Conclusions from 10 years research for pretreatment of lignocellulosic substrates for biogas production

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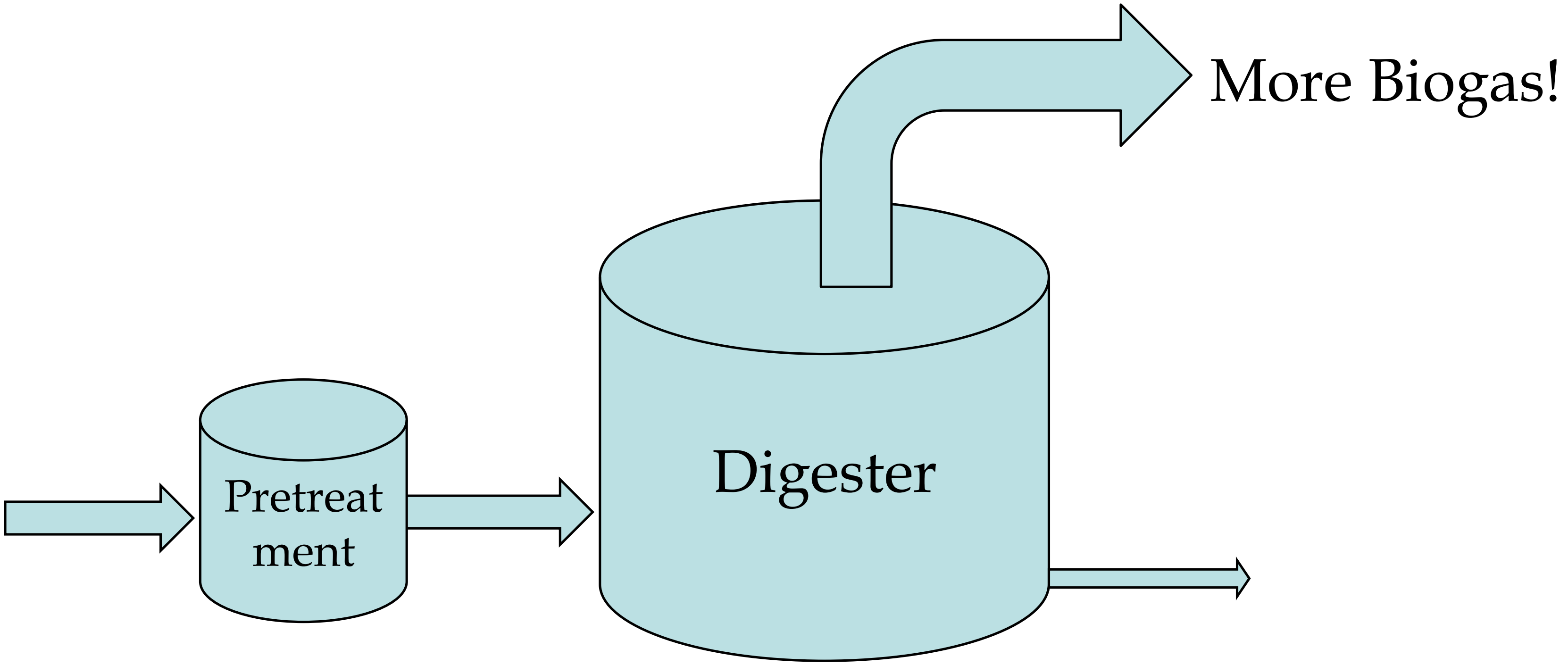
Pre-treatment …

Pretreatment for increased biogas production…



- Improved production of biogas
- Improved flexibility
- Economical benefits

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Pre-treatment of lignocellulosic biomass

- Physical methods
  - Milling
  - Irradiation

- Chemical and physicochemical methods
  - Thermal treatment
  - Steamexplosion
  - Addition of chemicals
    - alkaline
    - acid
  - Organic solvents

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Ref: MJ.Taherzadeh, K. Karimi Int. J. Mol. Sci. 2008

Pre-treatment with steam explosion

Ref: SGC 247 report 2012

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Paper tube residuals

Methane production from untreated paper:

0.23 Nm^3 CH_4 /kg VS

(≈ 200 Nm^3 CH_4 /ton dry paper)

The theoretical yield is:

≈ **0.5 Nm^3/kg VS**

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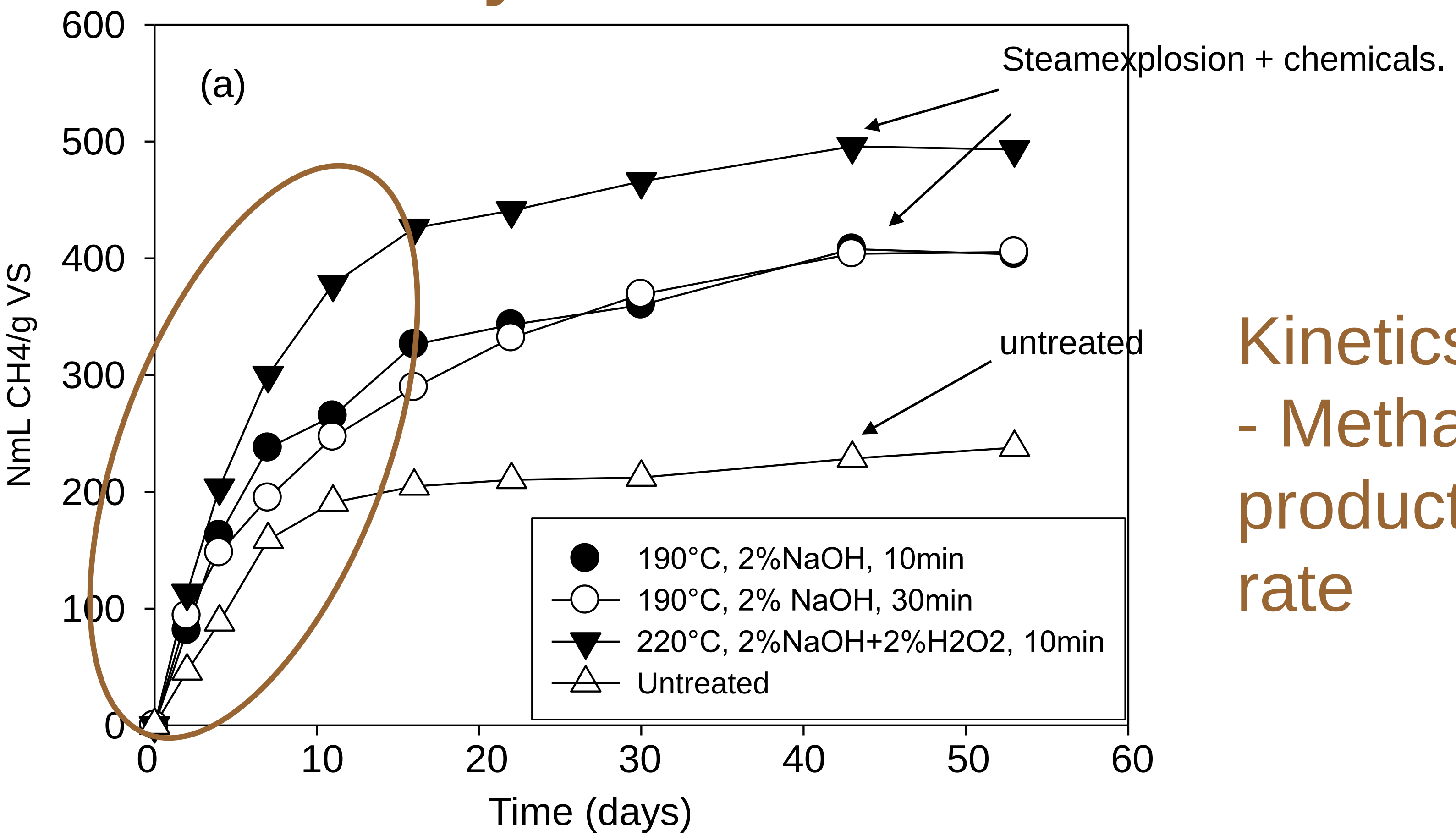
Methane yield



Kinetics;
- Methane production rate

Ref: A.Teghammar et al. Bioresource Technology 2010

- Treated samples:
  - ✓ More methane
  - ✓ Faster degradation!

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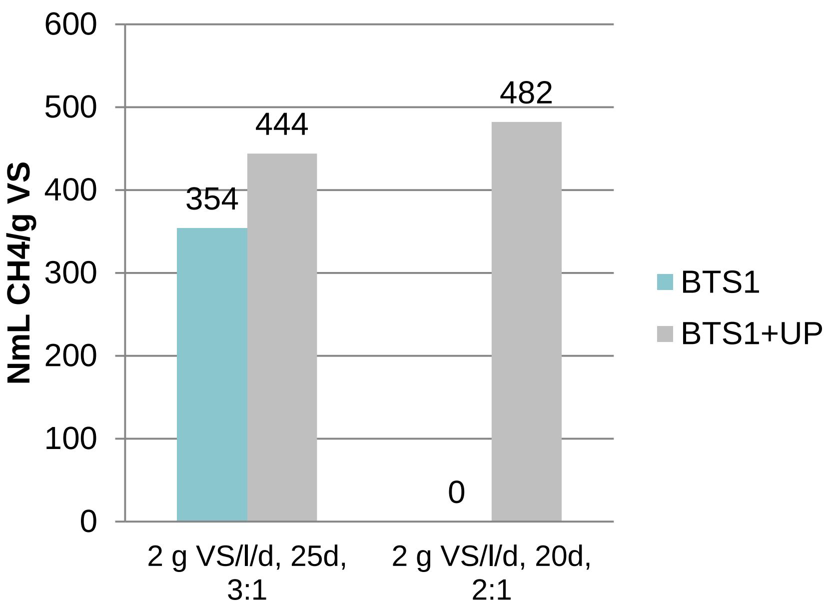
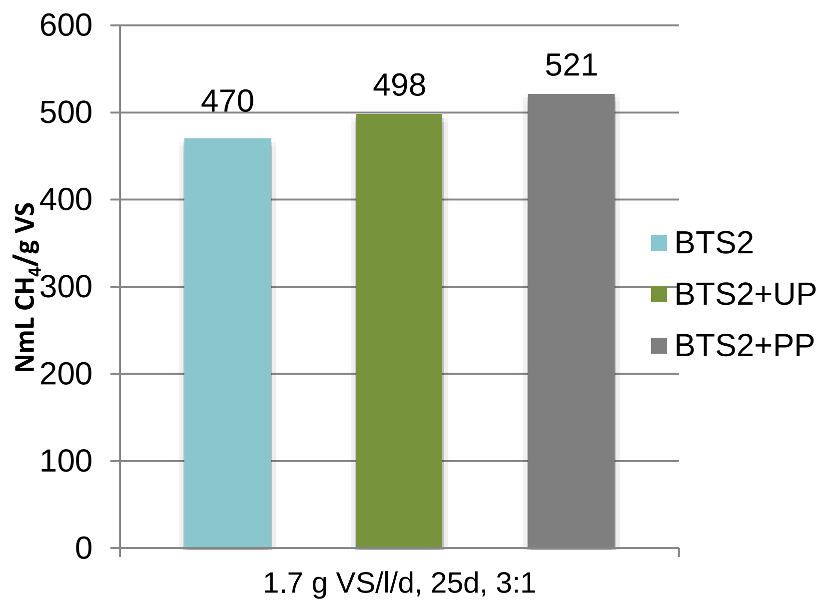
Paper tube residuals in continuous co-digestion





- BTS1 – unstable substrate
- Stabilizing effects
- Synergistic effects

- BTS2 – stable substrate
- Improved production after pretreatment
- Synergistic effects

Ref: A.Teghammar et al. Energy & Fuels 2013

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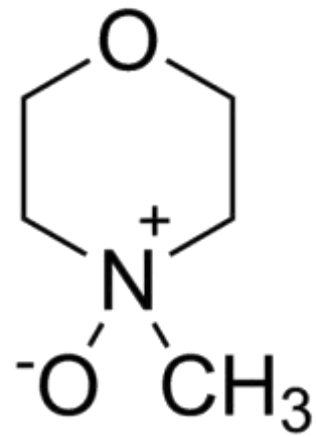
Dissolving cellulose by a chemical treatment

- **N-Methylmorpholine N-oxide (NMMO):**



  - A cyclic organic amine oxide with a high polar N-O group
  - Is able to break the hydrogen bonding network in cellulose

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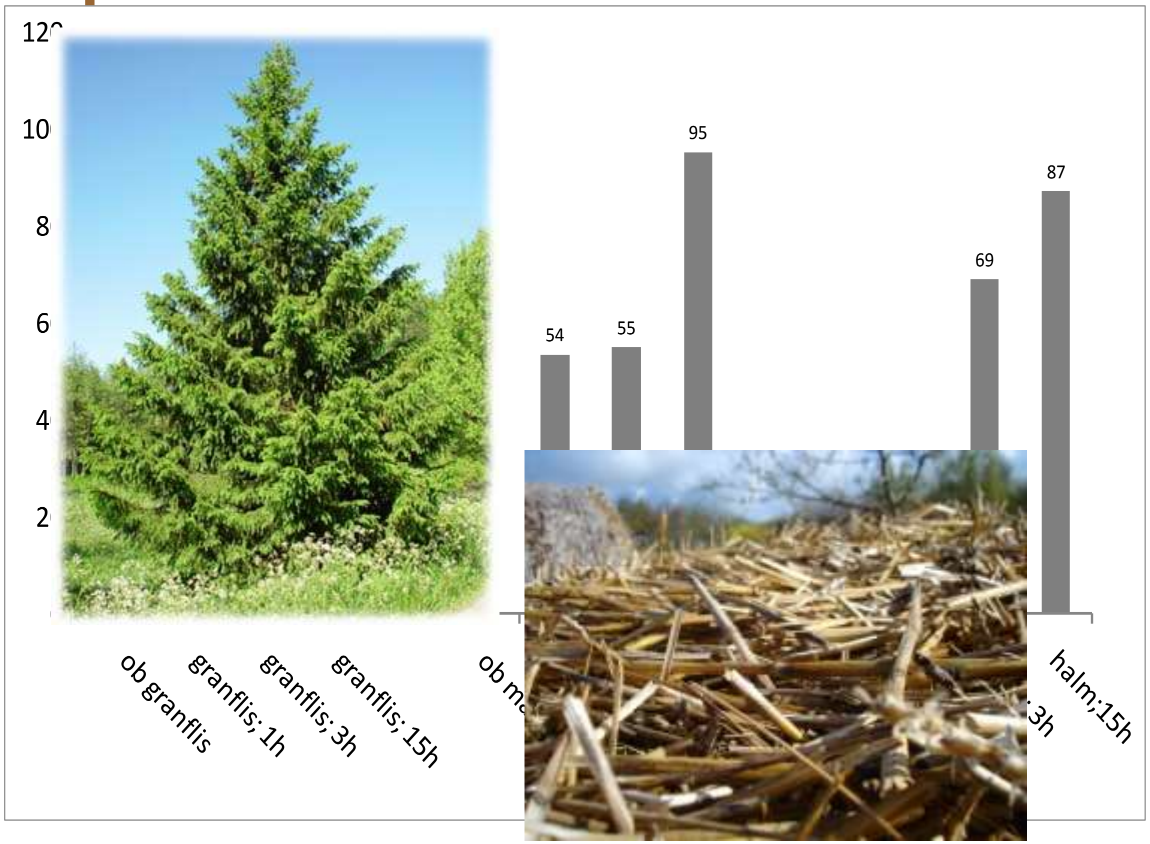
NMMO – treatment of spruce and straw



The production of methane expressed as procentage of the theoretical maximum

- Industrial use of NMMO
- Mild conditions
- Can be recycled after the treatment

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Ref: A.Teghammar et al, Biomass and Bioenergy, 2012

Achievements …

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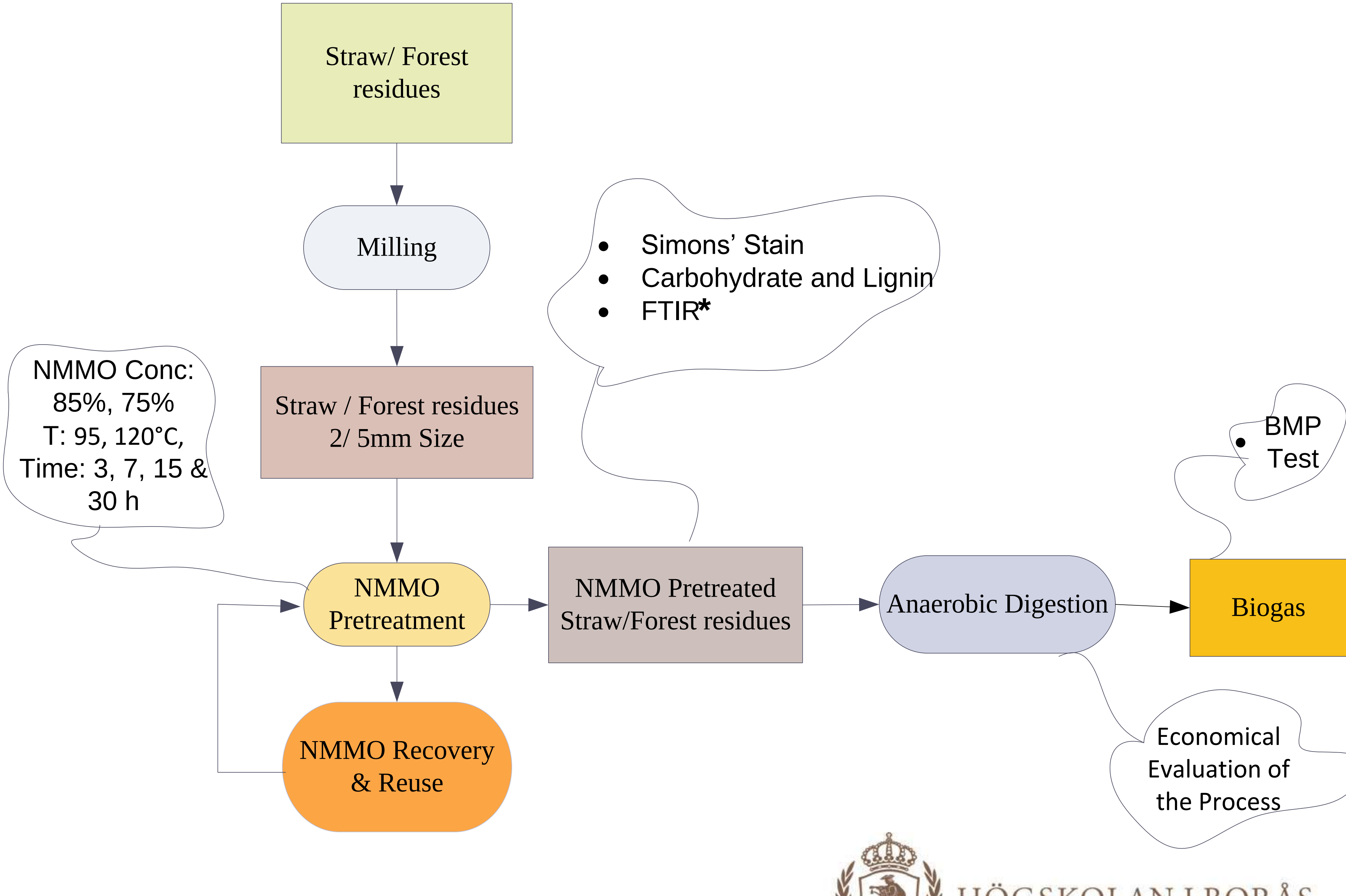
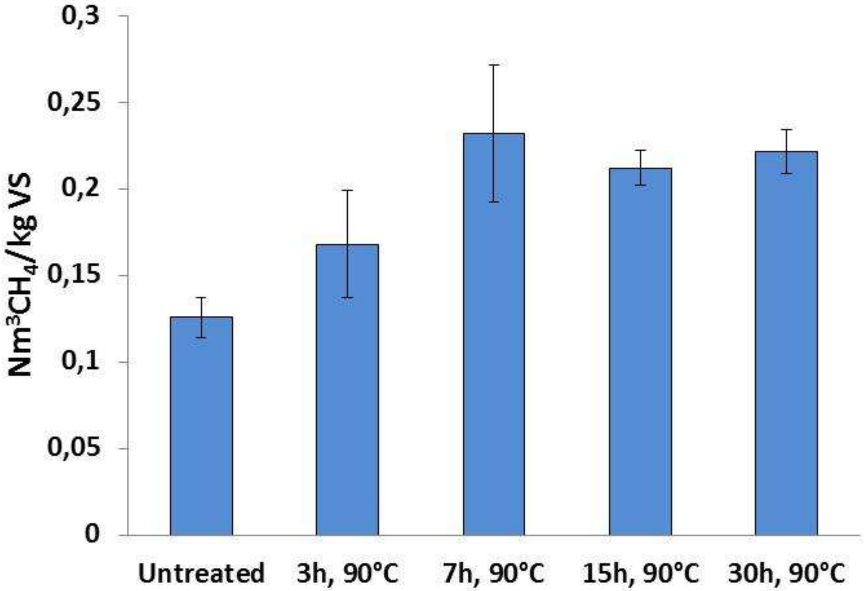


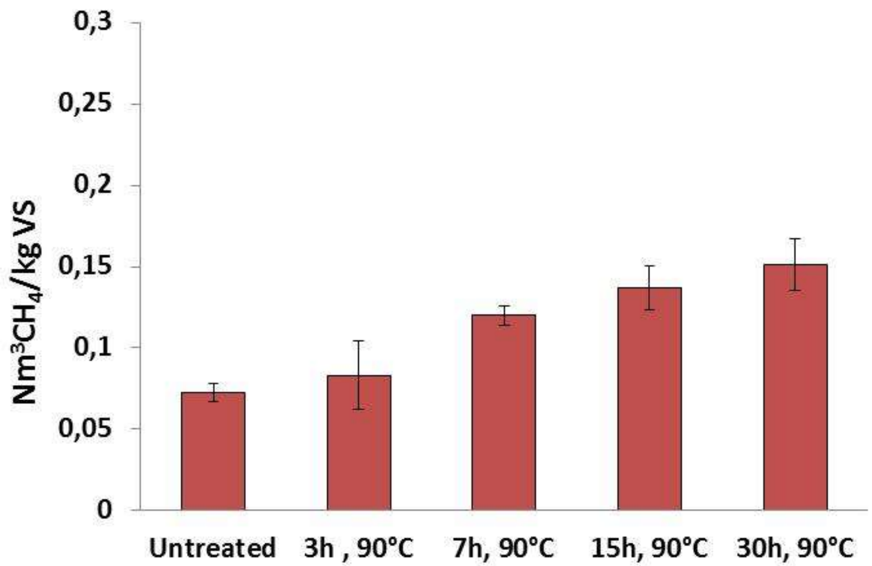
*Fourier transform infrared spectroscopy

Improved digestion after **NMMO** pretreatment!

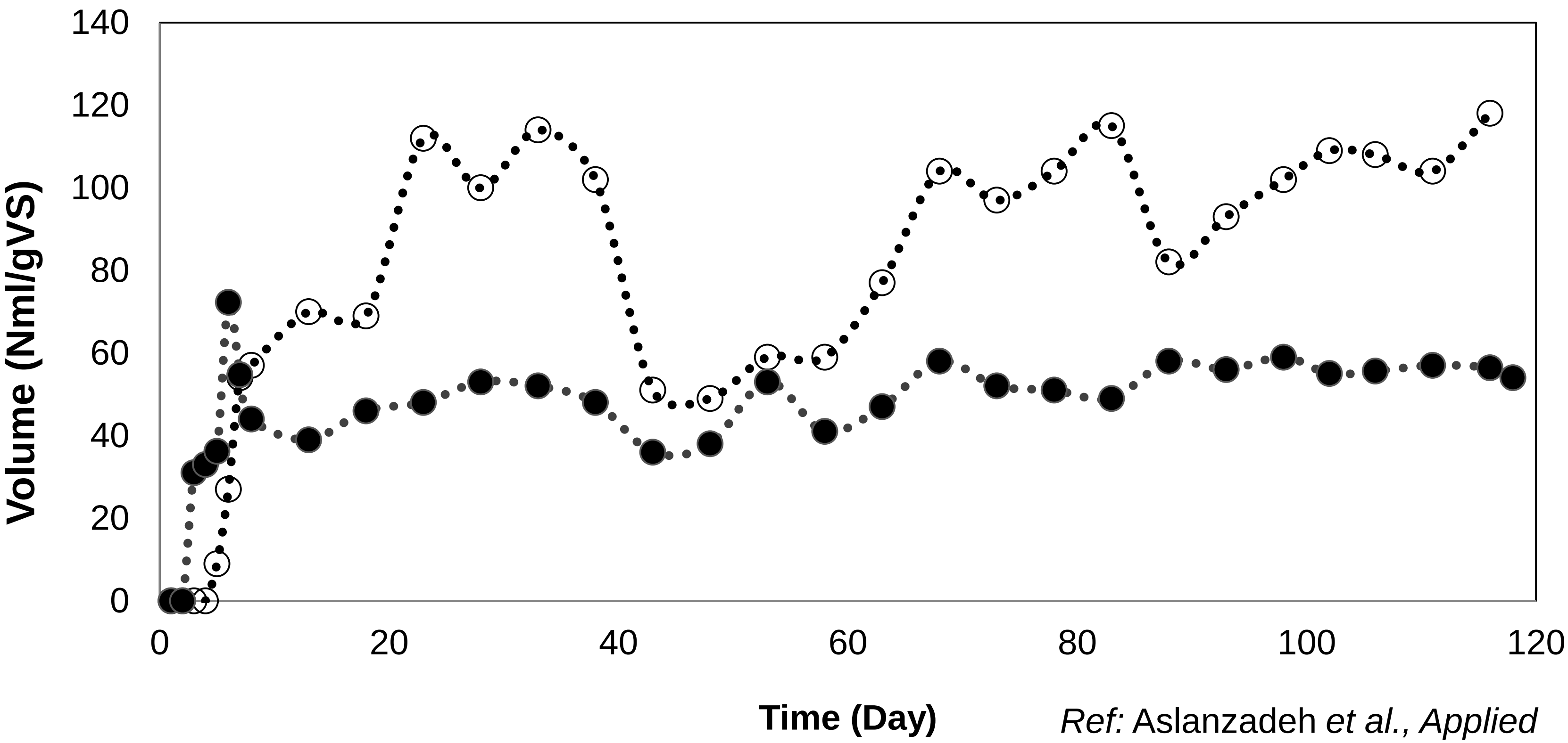
Barley Straw



Forest residues



Improved digestion after **NMMO** pretreatment!



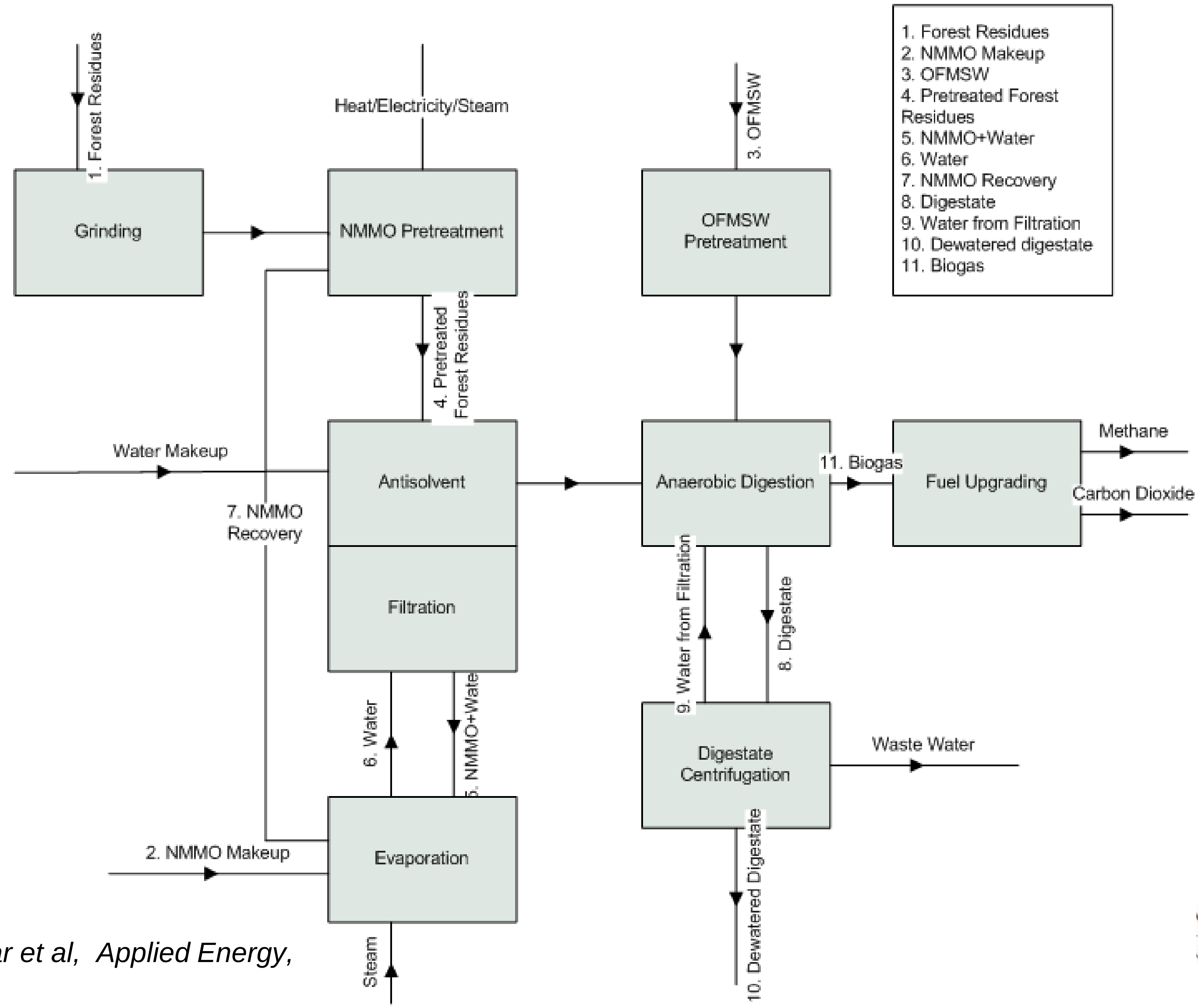
Ref: Aslanzadeh *et al.*, *Applied Biochemistry and Biotechnology, 2014*

Specific gas production from untreated forest residues (•…) and NMMO- treated forest residues (o…)

Challenges …

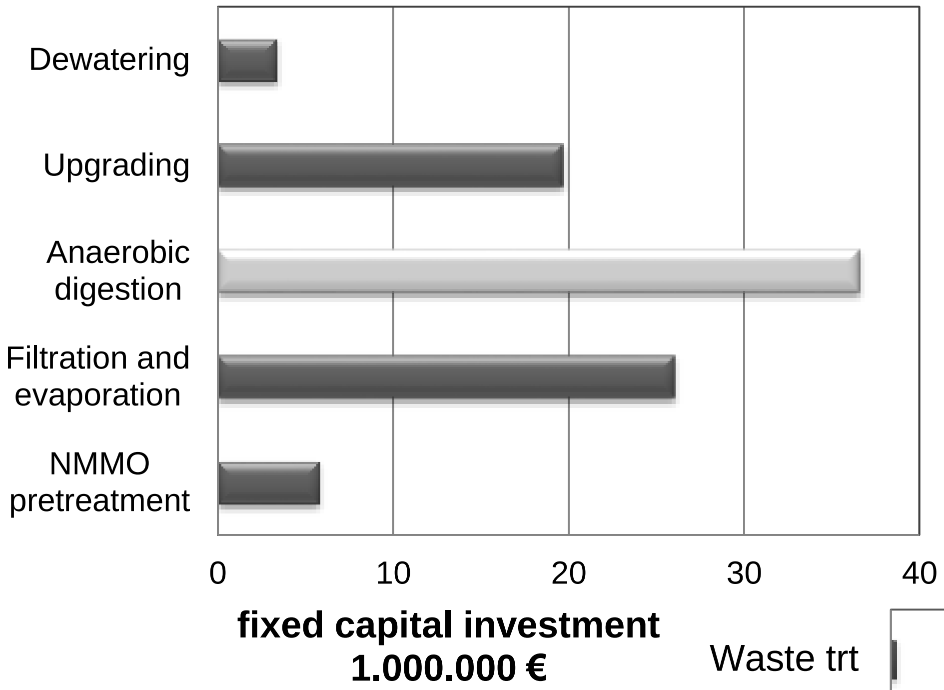
Economic evaluation – process design

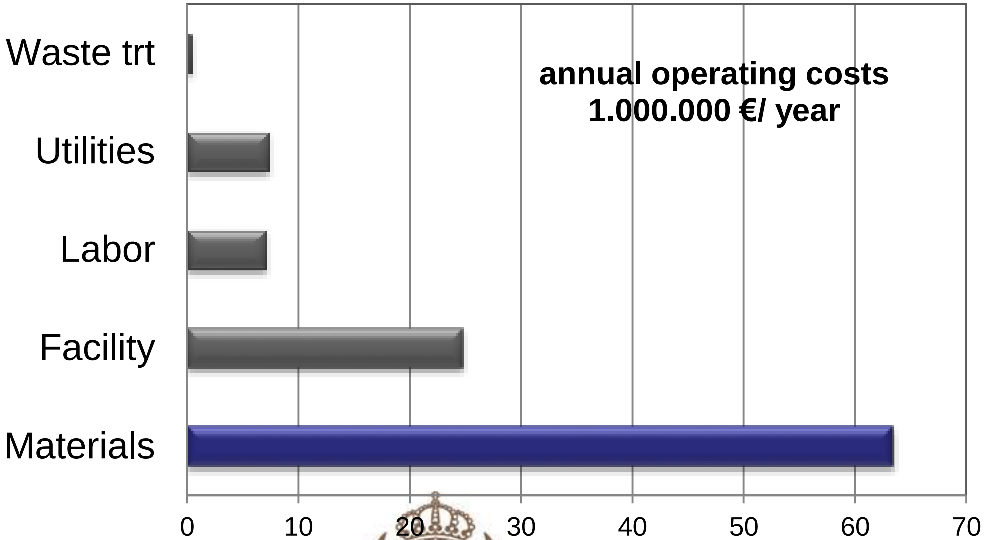
NMMO-pretreated forest residues in co-digestion with municipal solid waste



Ref: A.Teghammar et al, Applied Energy, 2014

Economic evaluation





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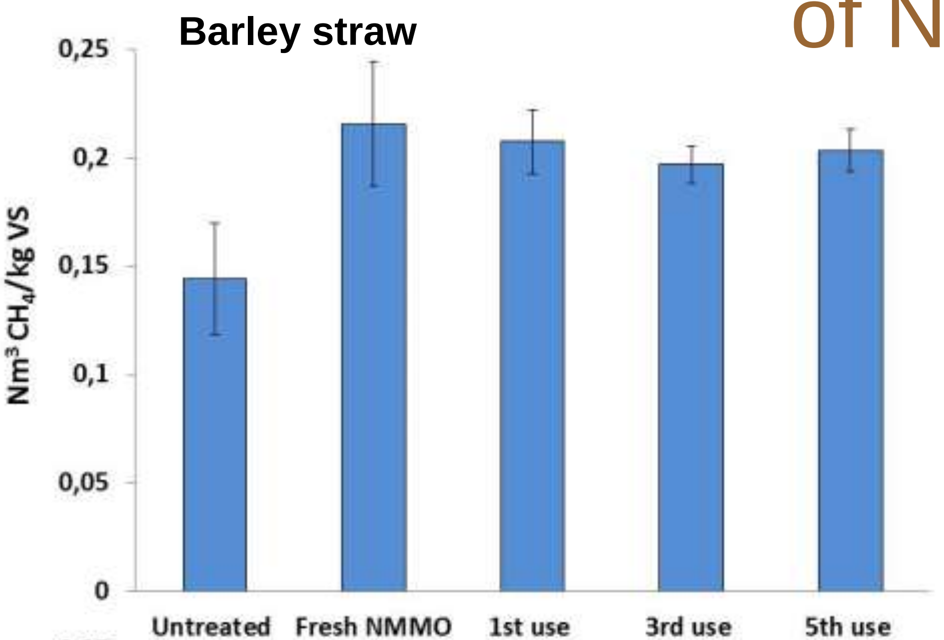
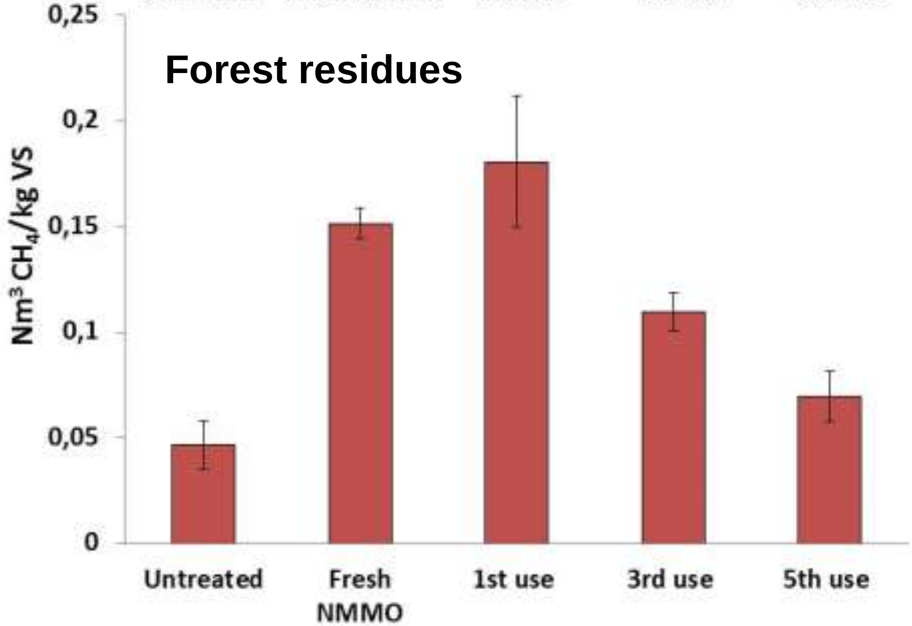
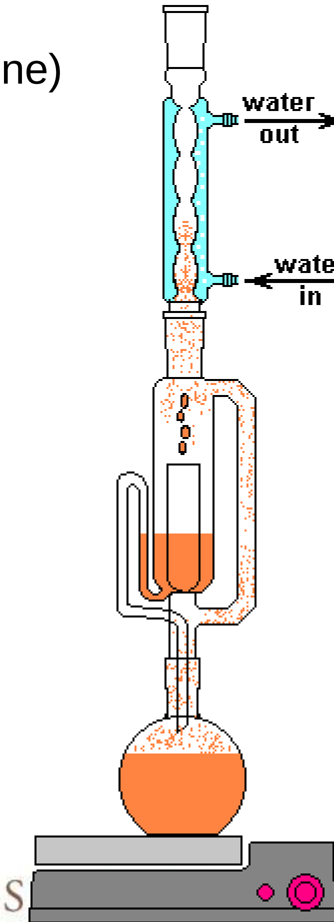
Ref: Teghammar *et al.*, *Applied Energy*, 2014

Methane production after Recovery and Reuse of NMMO



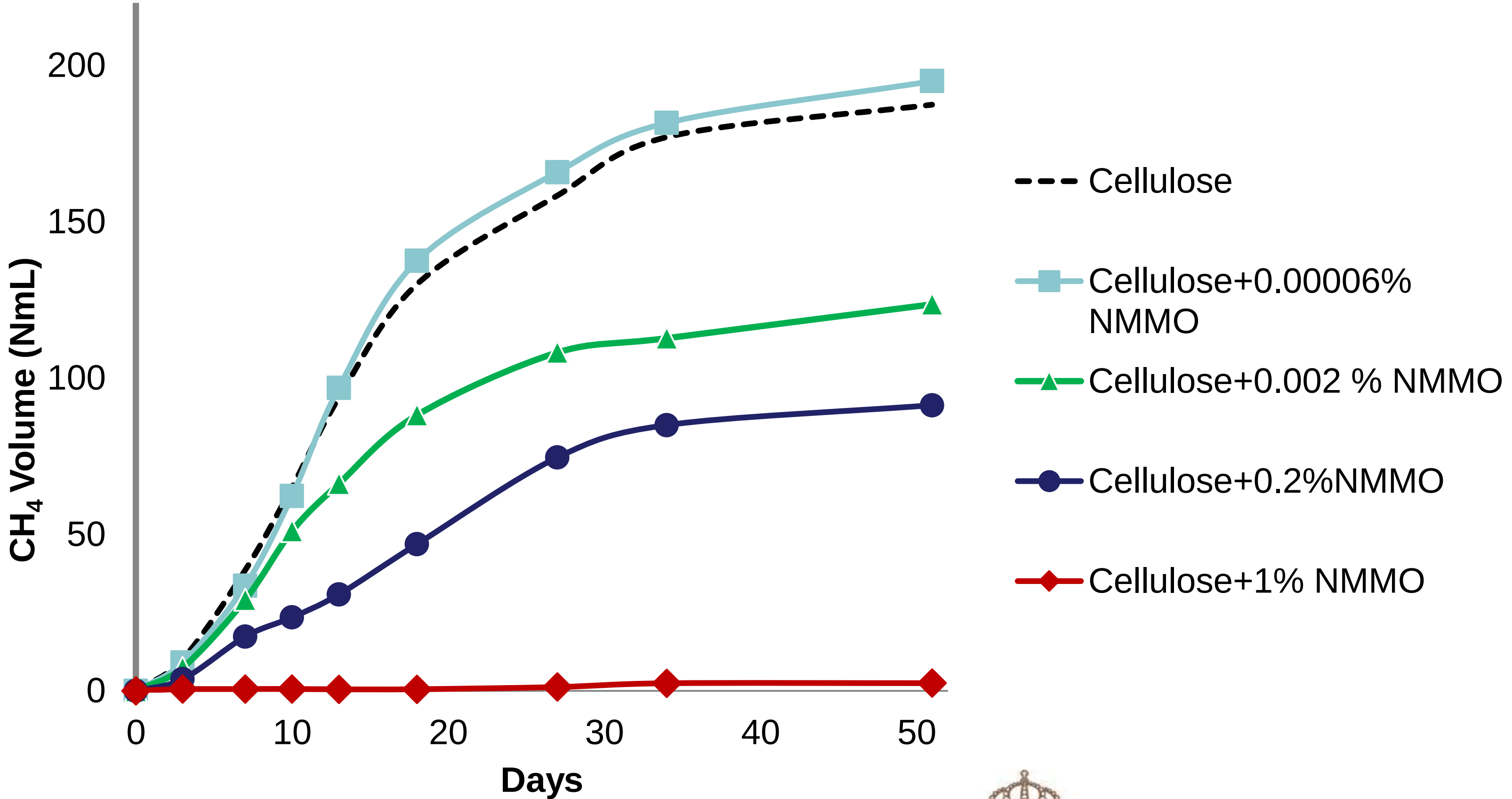


Softwoods:
- Resin acids: 40-45% of extractives
- Fatty acids: 40-60%
- Monoterpenes (turpentine)
- Phenolics



Ref: M.M. Kabir et al, Bioresource Technology, 2014

Inhibitory effect of the **NMMO** on **AD !**



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Ref: Kabir *et al.*, *BioResources*, 2013

Organosolv Pretreatment

Solvents applied
Ethanol
Ethanol & Acetic acid
Ethanol & Sulfuric acid
Methanol
Methanol & Acetic acid
Methanol & Sulfuric acid
Acetic acid
Acetic acid & Hydrochloridric acid
Acetic acid & Sulfuric acid

- Pretreatment conditions

- Forest residues- to- solvent ratio of 1:10, aqueous organic solvents (50%V/V)
- Catalyst were added (1% W/W) based on dried weight of forest residues

- At 190°C for 60 minutes

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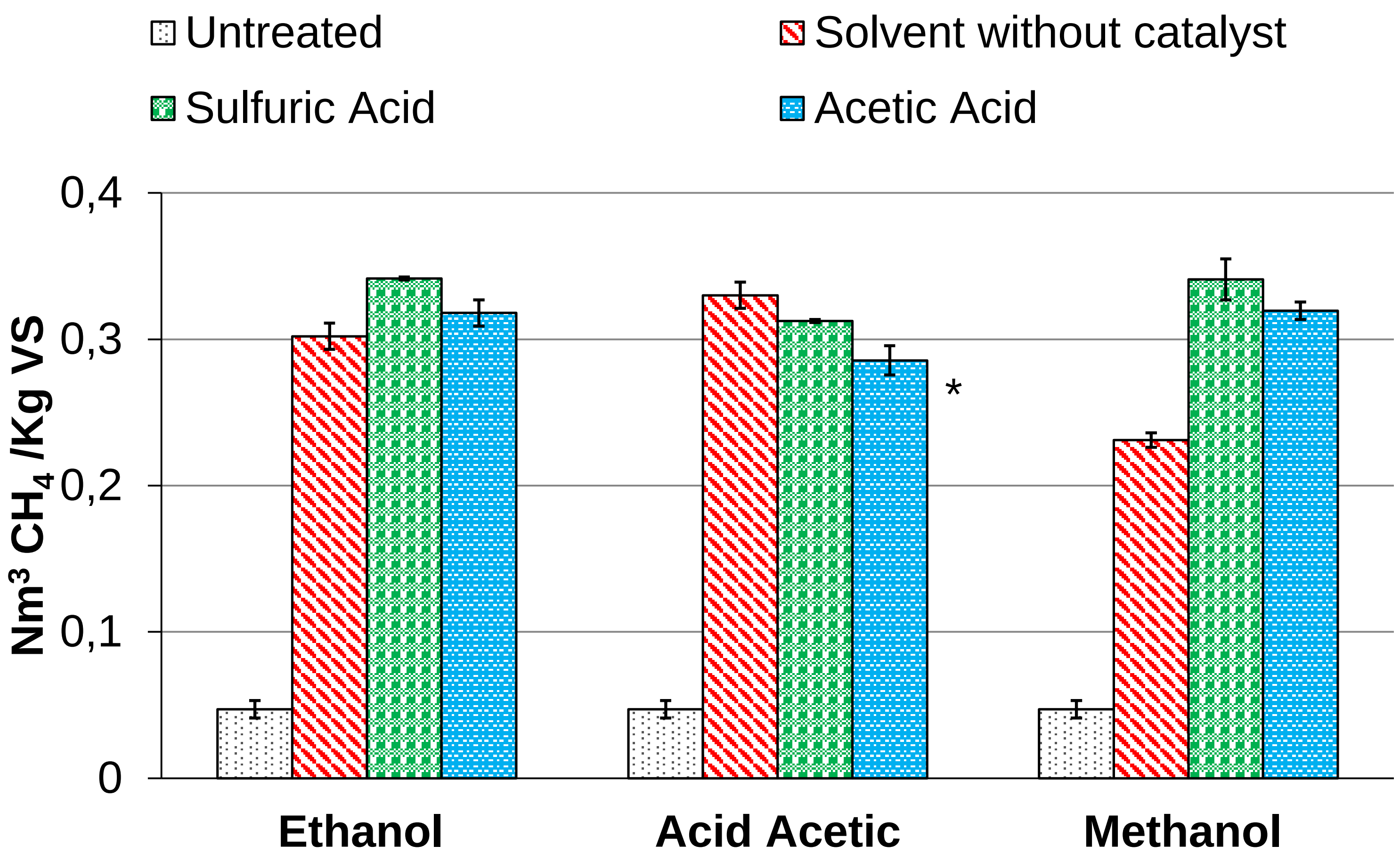
Results of BMP test



* Acetic Acid + HCl

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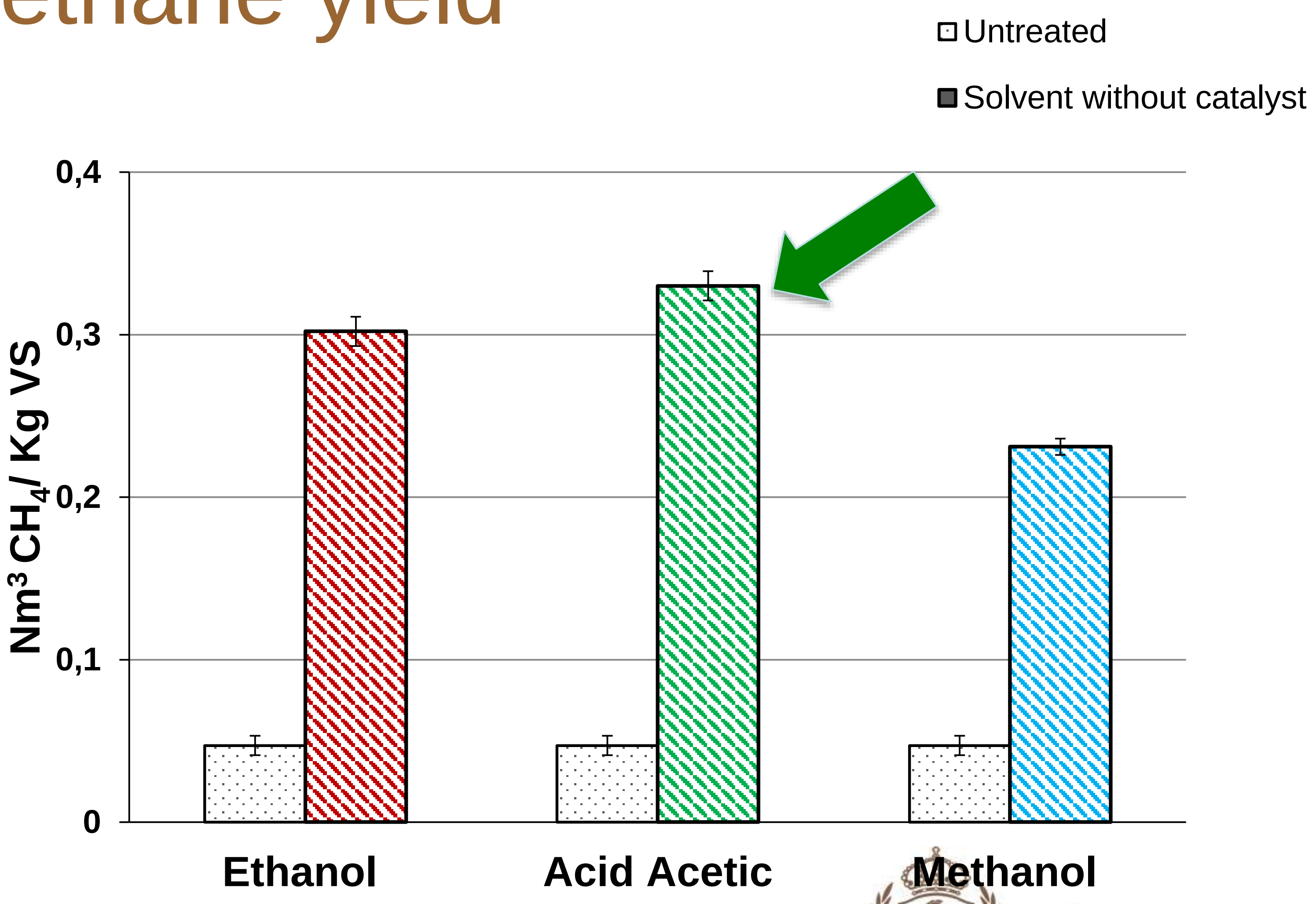
M.M. Kabir et al. ***Bioresource Technology, 2015***

Techno-economical evaluation

- Criteria for the feasibility of an industrial scale process

- ✓ Increase in digestibility of the forest residues after the pretreatment
- ✓ Effective recovery of the solvent
- ✓ Low-cost solvents
- ✓ The solvent itself should not be a source of inhibition in the AD system

Effect of the pretreatment on the methane yield



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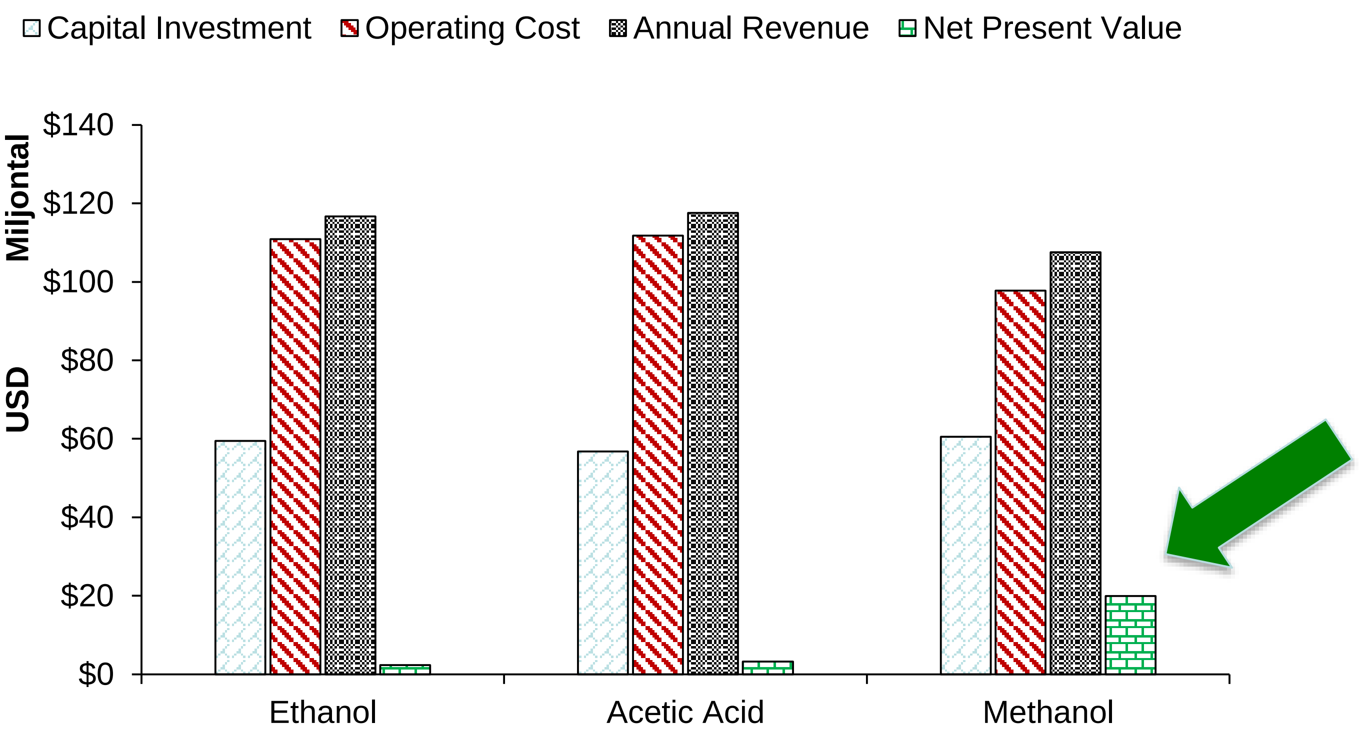
Effect of pretreatment on the economy of the process



- The base case is an annual capacity of 20,000 tons of FR/year
- Economical evaluation on the pretreatment of FR with either Ethanol, Methanol or Acetic acid without considering the addition of catalysts was performed

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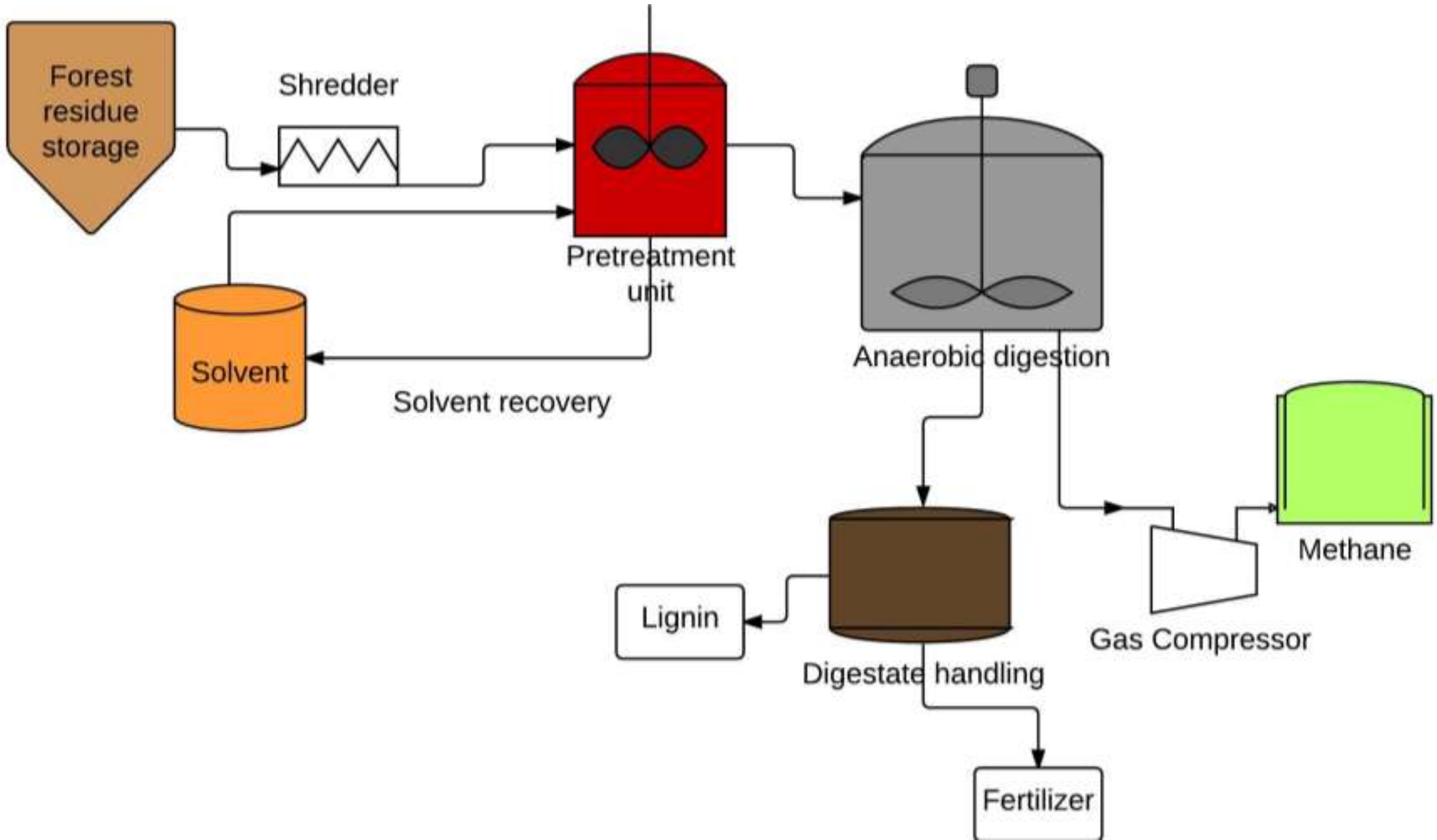
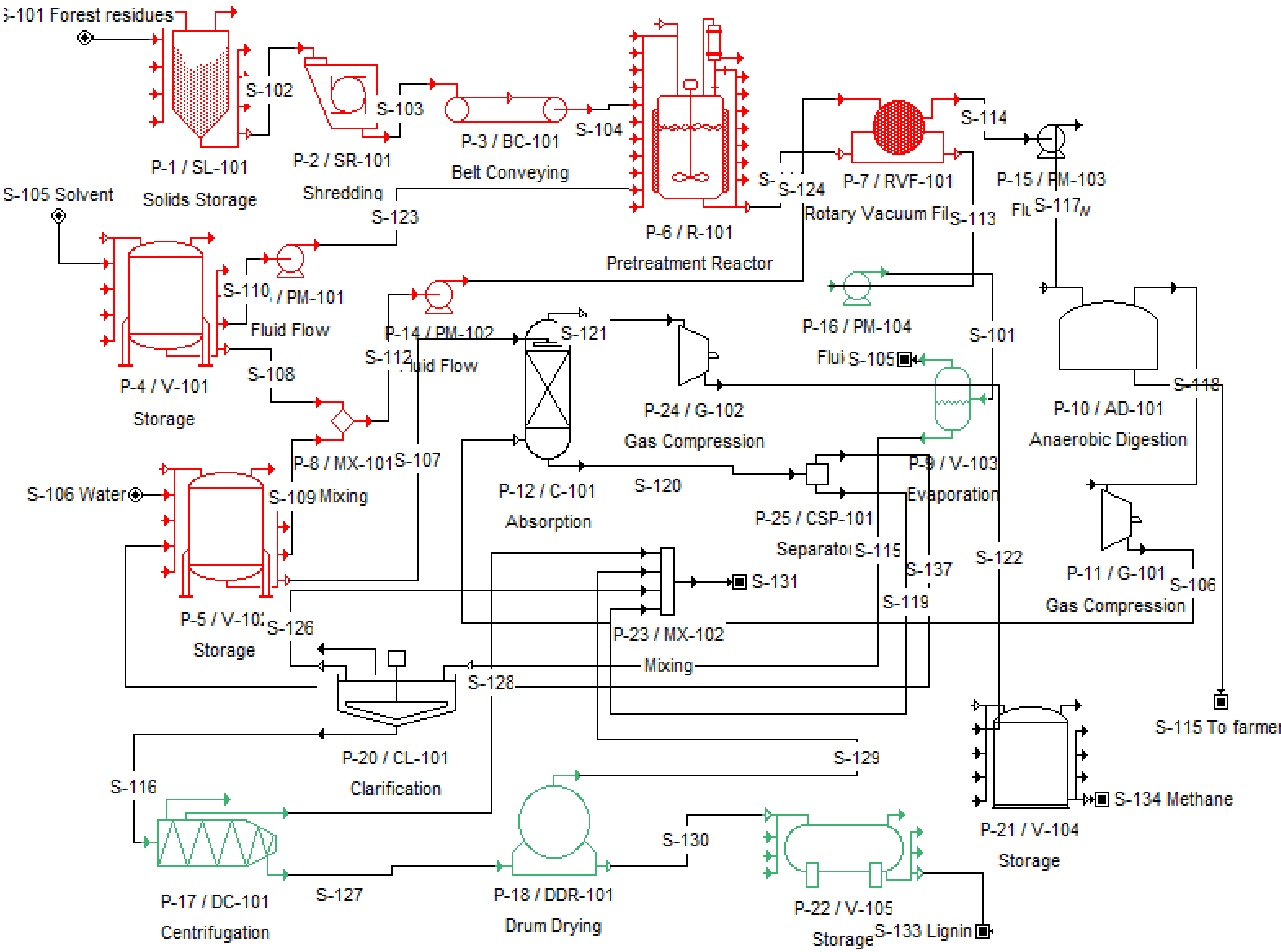
Process Flow Diagram



Process design



List of **assumptions** for the economical evaluation

Material	Assumption
Annual processing capacity	20,000 tons fresh matter
Interest rate	7%
Lifetime of the plant	15 years
Taxes	33%
Selling price of Methane	1.81 USD/L (gasoline equivalent)
Lignin	3.0 USD/kg
Cost of Forest residues	0.4 USD/kg
Ethanol	0.75 USD/kg
Acetic acid	0.70 USD/kg
Methanol	**0.30 USD/kg**

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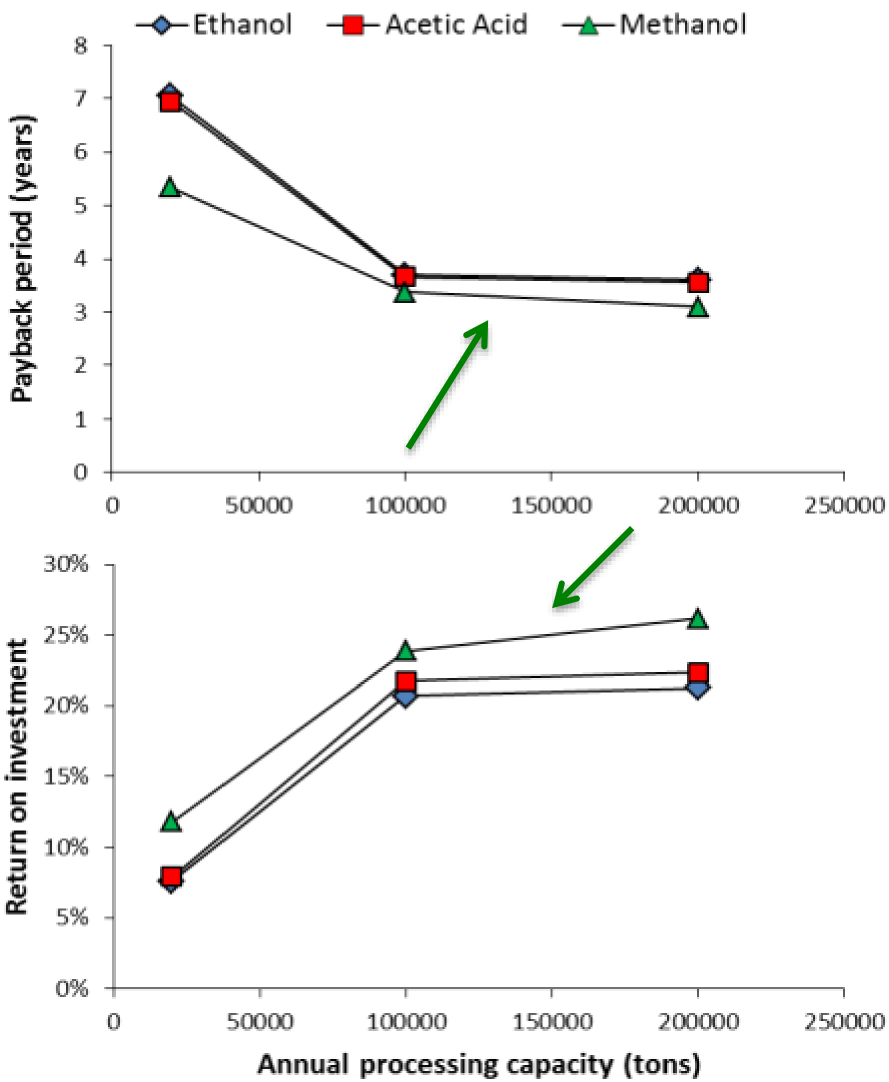
Sensitivity analysis



- The capacities considered were 10,000, 100,000, and 200,000 tons/year.
- The bigger the plant, the higher the profit is, however, the cost of transportation also increased exponentially
- Minimum of 20,000 tons/year capacity is required for the plant to be profitable.

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M.M. Kabir et al. ***Bioresource Technology, 2015***

Thank you! ☺

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- PhD
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- Karthik Rajendran

PhD students, UB

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- Biogas from lignocellulosic biomass
  - Difficult-to-digest materials
  - Pretreatment
    - Higher methane yield, higher degradation rate
    - Achievements and challenges
  - Techno-economic evaluation
    - Costs for operation are sets against the incomes from the products
    - Not always those pretreatment conditions which results in the best performance in the laboratory are the most feasible ones in the economical point of view

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