EUBCE 2025

Valencia, Spain

ORCHID https://orcid.org/0009-0003-5039-0772

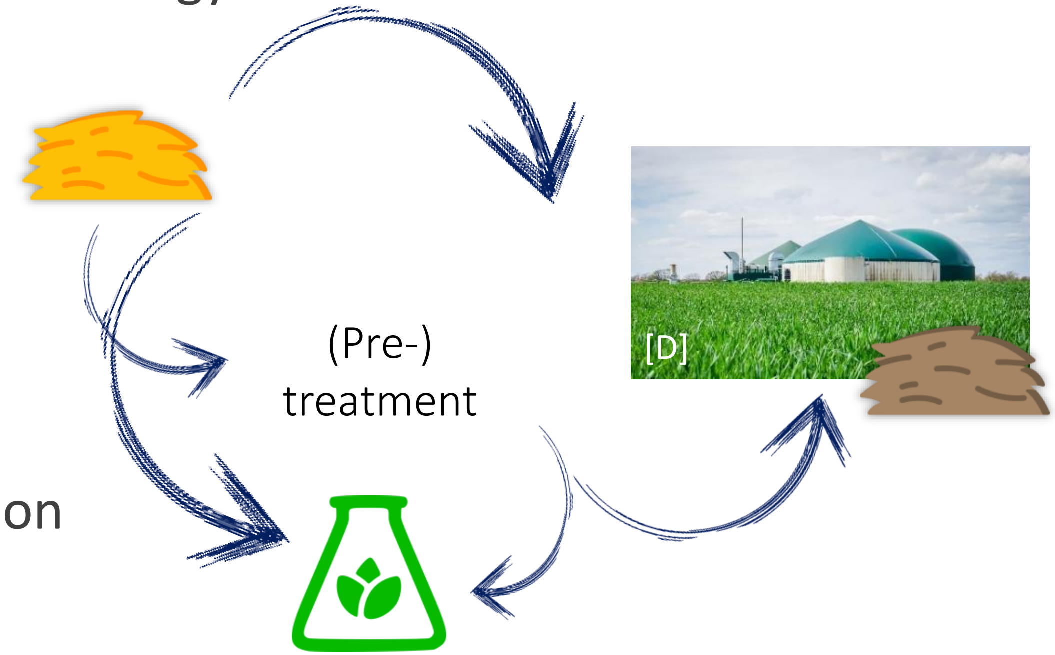
DOI https://doi.org/10.15480/882.15336

Vapothermal and hydrothermal pretreatment to enhance the anaerobic digestibility of recalcitrant substrates

Jana Schultz
Marvin Scherzinger, Martin Kaltschmitt

Technische Universität Hamburg (TUHH) | Institut für Umwelttechnik und Energiewirtschaft (IUE) | www.tuhh.de/iue

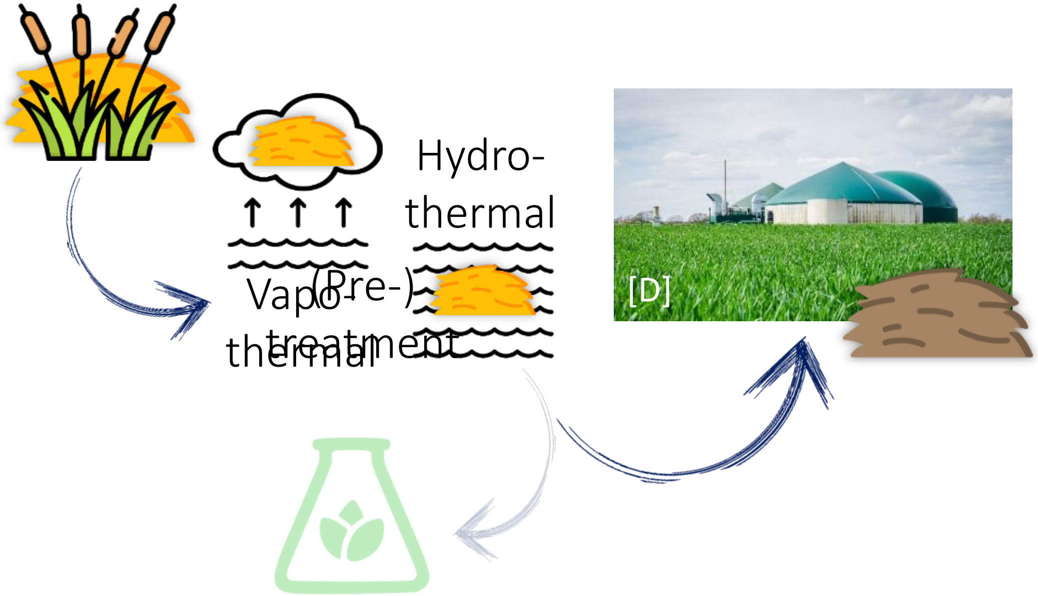
- Biorefineries
  - Fossil-free production of value-added products and energy
  - Management of wastes and residues
- (Pre-)treatment of lignocellulosic biomass
  - Production of value-added products
  - Reduce recalcitrance toward anaerobic degradation
- Role of anaerobic digestion in biorefineries
  - Final stage of biomass processing
  - Provision of biomethane, renewable energy & organic fertilizer



Lignocellulosic residues as substrates for biorefinery

Aim and scope

- Common reed
    - Residues originating from constructed wetland
- Pre-treatment
    - Vapothermal pre-treatment: hot stream
    - Hydrothermal pre-treatment: liquid water

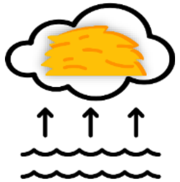


- Vapothermal vs. Hydrothermal pre-treatment
    - Optimizing biomass water content (vapothermal PT)
    - Influence of time & temperature → biogaspotential of solid processing residues
    - Analysis supported by: biomass characterisation & energetic evaluation

Vapothermal and hydrothermal pre-treatment of common reed

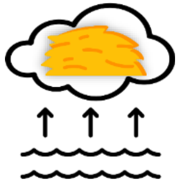
Materials and methods – pre-treatment

- Optimizing biomass water content via water impregnation
- Vapothermal pre-treatment



  - Parameter optimization via Box-Behnken design
  - Rotary evaporator: saturated steam, no “explosion”

- Optimizing biomass water content via water impregnation
- Vapothermal pre-treatment



  - Parameter optimization via Box-Behnken design
  - Rotary evaporator: satur

Parameter	Levels
Temperature (°C)	130 – 155 – 180
Time (min)	30 – 60 – 90
r content (%)	7.4 – 33.7 – 60.0

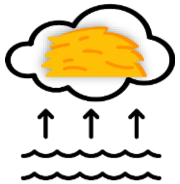
Anaerobic batch tests
Mass loss
Composition
Energey consumption

- Comparison of pre-treatment m
- Vapothermal pre-treatment usir
- Hydrothermal pre-treatment

  - Parr reactor, 1:10 solid-to-solvent ratio

Vapothermal and hydrothermal pre-treatment of common reed

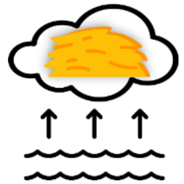
Results – biomass water content during vapothermal pre-treatment



$$Y_M = +327.2 - 4.65A - 8.43B + 26.45C + 21.93AB + 46.12AC + 25.28BS - 52.16A^2 - 28.55B^2 - 65.96C^2$$

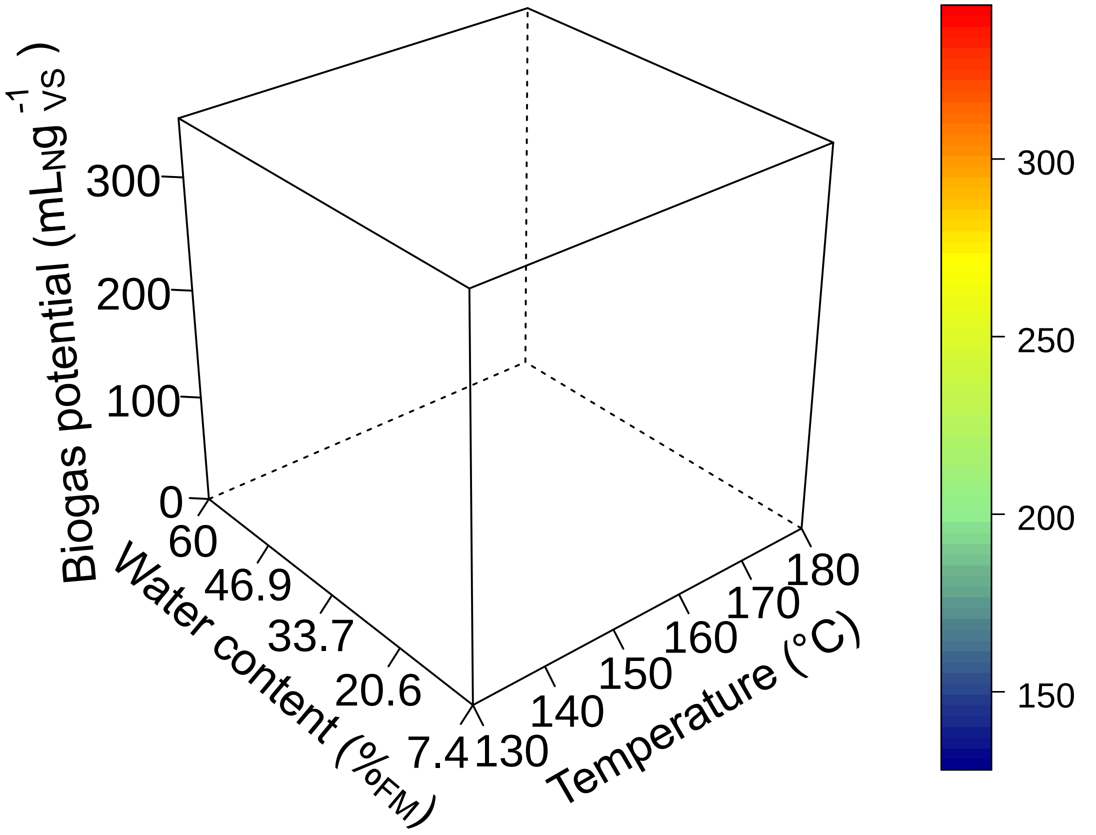
[1] | Y_M Biogas yield, Coded factors: A: Temperature, B: Time, C: Water content

Results – biomass water content during vapothermal pre-treatment



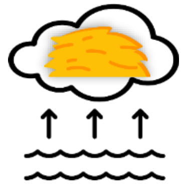
- Significant factors of the model equation (Box-Behnken design):
  - Water content
  - Interaction of temperature & water, residence time & water, all squared factors

$$Y_M = +327.2 - 4.65A - 8.43B + 26.45C$$
$$+21.93AB + 46.12AC + 25.28BS$$
$$-52.16A^2 - 28.55B^2 - 65.96C^2$$

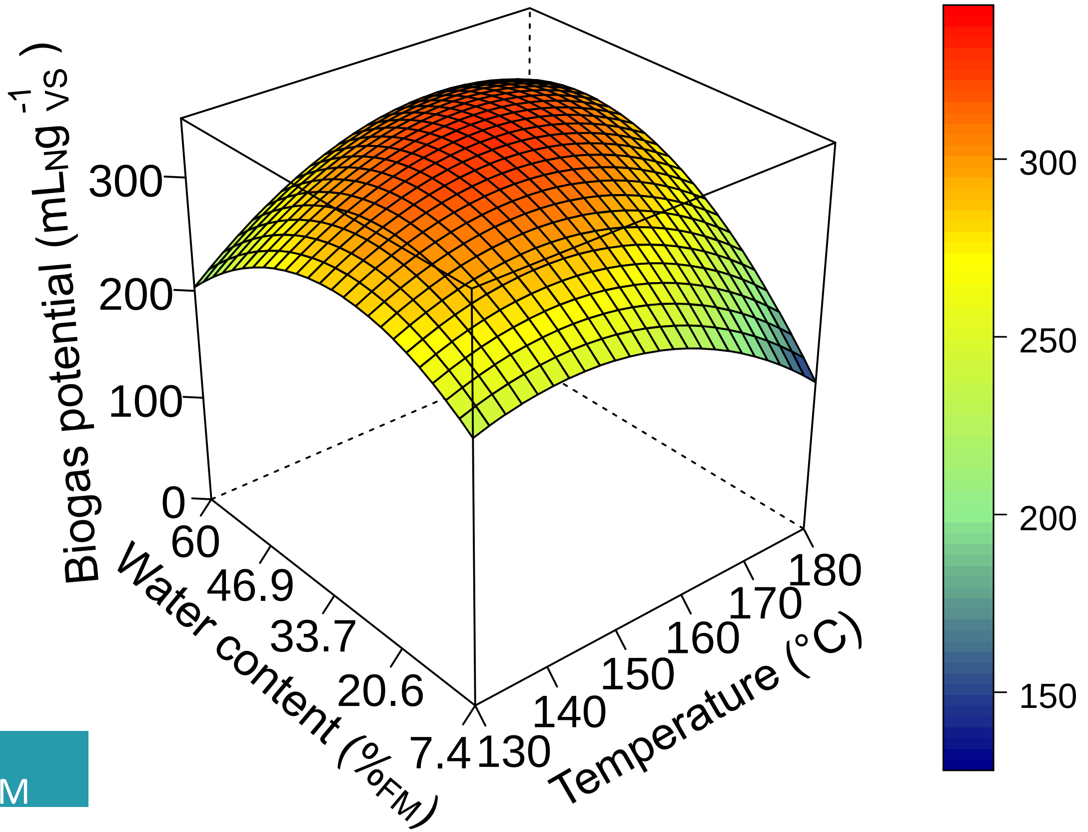


Results – biomass water content during vapothermal pre-treatment

- Significant factors of the model equation (Box-Behnken design):
  - Water content
  - Interaction of temperature & water, residence time & water, all squared factors
- Optimum range (tolerance of 5 $mL_N\ g_{VS}^{-1}$)
  - Water content 32 – 46 $\%_{FM}$
  - Temperature 149 – 163 °C
  - Residence time 47 to 71 min



$$Y_M = +327.2 - 4.65A - 8.43B + 26.45C$$
$$+21.93AB + 46.12AC + 25.28BS$$
$$-52.16A^2 - 28.55B^2 - 65.96C^2$$



Medium water content facilitates steam penetration and heat transfer [11]

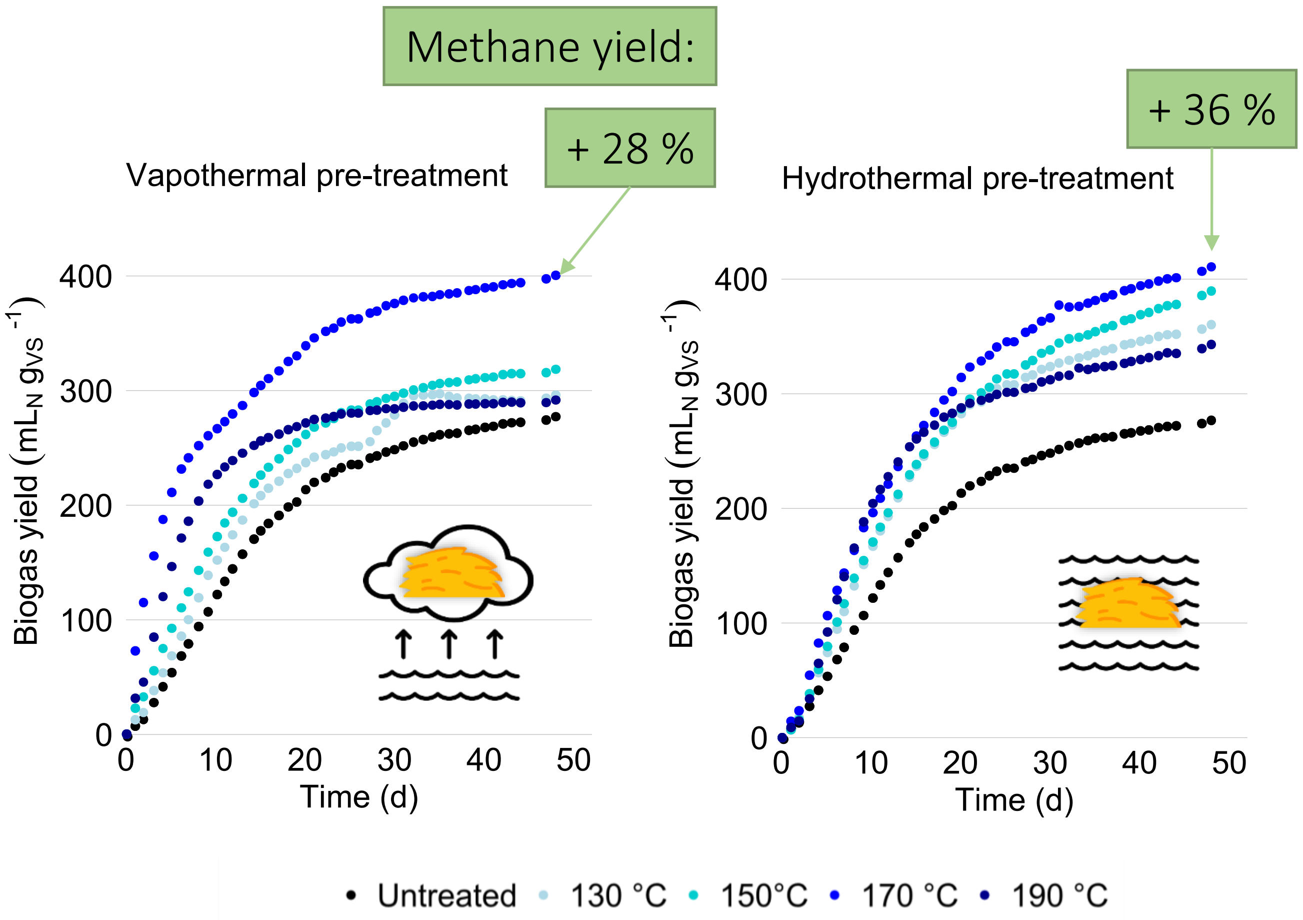
→ Adjustment of biomass water content to 35 $\%_{FM}$

[1] | Y_M Biogas yield, Coded factors: A: Temperature, B: Time, C: Water content

Vapothermal and hydrothermal pre-treatment of common reed

Results – biogas potential of residues

- Effect of temperature on anaerobic degradation
- Vapothermal pre-treatment
  - + 28 % methane yield at 170 °C
  - Narrow temperature optimum
  - Shift in degradation kinetics
- Hydrothermal pre-treatment
  - + 36 % methane yield at 170 °C
  - Significant increase also at 150 and 190 °C
  - Impact in degradation kinetics less strong



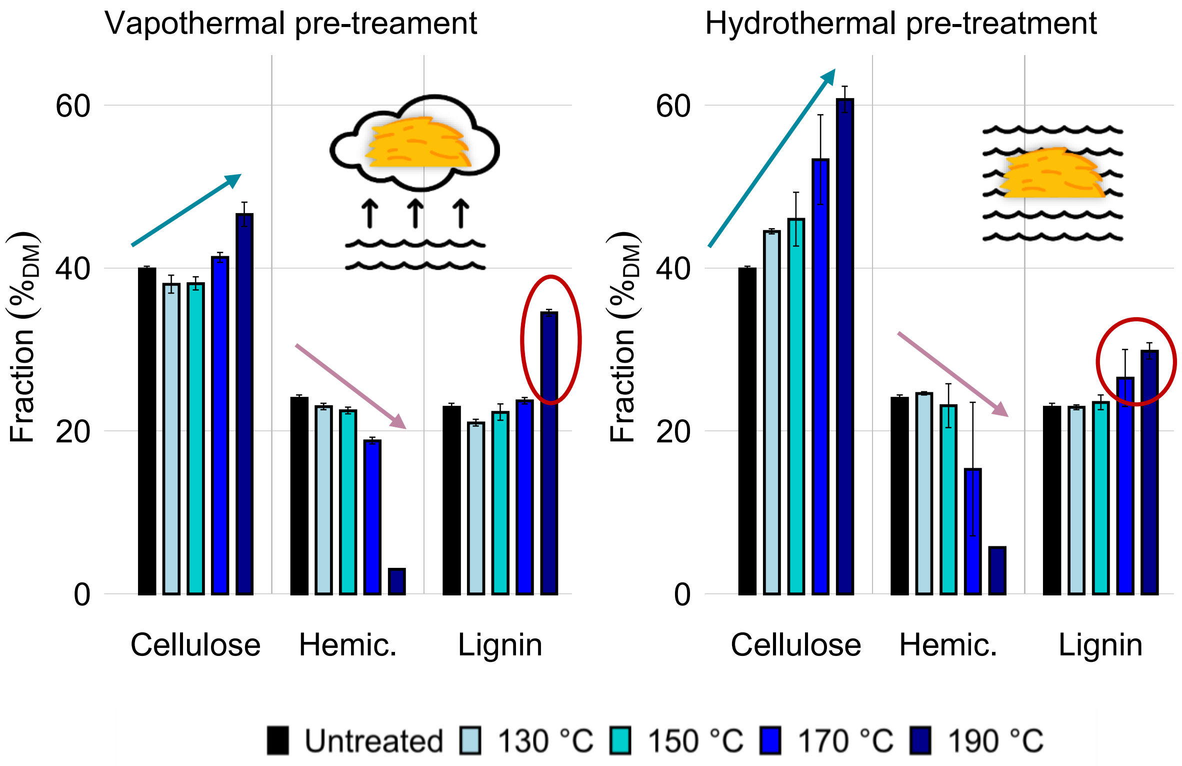
→ both methods had their highest methane yield at 170 °C
→ yield was similar

Vapothermal and hydrothermal pre-treatment of common reed

Results – biomass composition

- Hemicellulose
  loss at high temperatures
- Cellulose
  increase due to retention in the solid biomass
- Lignin
  partial retention
- Effect stronger for hydrothermal pre-treatment

→ Compositional changes facilitate anaerobic degradation

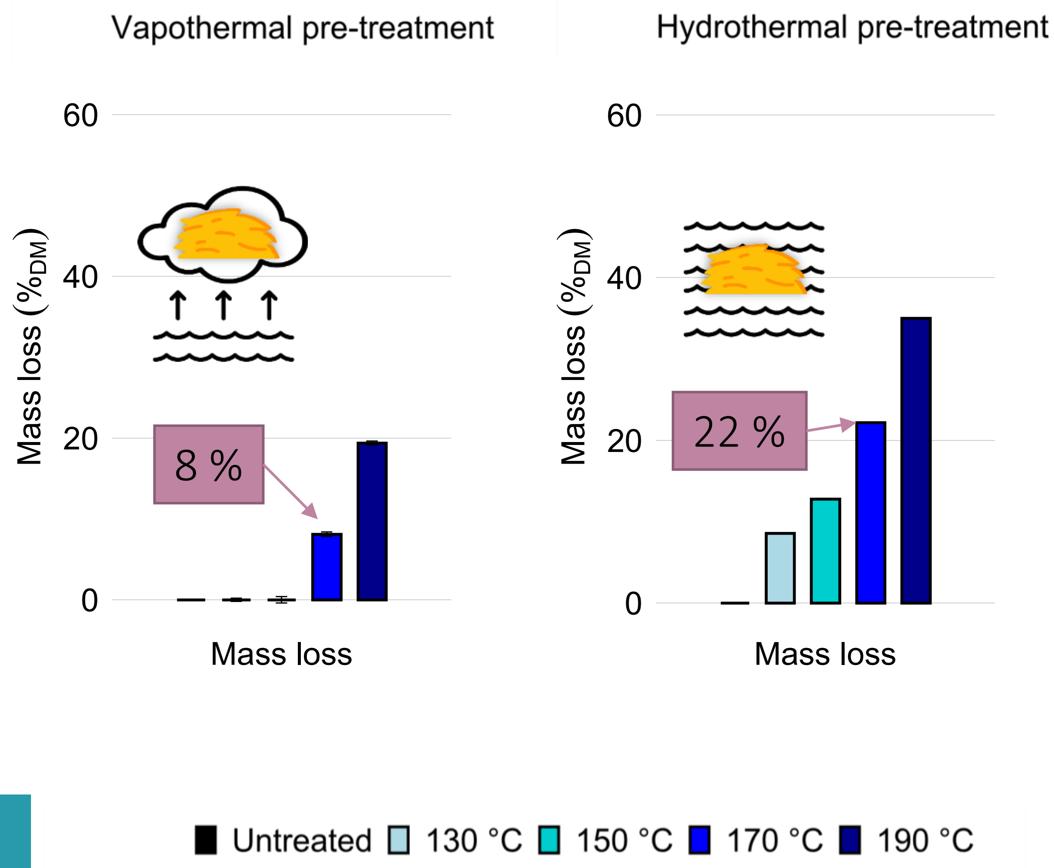


- Mass loss caused by pre-treatment
  - Increases with temperature
  - Is much stronger for hydrothermal pre-treatment

→ Mass loss diminishes increase of biogas potential

- Vapothermal pre-treatment
  - + 28 % → + 18 % methane yield at 170 °C
- Hydrothermal pre-treatment
  - + 36 % → + 6 % methane yield at 170 °C

→ methane potential after
vapothermal pre-treatment > hydrothermal pre-treatment

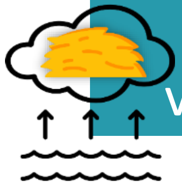


Vapothermal and hydrothermal pre-treatment of common reed

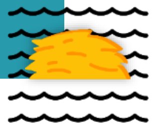
Results – energetic estimation

- Simplified estimation of energy consumption based on:
  - Energy to heat **(dry) biomass** to process temperature
    - Heat capacity of common reed $Q = m\, c_p\, \Delta T$
  - Energy to heat **water/steam** (biomass water content & process medium)
    - Heat capacity of water/steam $Q = m\, c_p\, \Delta T$
  - Energy to **evaporate/provide steam**
    - Enthalpy of evaporation of water $Q = m\, H_V$

Energy required (kJ kg_{DM}^{-1})	**Vapothermal**	**Hydrothermal**
Biomass, dry	180	180
Water (biomass/medium)	342	5540
Steam (evaporation+heating)	116	1418
Total	**638**	**7138**

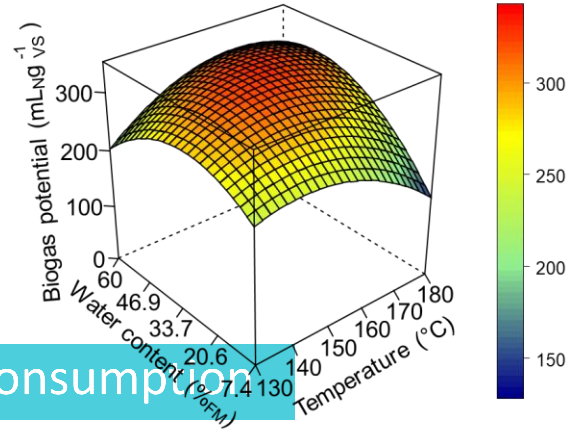


→ Energy consumption vapothermal << hydrothermal



- Biomass water content during vapothermal pre-treatment

Medium water content is favourable



- Vapothermal pre-treatment

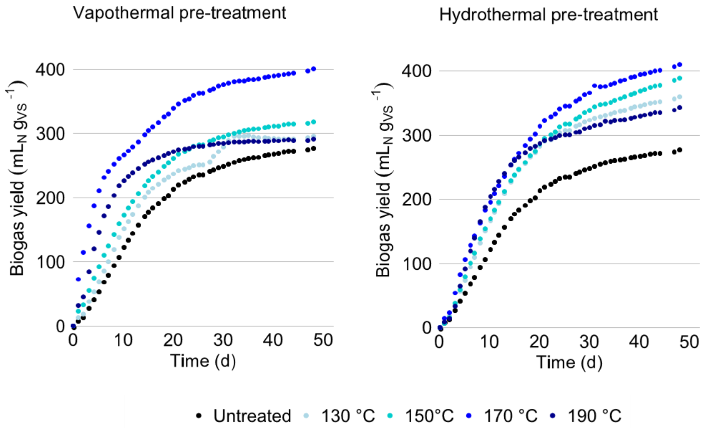
170 °C | Narrow temperature optimum

+ 18 % | Lower mass loss | Lower energy consumption

- Hydrothermal pretreatment

170 °C | Broader temperature optimum

+ 6 % | Higher cellulose retention



Effect on biogas production

Effect on composition

Energetic estimation

→ Vapothermal pre-treatment can yield competitive results while comprising lower mass loss and energy consumption

Thank you for your attention!

Questions?

TUHH IUE

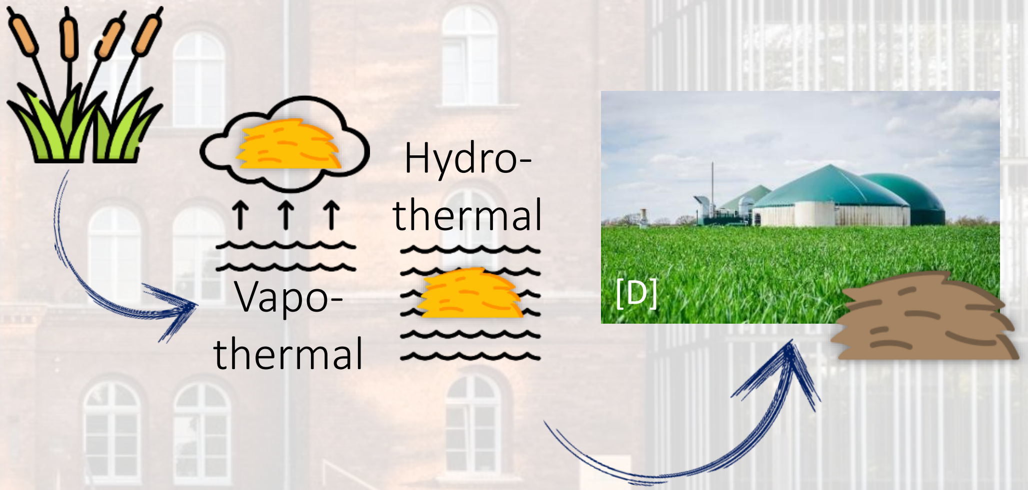
Jana Schultz M.Sc.
Technische Universität Hamburg (TUHH)
Institut für Umwelttechnik und Energiewirtschaft (IUE)
Eißendorfer Str. 40, D-21073 Hamburg
+49 40 42878 4747 | jana.schultz@tuhh.de | www.tuhh.de/iue

Thank you for your attention!

Questions?

Vapothermal and hydrothermal pretreatment

to enhance the anaerobic digestibility of recalcitrant substrates



SPONSORED BY THE
Federal Ministry of Education and Research

Project:

ReMe-diation
Resilient Mediterranean

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

Jana Schultz M.Sc.
Technische Universität Hamburg (TUHH)
Institut für Umwelttechnik und Energiewirtschaft (IUE)
Eißendorfer Str. 40, D-21073 Hamburg
+49 40 42878 4747 | jana.schultz@tuhh.de | www.tuhh.de/iue

References

[1] Schultz, J., Scherzinger, M., Steinbrecher, T., Isci, A., Kaltschmitt, M., 2025. Influence of vapothermal and hydrothermal pre-treatment on anaeroobic degradability of lignocellulosic biomass. Bioresource Technology, 132329. https://doi.org/10.1016/j.biortech.2025.132329.

[2] Verein Deutscher Ingenieure, 2016. VDI 4630. Fermentation of organic materials - Characterisation of the substrate, sampling, collection of material data, fermentation tests. Beuth, Berlin 13.030.30, 27.190.

[3] Velázquez-Martí, B., Meneses-Quelal, O.W., Gaibor-Chavez, J., Nino-Ruiz, Z., 2019. Review of Mathematical Models for the Anaerobic Digestion Process. In: Rajesh Banu, J. (Ed.), Anaerobic Digestion. IntechOpen.

[4] Deutsches Institut für Normung e. V., 2015. DIN EN ISO 18134. Solid biofuels – Determination of moisture content. Deutsches Institut für Normung e. V

[5] Deutsches Institut für Normung e. V., 2012. DIN EN 15935. Sludge, treated biowaste, soil and waste - Sludge, Sludge, treated biowaste, soil and waste - Determination of loss on ignition loss on ignition. Deutsches Institut für Normung e. V.

[6] Lizasoain, J., Rinc´on, M., Theuretzbacher, F., Enguídanos, R., Nielsen, P.J., Potthast, A., Zweckmair, T., Gronauer, A., Bauer, A., 2016. Biogas production from reed biomass: Effect of pretreatment using different steam explosion conditions. Biomass and Bioenergy 95, 84–91. https://doi.org/10.1016/j.biombioe.2016.09.021.

[7] Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D., Crocker, D., 2008. Determination of Structural Carbohydrates and Lignin in Biomass: Laboratory Analytical procedure (LAP). NREL/TP-510-42618. National Renewable Energy Laboratory.

Fotos and graphics

[A] https://www.naturescape.co.uk/product/common-reed/

[B] https://www.lehm-laden.de/en_GB/shop/reed-straw-coarse-60-litres-13728#attr=

[C] Schultz, J.

[D] https://www.agrarheute.com/energie/strom/wirtschaftsausschuss-befuerwortet-verbesserungen-fuer-bioenergie-549925

[E] https://www.fertilizer-machines.com/solution/fertilizer-technology/biogas-digestate-compost-fertilizer-produ.html