Life-Cycle Assessment of Cellulosic Biofuel Production with Ionic Liquid Pretreatment

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Overview

• Advanced biofuels research @ JBEI

• Ionic liquid (IL) pretreatment

• IL Process Configurations / Variations
  – Past, Present, and Future
  – Biocompatible ILs, Protic/Neutral ILs

• LCA results
  – Greenhouse gas emissions & Water intensity

• Conclusions
Lignocellulosic Biofuels:
Fuels derived from the solar energy stored in plants/biomass

Efficient, economical and scalable technologies at each stage are necessary

Focus is on drop-in biofuels
Ionic Liquid (IL) Pretreatment

• **What are ILs?**
  – Essentially, salts in liquid phase at room temperature

• **Why ILs?**
  – Effective in reducing biomass recalcitrance
  – Facilitates efficient hydrolysis
  – Numerous options (cations / anions) → Tunable properties
  – Feedstock agnostic
  – Facilitate operation at milder conditions (low Temp etc.)
  – Lignin valorization possibilities

• **@ JBEI**
  – IL pretreatment technologies are being developed
  – With a focus on efficient, economical & scalable technologies
Process configurations (variations)

Water-wash route (traditional)

- Biomass
- IL

  Pretreatment → Hydrolysis → Fermentation → Biofuel

  IL recovery

Integrated processes (novel approach)

- Biomass
- IL

  Pretreatment → Hydrolysis → Fermentation → Biofuel

  IL recovery
Integrated High Gravity Process (iHG-Current)

Biomass

10 wt % [Ch][Lys] + 90 wt% H₂O

Pretreatment

Enzyme

HCl

Hydrolysis

Seed Batch

Operating Batch (Fed-batch)

Fermentation

S/L separation (Centrifugation)

IL recycle

IL regeneration

No dilution & Fed-batch operation

Sols (to boiler)

Ultrafiltration

Solids (to boiler)

Product recovery

Water (to WWT)

Distillation

Biofuel

Protic IL (PIL) process (iHG-Projected)

Biomass → Pretreat → Pre-Hydrolysis (2 MPa) → SSF (2 MPa) → S/L separation (Centrifugation)

Enzyme

Aq. [Ch][Lys] → Enzyme → IL_{recycle}

Solids (to boiler)

Ultrafiltration

Water (to WWT)

Product Recovery

Distillation

Ethanol

GHG footprint: [Ch][Lys] Production

- Lysine Production (China)
- Lysine Production (US)

Contributors:
- Corn Farming
- Petroleum Products
- Electricity
- Transportation
- Facility Direct Emissions
- Chemicals and Fertilizers
- Other
GHG footprint: Biofuel Production

Gasoline Baseline = 93 g CO$_2$e/MJ
Water intensity: Biofuel Production

Contributors:
- Petroleum Products
- Upstream Electricity
- Electricity Credits
- Chemicals and Fertilizers
- Facility Direct Consumption/Withdrawal

Gasoline Baseline
Sensitivity Analysis

- Yield (± 10%)
- Electricity (±0.2 kWh)
- IL recovery (±10%)
- Enzyme (±10%)
- H2SO4 vs. HCl for pH
- Potential NaOH required

Net Change in Greenhouse Gas Emissions (g CO₂e/MJ)

Net Change in Water Consumption (Liters/MJ)
Concluding remarks

• Ionic liquid (IL) pretreatment facilitates efficient hydrolysis

• Life-cycle assessment has been performed (for the first-time)

• GHG emissions:
  – Water-wash (traditional) route is water/energy intensive → high GHG footprint
  – iHG processes have the potential to reduce GHG footprint significantly

• Water intensity (both consumption & withdrawal) can be comparable to other pretreatment technologies

• Sensitivity analysis highlights the potential impact of key yet uncertain parameters
Thank You!

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The role of biocompatible ILs (BILs)

• BILs eliminate the need for water-wash and/or other separation operations prior to hydrolysis/fermentation
  – Reduced water-usage and therefore lower costs (by eliminating or minimizing the need for subsequent IL dehydration)
  – Elimination of glucan/xylan losses in water-washing step

• Possibility to be used in aqueous form (e.g., 10% IL, w/w)
  – Reduced usage of IL
  – Enables higher solids loading
  – No further dilution required prior to hydrolysis and fermentation
Protic ILs (PILs)

- No pH adjustment during hydrolysis/fermentation
  - No mineral acids are used
  - No Need for IL regeneration
    - Improved recovery efficiency and reduced recovery costs

Sun J., Konda N.V.S.N.M. et al., (2017) Green Chemistry (accepted)