Lignocellulosic Biomass Valorisation using Deep Eutectic Solvents for Sustainable Biorefineries

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INTRODUCTION

Lignocellulosic biomass (LBM) represents a renewable, widespread and low-cost source which can potentially be converted to fine chemicals and bio-fuels.

30-40% of the total production costs accounts for the feedstock cost.

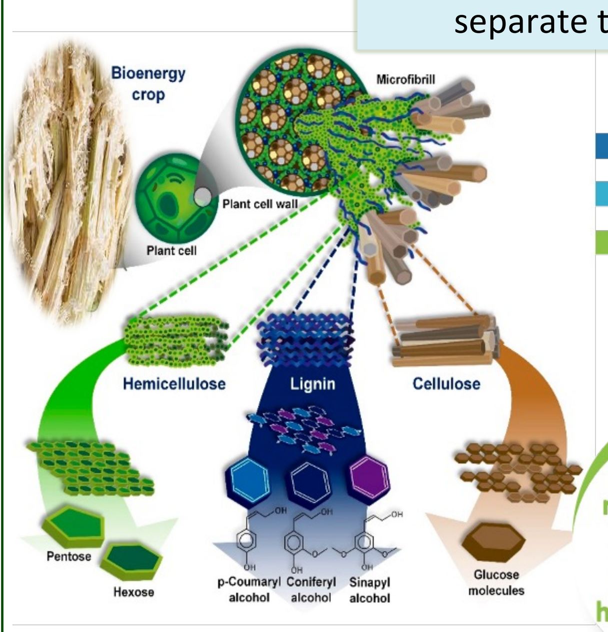
Sources of Agricultural residue	Annual production (million tons)
Barley Straw	51.3
Corn Stover/ Straw	376.8
Rice Straw	657.5
Wheat Straw	472.2
Sugarcane Bagasse	1044.8

Source: Y.Y. Tye et al. Renewable and Sustainable Energy Reviews 60 (2016) 155–172

Feedstock that is available throughout the year and at low cost is beneficial.

Pre-treatment: Process for depolymerising biomass to separate the carbohydrate polymers from lignin

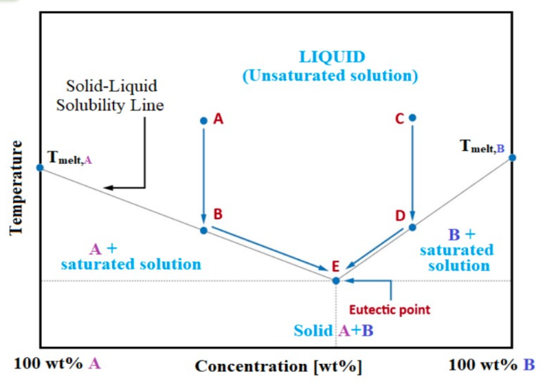
Deep Eutectic Solvents (DESs)

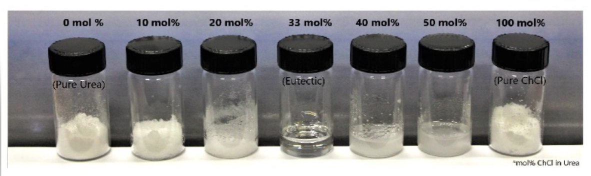


Reduces recalcitrance formed by lignin and hemicellulose

Reduces the degree of polymerization of cellulose

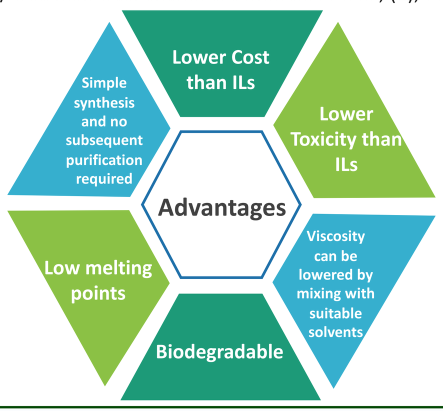
Most energy intensive and expensive step





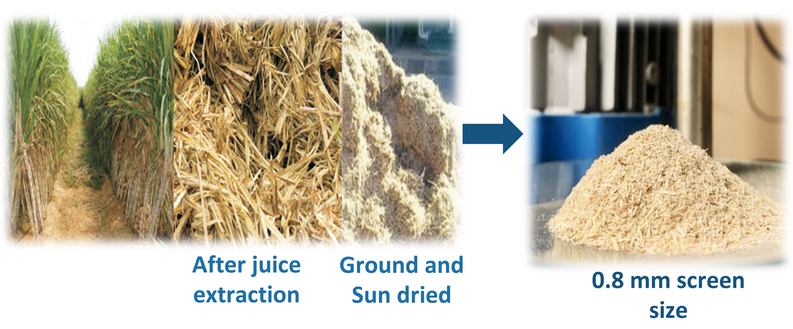
Abbott, A. P., Capper, G., Davies, D. L., Rasheed, R. K., & Tambyrajah, V. (2003). Novel solvent properties of choline chloride/urea mixtures. *Chemical communications*, (1), 70-71.

- DESs are greener alternatives to ionic liquids with identical properties.
- Melting points lower than that of the individual liquid.
- Consist of hydrogen bond acceptor (HBA), commonly a quaternary ammonium salt, complexed with a hydrogen bond donor (HBD) at appropriate molar ratios.



MATERIALS AND METHODS

Preparation of Sugarcane bagasse (SB)



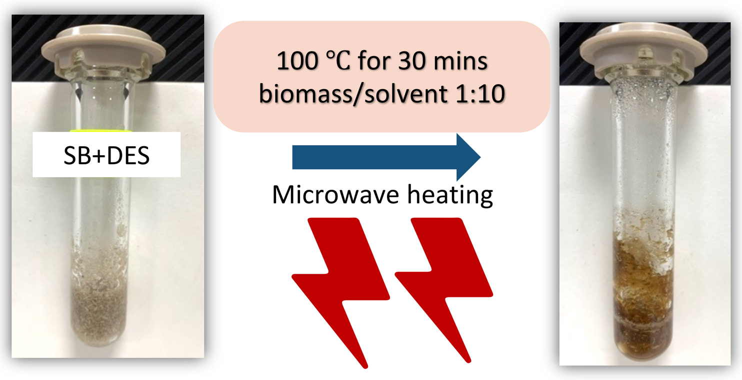
Preparation of DESs

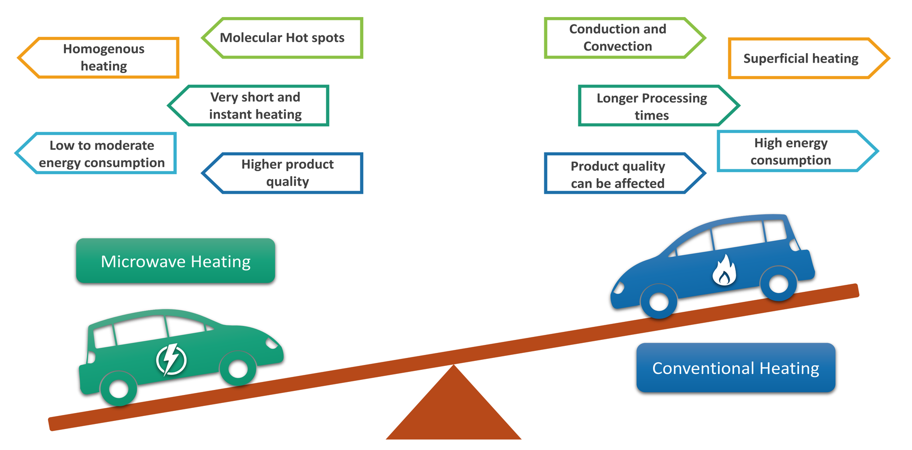
DES Components (1:2:0.016)
- Choline chloride : Ethylene Glycol: $MgCl_2.6H_20$ (CC:EG:MG)
- Choline chloride : Glycerol: $MgCl_2.6H_20$ (CC:GLY:MG)
- Choline chloride : Ehylene Glycol: $NiCl_2.6H_20$ (CC:EG:Ni)
- Choline chloride : Glycerol: $NiCl_2.6H_20$ (CC:GLY:Ni)

Process
Mixing with continuous stirring @ 70°C for 2h

Microwave assisted Pre-treatment of SB using DESs

100 °C for 30 mins
biomass/solvent 1:10

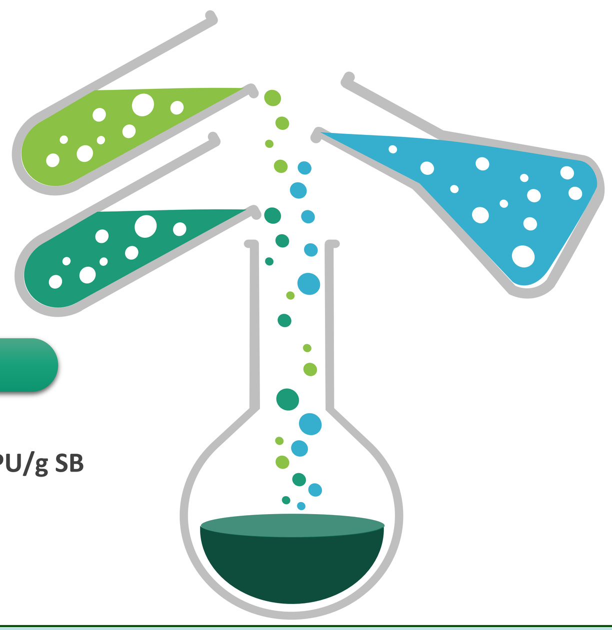




One Pot Integrated Bioethanol Production

1. DES Pre-treatment
- CC:EG:MG and CC:EG:NI
- Biomass : Solvent :: 1:10
- Conditions: 100 °C, 30 mins

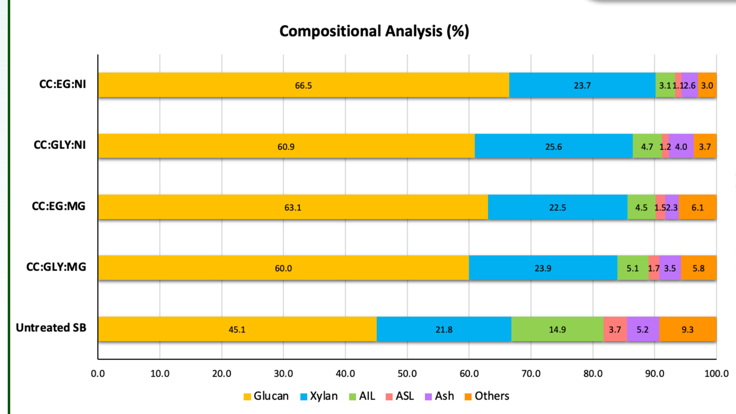
2. Saccharification
- Cellulose enzyme (
- Enzyme Loading: 10 FPU/g SB
- Conditions: 50 °C, 24 h

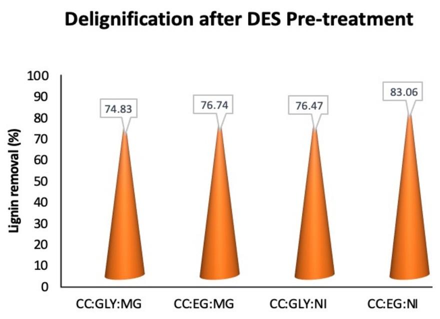


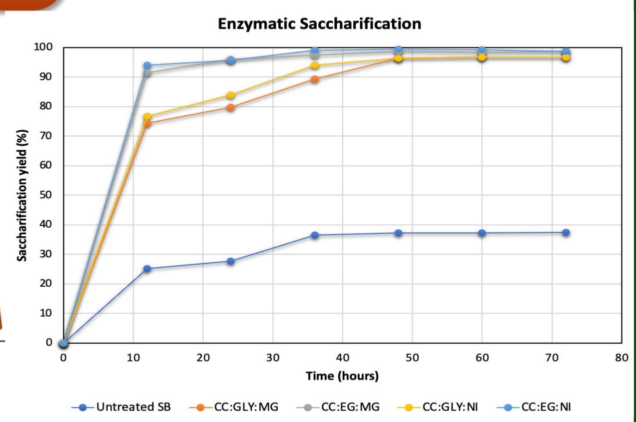
3. Fermentation
- Yeast (*Saccharomyces cerevisiae*, (OD_{660} ~ 1.5 – 2.0; cell concentration- 10^6 cells/mL)
- Inoculum: Hydrolysate::1:10
- Conditions: 37 °C, 48 h

RESULTS AND DISCUSSION

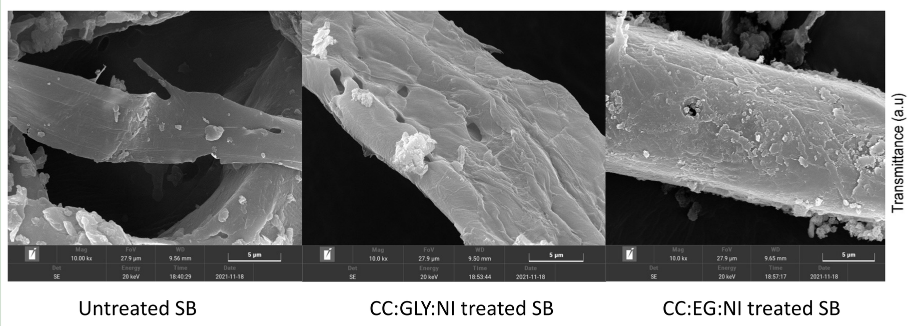
Biomass Characterization



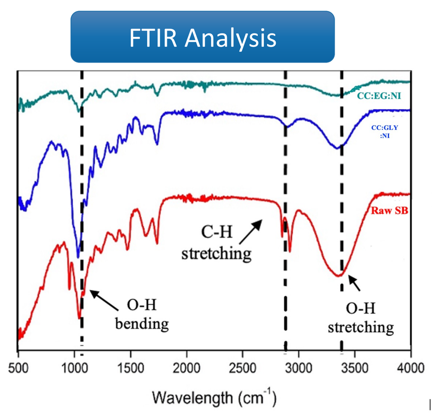




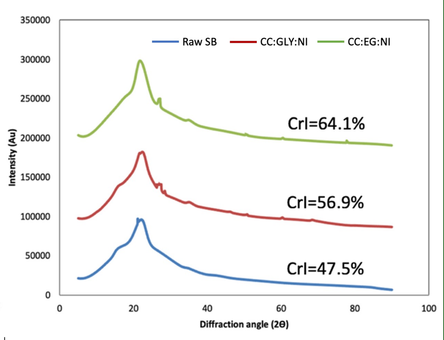
SEM Analysis



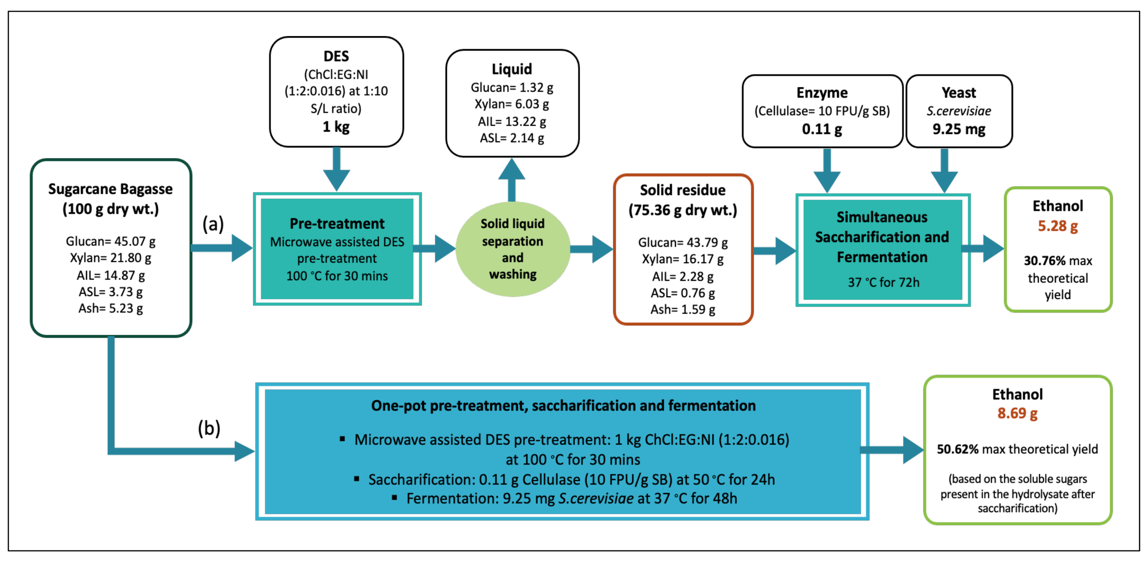
FTIR Analysis

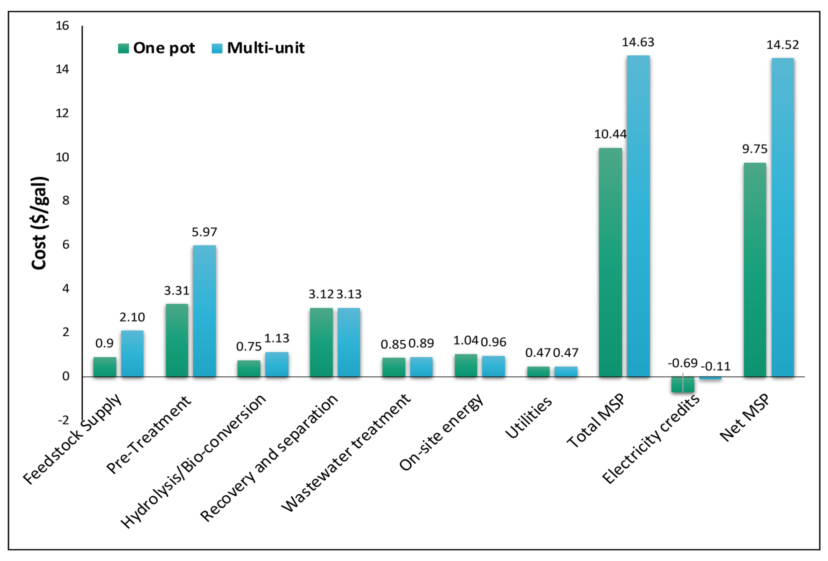


XRD Analysis



One Pot Bioethanol Production



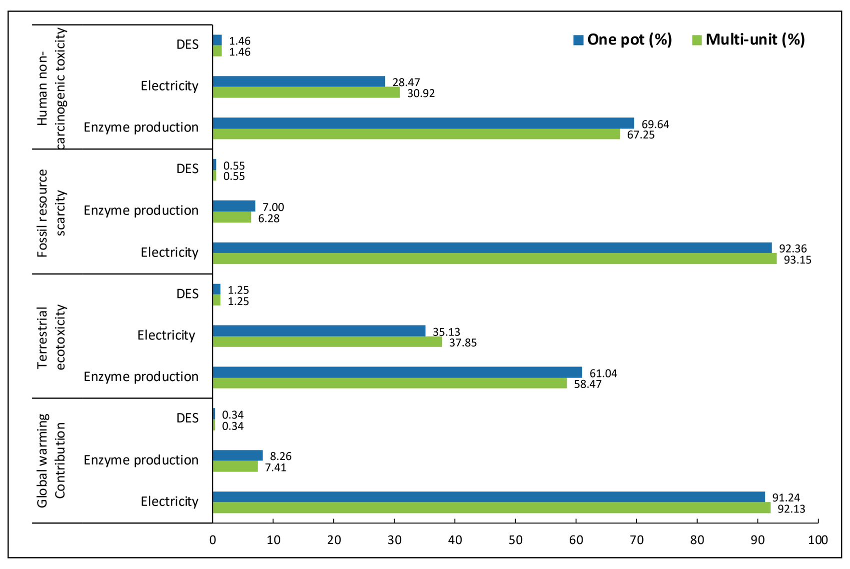


- Equipment cost data was taken from NREL technical report, 2011 and was adjusted for year 2022 using chemical engineering plant cost index.
- Cost calculation done by the method proposed by Sinnott and Towler.

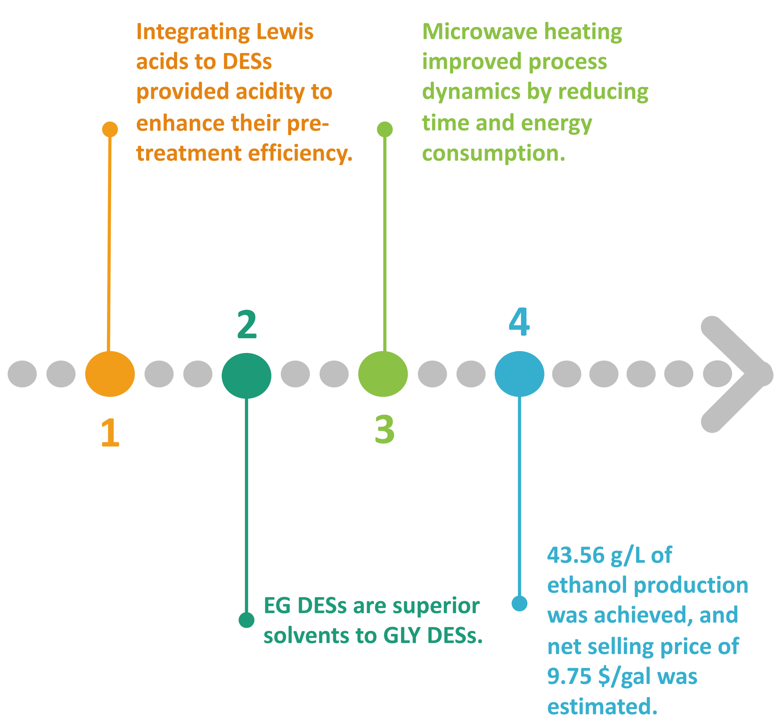
Minimum Ethanol Selling Price (MESP) =

$$\frac{\text{Annual capital cost investment} + \text{Annual operating cost} + \text{cost of lignocellulosic feedstock}}{\text{Annual ethanol flow rate}}$$

- Open LCA with *ecoinvent* 3.8 database
- Impact assessment method: ReCiPe 2016.
- Electricity consumption (70-93%), enzyme production (7-36%), DES ~1%.
- The impacts can be reduced by:
  1. Changing the electricity mix.
  2. Using engineered microbes can produce enzyme *in-situ* and co-utilize xylose
  3. Further process optimization and intensification



CONCLUSION



STRENGTHS
- Sustainable energy supply
- Policy support for ethanol blending
- High demand at high priority
- Availability of abundant feedstock

WEAKNESS
- Technical Immaturity
- Higher CAPEX and OPEX
- Lower energy content per volume than gasoline
- Low yields because of product inhibition
- Difficult to predict the precise fermentation outcome
- Downstream processes are energy demanding and expensive

OPPORTUNITIES
- The development process can be used for other value-added products
- Employment opportunities
- Young research field: more scope to improvements with genetically engineered microbes, feedstock etc.

THREATS
- Other technologies may develop faster and be more competitive
- Eventually too cost intensive

ACKNOWLEDGMENT

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