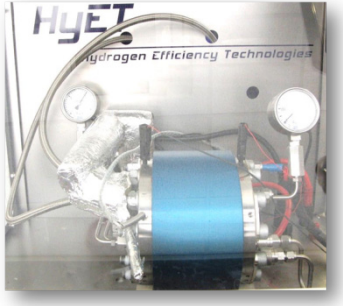
Key: we reduce the SNG yield but…

- We can produce high-pressure, high-purity, high-value $H_2$ → transportation biofuel.
- Reduction of production cost of biofuels, but keeping the overall process efficiency.



# HyET mission

- Mission: development of innovative, efficient, silent technologies enabling purification and compression of hydrogen
- Core competence: HyETs “pumping heart” achieved 100MPa pressure thanks to HyETs membrane, stack and system
- Industry and research partners



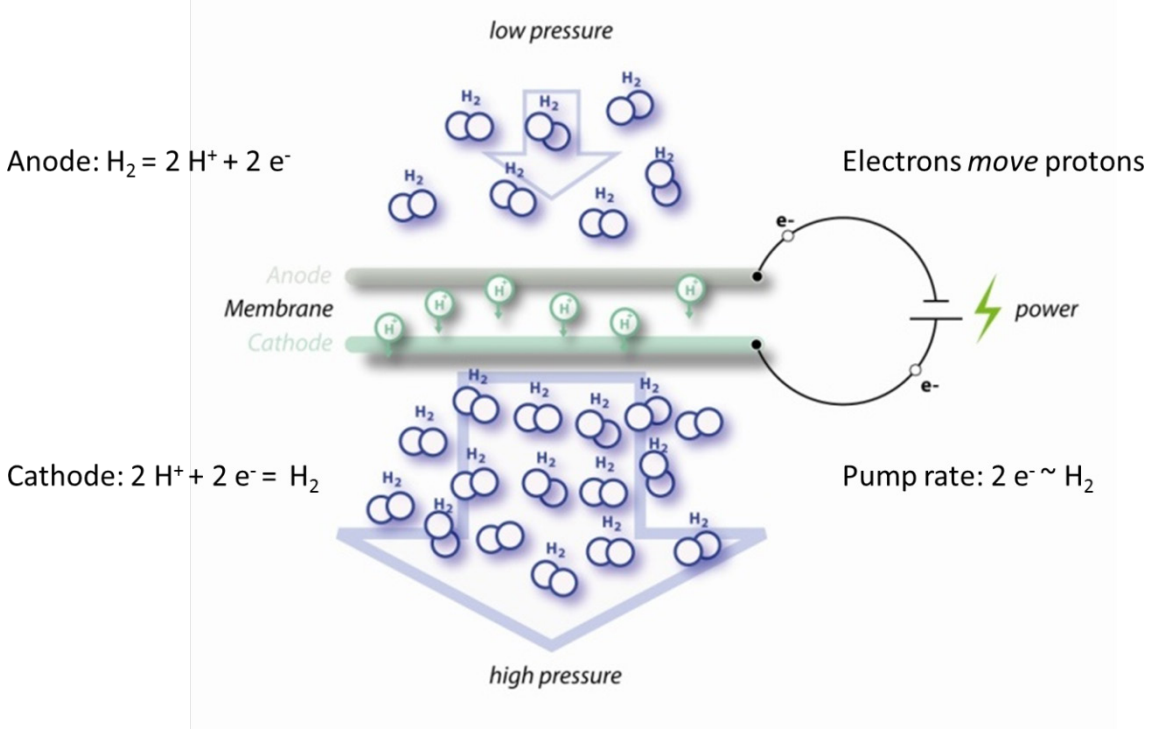


**Partners from industry:**
**Car manufacturers (Japan, Germany)**
**Oil and gas companies (Dutch, French)**
**Hydrogen infrastructure (Electrolysis, storage, fuel cells, refuelling stations)**
**Research institutes:**
**Universities (Dutch: TUD, UT, TUE, WUR; Germany, France, Japan)**
**ECN, TNO**

# HyET Electrochemical Hydrogen Compressor (EHC)

HyET Hydrogen Efficiency Technologies

- High pressure (>20 MPa), high purity (> 99.9%) $H_2$ from product gas[1)]
- 3x less energy compared to mechanical $H_2$ compression
- High value 'fuel cell grade' $H_2$
- (2 – 10 €/kg = 15-84 €/GJ)






[1)] [9] Bouwman, P.J. Fundamentals of Electrochemical Hydrogen Compression; chapter in book PEM Electrolysis for Hydrogen Production (2015) ISBN 978-1-4822-5229-3

# EHC experimental setup

HyET MoHyTO (Mobile Hydrogen Test Object) system.

- Pure, high pressure (30 bar) hydrogen (permeate) on one side and retentate off-gas on the other side.
- EHC stack: 30 electrochemical cells with active area of 42.6 $cm^2$/cell.
- Optimal temperature for membrane + catalyst: 150 °C (limit CO adsorption on catalyst).
- Autonomous operation and remote control.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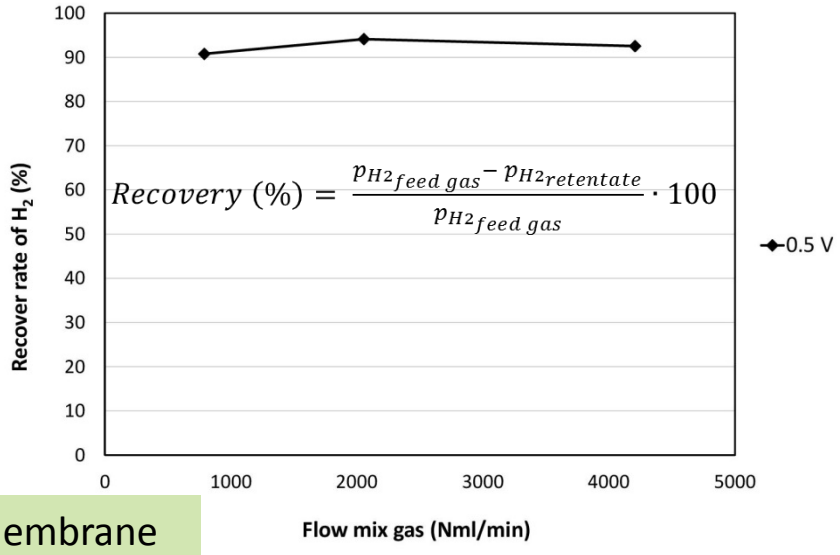
# Performance of HyET technology

Experimental conditions:

- Single membrane setup.
- $H_2$ / $N_2$ mixture, $H_2$ concentration: 3.5 vol.%
- Inlet gas flow to EHC: 0.79, 2.06 and 4.20 NL/min.
- Cell potential: 0.5 V.

Recovery: 91-94%, constant with flow.



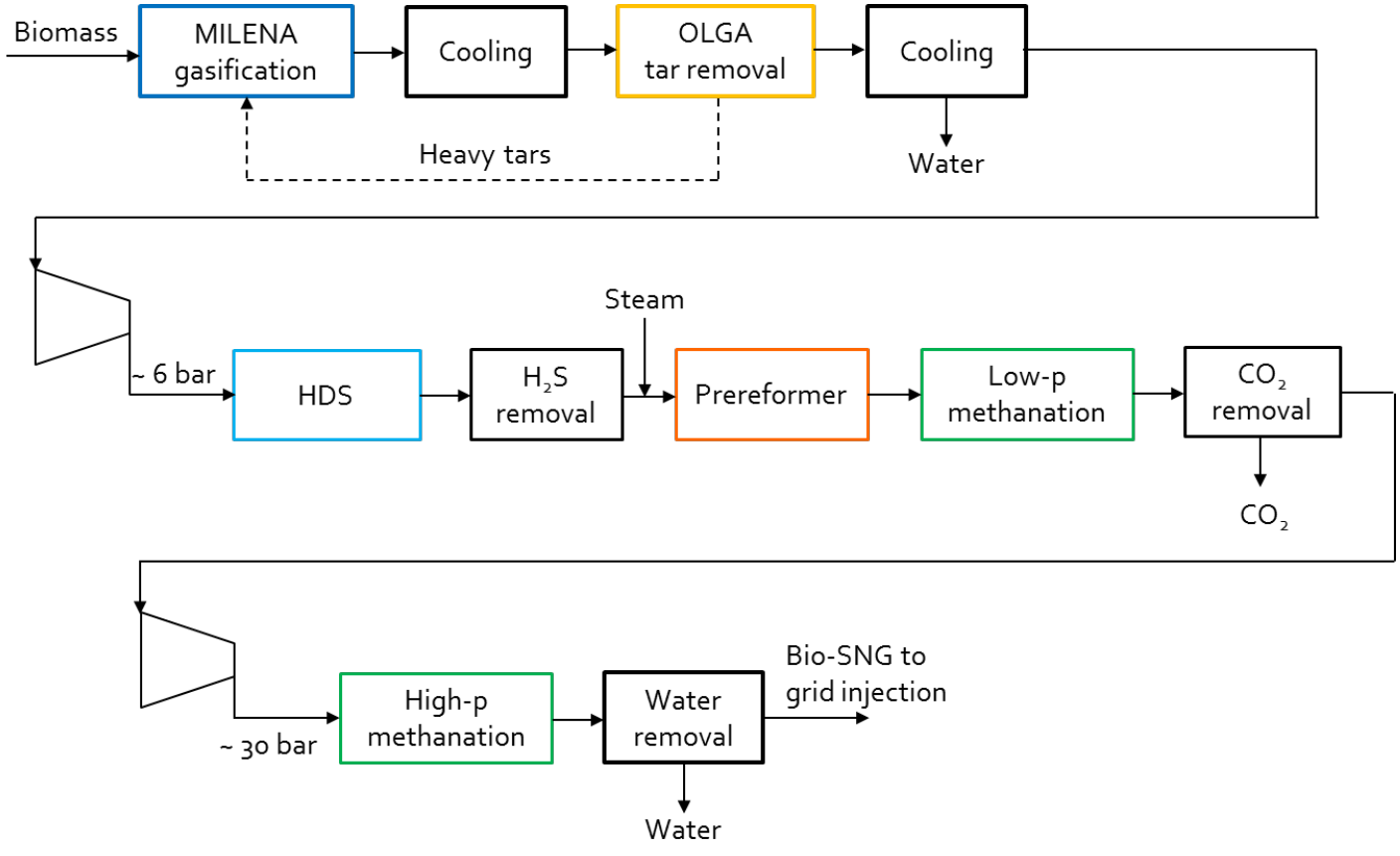

$$Recovery\ (\%) = \frac{p_{H2_{feed\ gas}} - p_{H2_{retentate}}}{p_{H2_{feed\ gas}}} \cdot 100$$

Improved flow pattern distribution of $H_2$ to the membrane

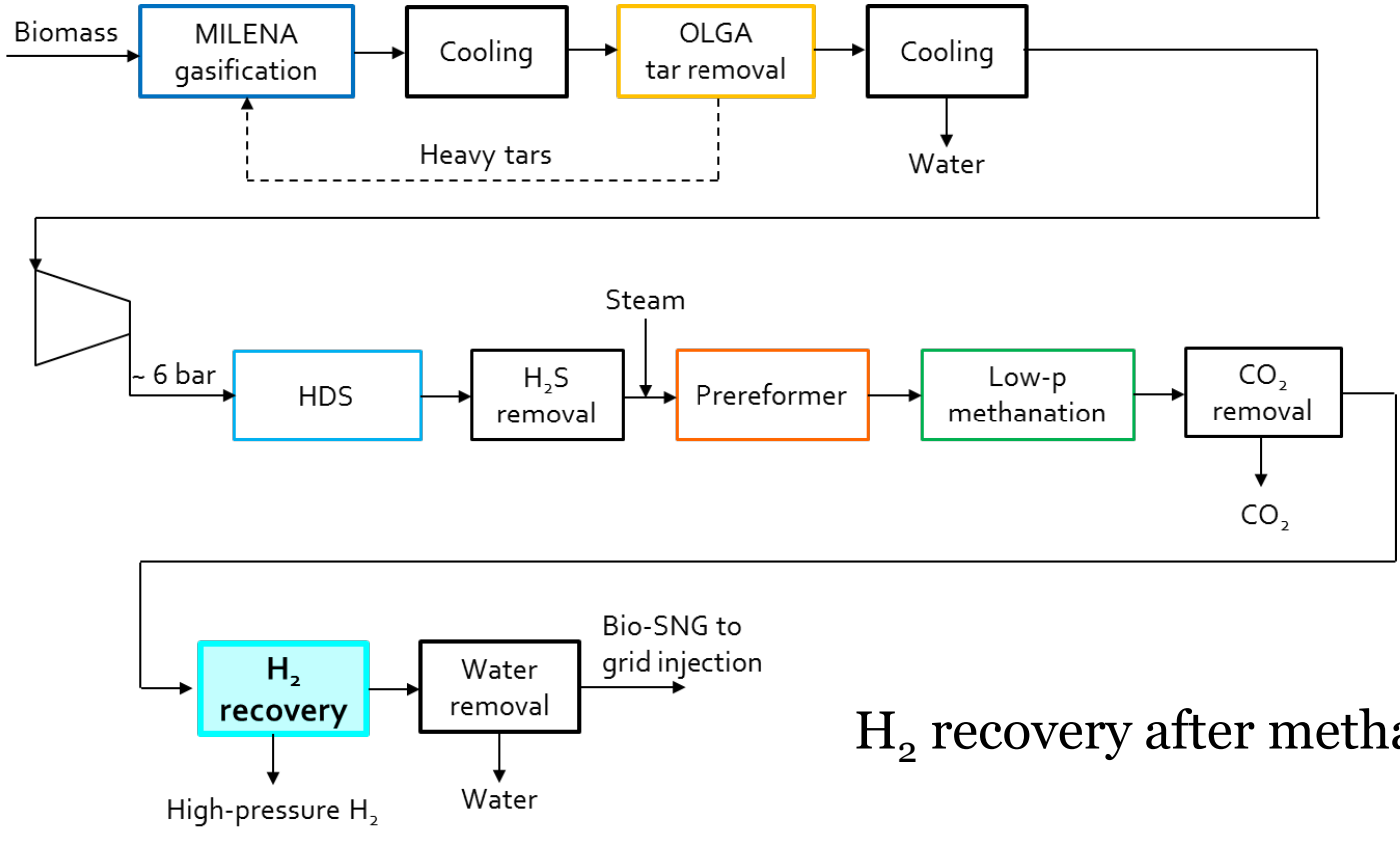


✓ Extraction of $H_2$ out of bio-SNG proven at small scale

# Case a): bio-SNG base case

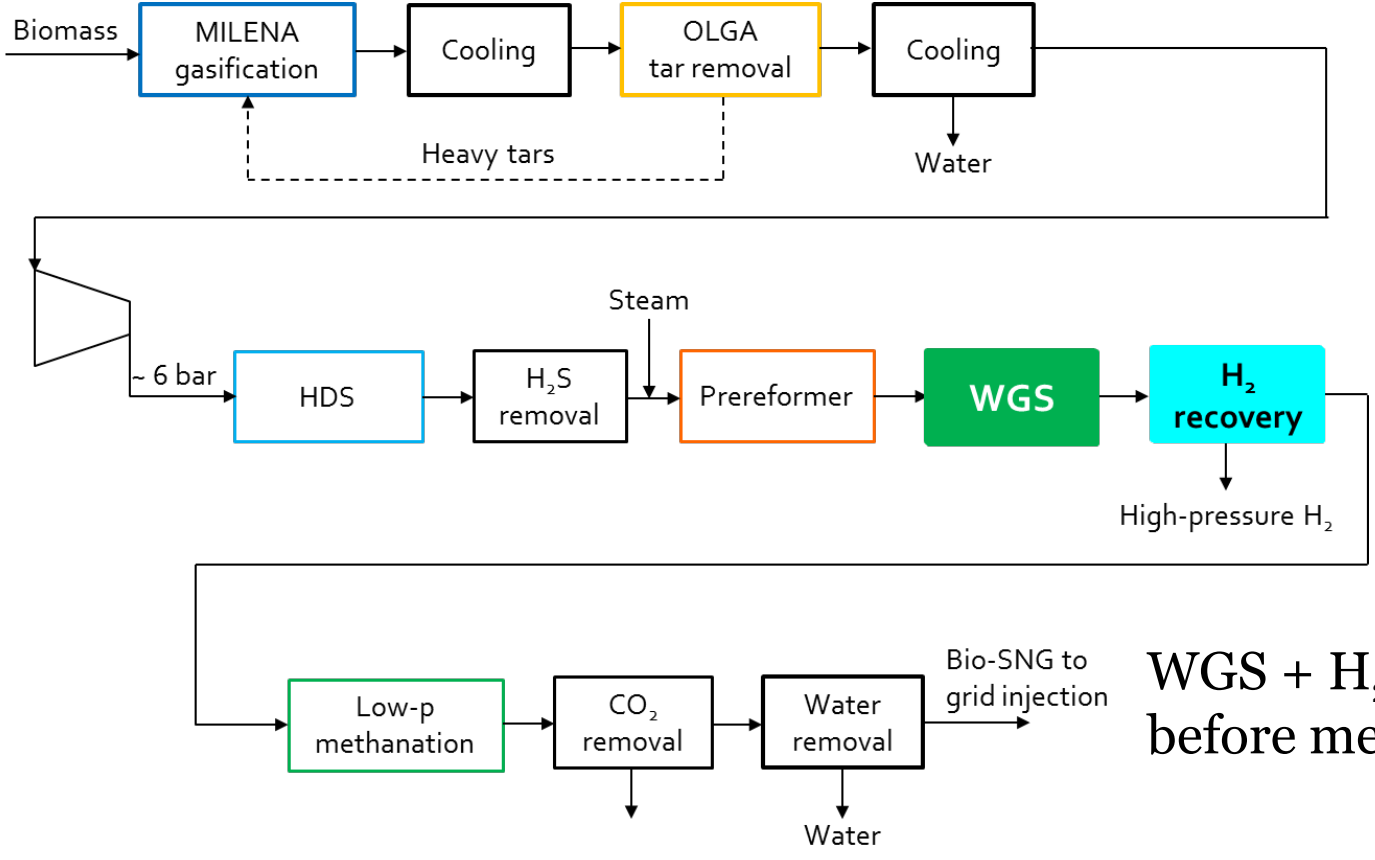


# Case b): SNG + $H_2$




$H_2$ recovery after methanation

# Case c): SNG + $H_2$




WGS + $H_2$ recovery before methanation

# Co-production of bio-SNG + $H_2$: effect on energy efficiency

| | Case a) | Case b) | Case c) |
|---|---|---|---|
| Input biomass ($MW_{th}$) | 100 | 100 | 100 |
| Output SNG (MW) | 69.1 | 67.6 | 50.5 |
| Output $H_2$ (MW) | 0.0 | 1.7 | 22.4 |
| Energy efficiency[1)] (% LHV) | 69.1 | 69.3 | 72.9 |

[1)] chemical energy contained in the products/energy contained in the solid biomass

- Case b) does not improve/degrade the energy efficiency
- Case c) improves efficiency because of extra $H_2$ production via WGS:

$$CO + H_2O \leftrightarrow H_2 + CO_2$$



No negative effect on energy efficiency, but what about the economics?

# Co-production of bio-SNG + $H_2$: high-level business case

Assumptions:

- 100 $MW_{th}$ scale Bio-SNG + green $H_2$
- Fixed SNG price of 10 €/GJ[1)]
- High pressure, high purity $H_2$ price of 50 €/GJ (6.7 €/kg)
- CAPEX based on data from ECN report[2)]

- Criteria: EBITDA[3)], ROI[4)]

[1)] International Energy Agency. World Energy Outlook 2014 (WEO2014)

[2)] Aranda, G.; van der Drift, A.; Smit, R. The economy of large scale biomass to Substitute Natural Gas (bioSNG) plants. ECN-E—14-008 (2014)

[3)] EBITDA = Earnings before interest, taxes, depreciation and amortization

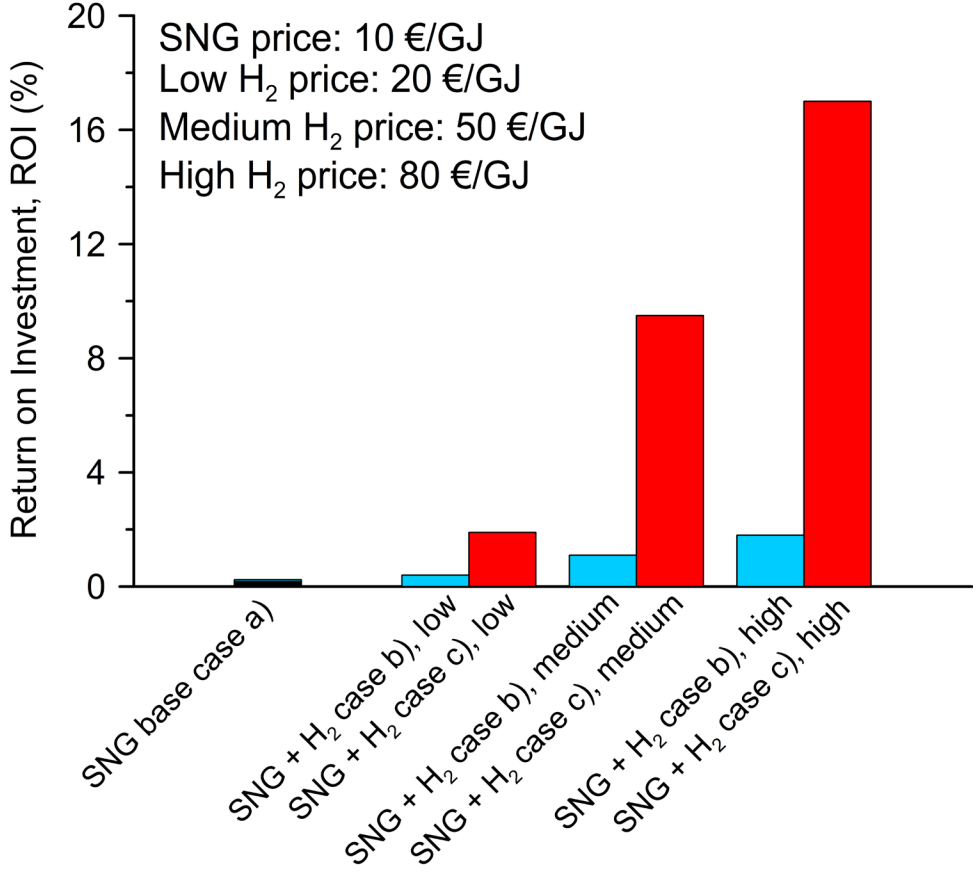
[4)] ROI (%) = Return On Investment = net plant income (EBITDA)/investment cost

# Co-production of bio-SNG + $H_2$: high-level business case

| | Case a) | Case b) | Case c) |
|---|---|---|---|
| OPEX (M€) | 19.3 | 19.6 | 22.6 |
| Revenues SNG (M€) | 19.9 | 19.5 | 14.5 |
| Revenues $H_2$ (M€) | 0.0 | 2.5 | 32.3 |
| EBITDA (M€) | 0.6 | 2.4 | 24.2 |
| | | | |
| CAPEX Bio-SNG (M€) | 231 | 216 | 221 |
| CAPEX $H_2$ recovery (M€) | 0 | 2 | 35 |
| CAPEX total (M€) | 231 | 218 | 256 |
| ROI (%) | 0.3 | 1.1 | 9.5 |

# Co-production of bio-SNG + $H_2$: effect of $H_2$ price on ROI

- Case b) improves slightly base case, but still unattractive.
- Significant improvement in case c): $H_2$ price > 50 €/GJ makes investment attractive (ROI ~ 9%).
- SNG base case needs subsidy to be profitable.



# $H_2$ + bio-SNG co-production

- $H_2$ extraction from raw bio-SNG stream proven at lab scale.
- Improved recovery rate > 95% with optimized flow pattern and potential.
- Economic analysis: WGS + $H_2$ recovery before methanation increases ROI significantly.

✓ Co-production of $H_2$ + bio-SNG improves the economy of bio-SNG → effective decrease of bio-SNG production cost

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# THANKS FOR THE ATTENTION


**Sander Grootjes**

**ECN**

Westerduinweg 3
1755 LE Petten
The Netherlands

P.O. Box 1
1755 ZG Petten
The Netherlands

T +31 88 515 4983

grootjes@ecn.nl
www.ecn.nl


HyET: www.hyet.nl
Publications: www.ecn.nl/publications
Fuel composition database: www.phyllis.nl
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**ECN**
Westerduinweg 3
1755 LE  Petten
The Netherlands

P.O. Box 1
1755 LG Petten
The Netherlands

T +31 88 515 4949
F +31 88 515 8338
info@ ecn.nl
www.ecn.nl