A techno-economic comparison between technologies for biomass fractionation including liquor re-use

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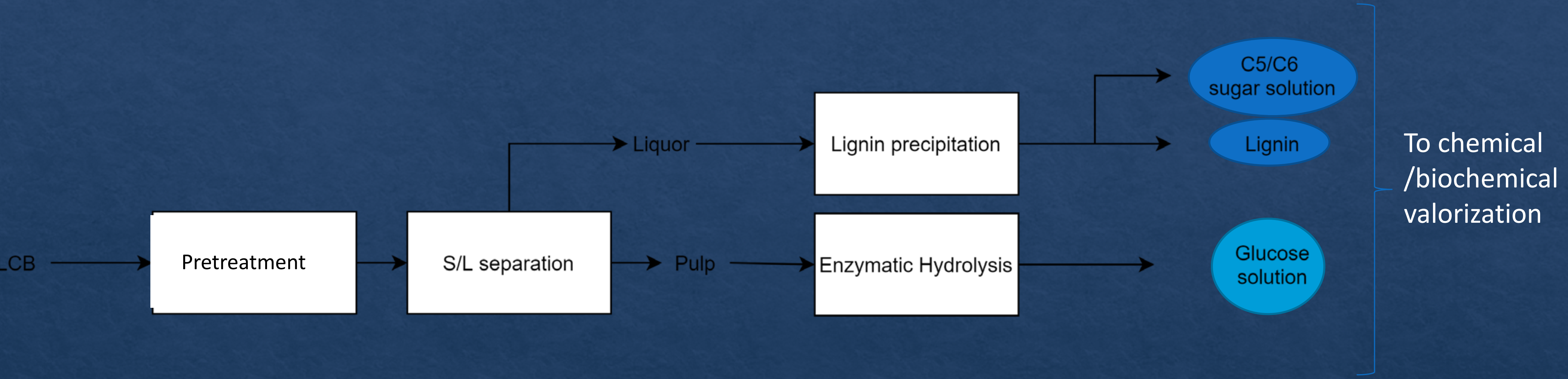
Sustainable production of bio-based fuels and chemicals

- Agricultural residues are low cost and abundant
- Lignocellulosic Biomass (LCB) as a source of carbohydrate platform chemicals
- Economy of this process is still challenging

LCB to sugars



- Our focus is to valorize all streams not only glucose solution

Pre- treatment alternatives for LCB

- **Diluted mineral acids** (0.5-4%), T: 120-200 ºC
- **Steam explosion**, saturated steam at 160-250ºC. Rapid decompression after few minutes
- **Ethanol/Water (EW) extraction** Solvent-Water mixtures. Acid catalysts improve hemicelluloses hydrolysis.
- **Alkalyne pulping** Sodium/potassium hydroxides, T < 120ºC

Pre-treatment economy

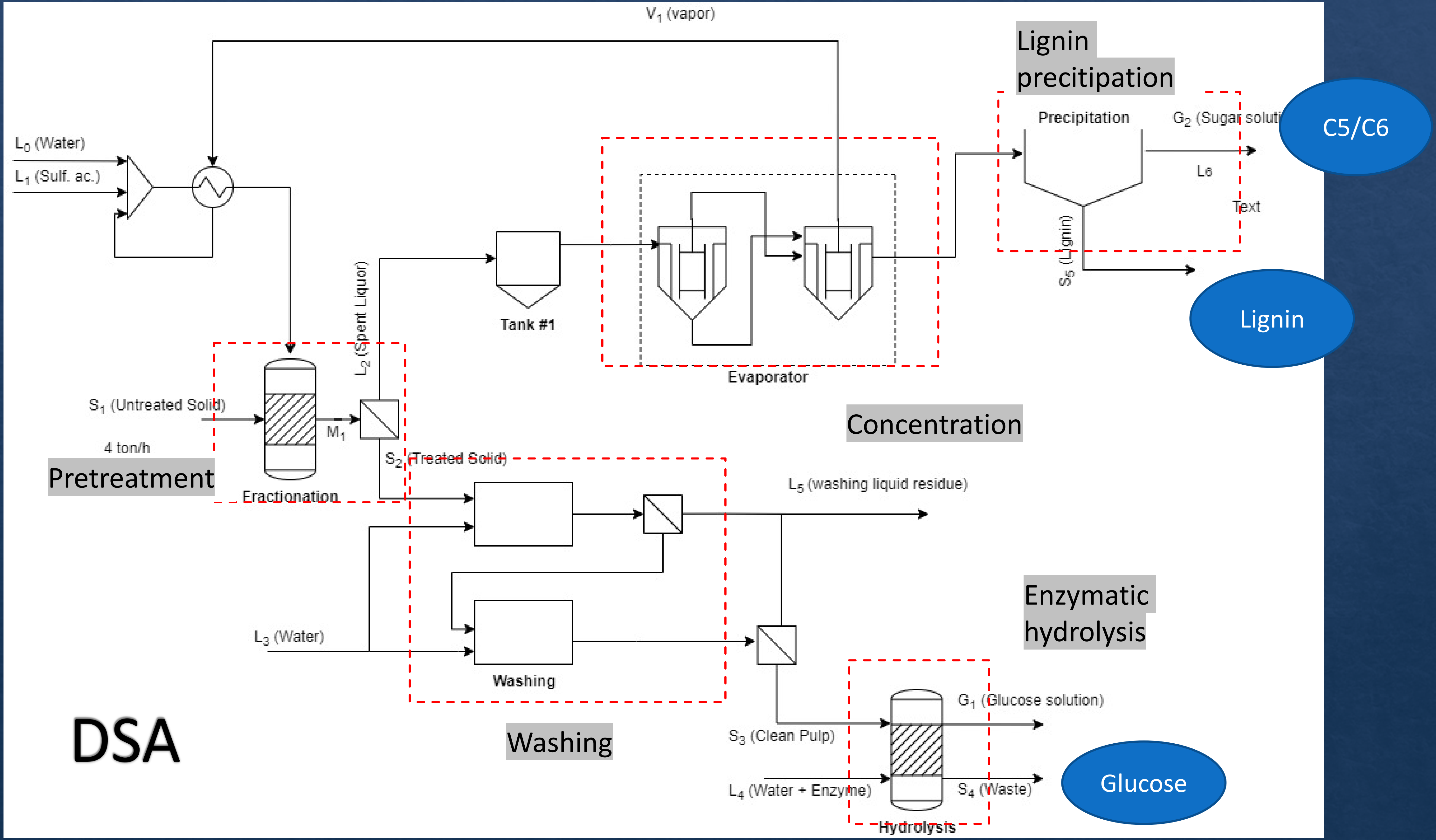
- The main drawback of pre-treatments is the associated costs of energy and product concentration stages
- This issue is a bottleneck for the development of a cost effective bioprocess which results in increased downstream processing cost, when compared with crude oil alternative
- In the case of the water-solvent fractionation they increase with the additional energy involved in the solvent recovery
- Raw material is cheap, eventually a residue
- Herbaceous vs. Wood: L/S ratio

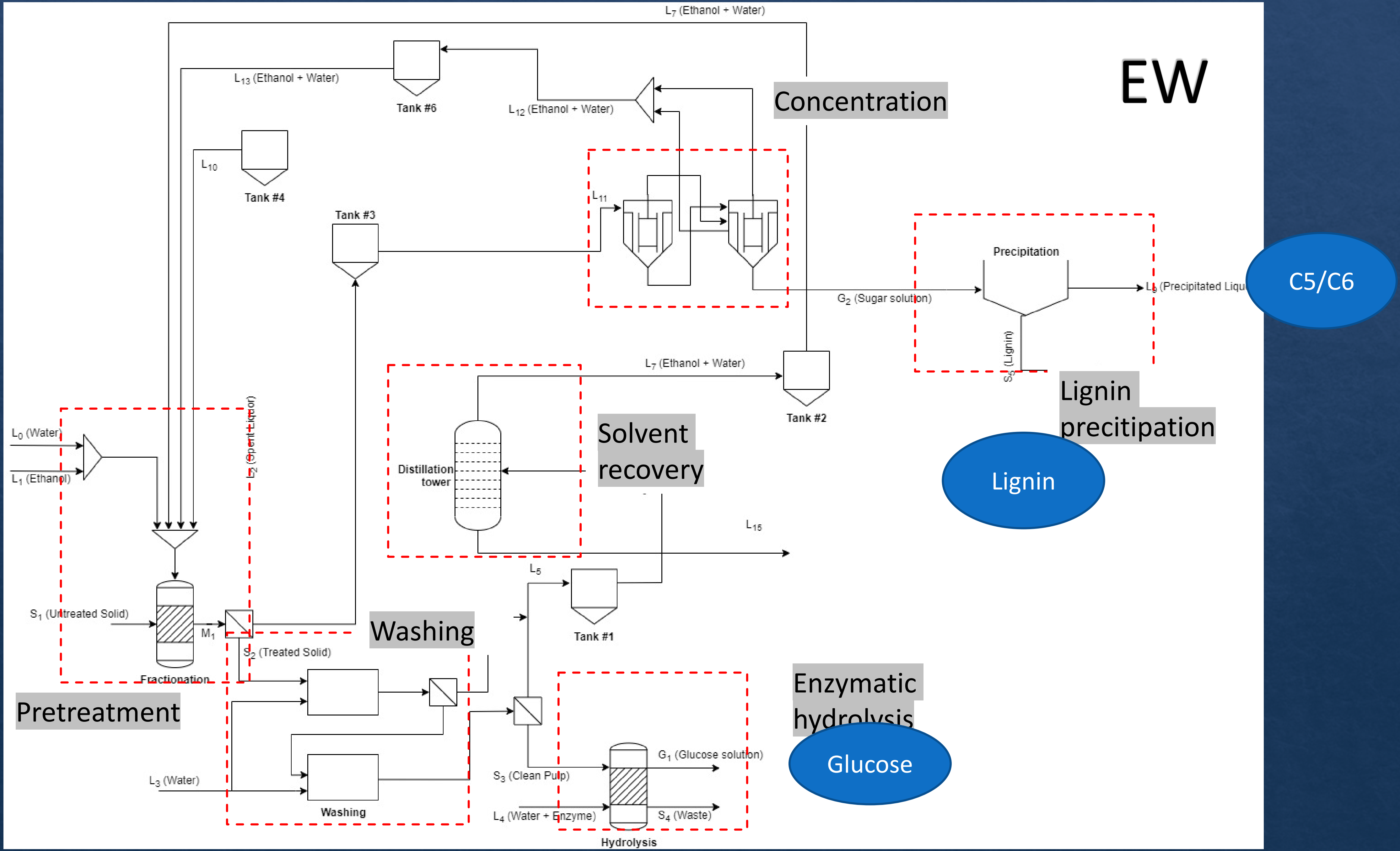
EW Pre-treatment economy

- EW pre-treatment is, apparently, the less favourable pre-treatment in terms of energy consumption (Kautto et al., 2014; Rodrigues Gurgel et al2018)
- It is more efficient in the delignification than diluted acid pre-treatments. Moreover, EW pulps exhibit less inhibition problems in the further saccharification and fermentation stages (Palmqvist and Hahn-Hägerdal, 2000).

Aim of the study

- To set up EW and DSA fractionation process simulations for wheat straw
- To evaluate how a liquor re-use a strategy (EWR) affects the economy of EW process
- To conduct an economic comparison of the EW EWR , and DSA traditional method as a reference

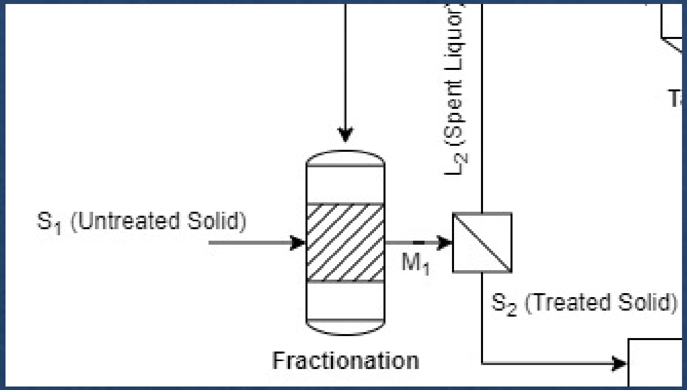

V1 (vapor)
Lignin precipitation
Precipitation
G2 (Sugar soluti
C5/C6
L6
Text
S5 (Lignin)
Lignin
L0 (Water)
L1 (Sulf. ac.)
L2 (Spent Liquor)
Tank #1
Evaporator
Concentration
S1 (Untreated Solid)
4 ton/h
M1
Pretreatment
Fractionation
S2 (Treated Solid)
L5 (washing liquid residue)
Enzymatic hydrolysis
L3 (Water)
Washing
Washing
G1 (Glucose solution)
S3 (Clean Pulp)
L4 (Water + Enzyme)
S4 (Waste)
Glucose
Hydrolysis
DSA



EW
L_7 (Ethanol + Water)
L_{13} (Ethanol + Water)
Tank #6
L_{12} (Ethanol + Water)
Concentration
L_{10}
Tank #4
Tank #3
L_{11}
Precipitation
G_2 (Sugar solution)
L_6 (Precipitated Liqu
C5/C6
S_5 (Lignin)
Lignin precipitation
Lignin
L_7 (Ethanol + Water)
Tank #2
Distillation tower
Solvent recovery
L_{15}
L_0 (Water)
L_1 (Ethanol)
L_2 (Spent Liquor)
S_1 (Untreated Solid)
M_1
Fractionation
Pretreatment
S_2 (Treated Solid)
Washing
L_5
Tank #1
Enzymatic hydrolysis
Glucose
G_1 (Glucose solution)
S_3 (Clean Pulp)
L_3 (Water)
Washing
L_4 (Water + Enzyme)
S_4 (Waste)
Hydrolysis

Simulation conditions DSA/EW

- Aspen Plus V9
- Feed rate 100 ton WS/day
- Pretreatment
  - L/S ratio: 10/20/30 $L.kg^{-1}$
  - 160 °C /10 bar/1 hour
- Solid separation thickened until 40% w/w



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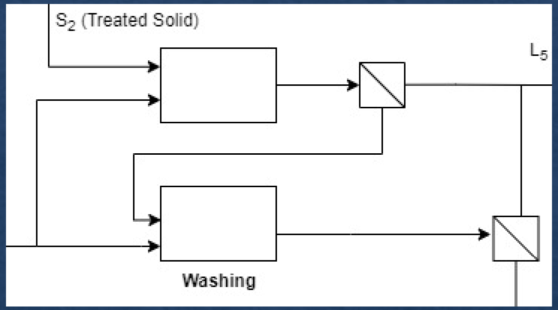

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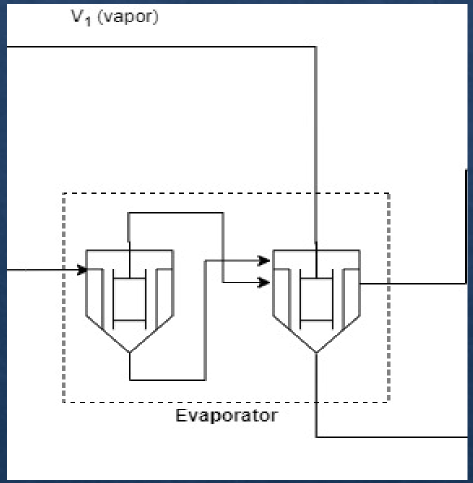
- Liquor concentration   2-step evaporators, final concentration 40% w/w Xylose + Glucose



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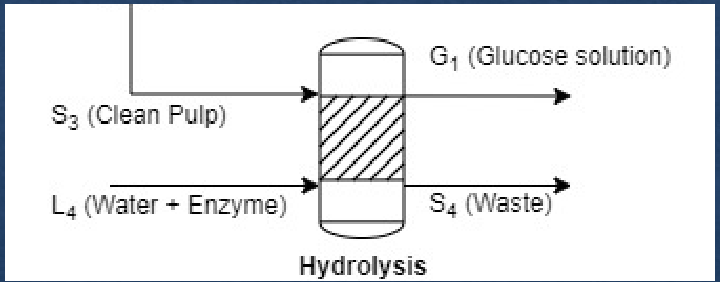
- Enzymatic hydrolysis 48 h, Consistency10%



Simulation conditions DSA/EW

- **DSA:** 1% (w/w) H_2SO_4 based on WS weight in water
- **EW:**
  - 1% (w/w) H_2SO_4 based on WS weight in EW mixture with 25% v/v (28.8% w/w) of ethanol
  - Distillation column:
    - Fed with 1st. washing liquid stream
    - Eficiency in Ethanol 98%

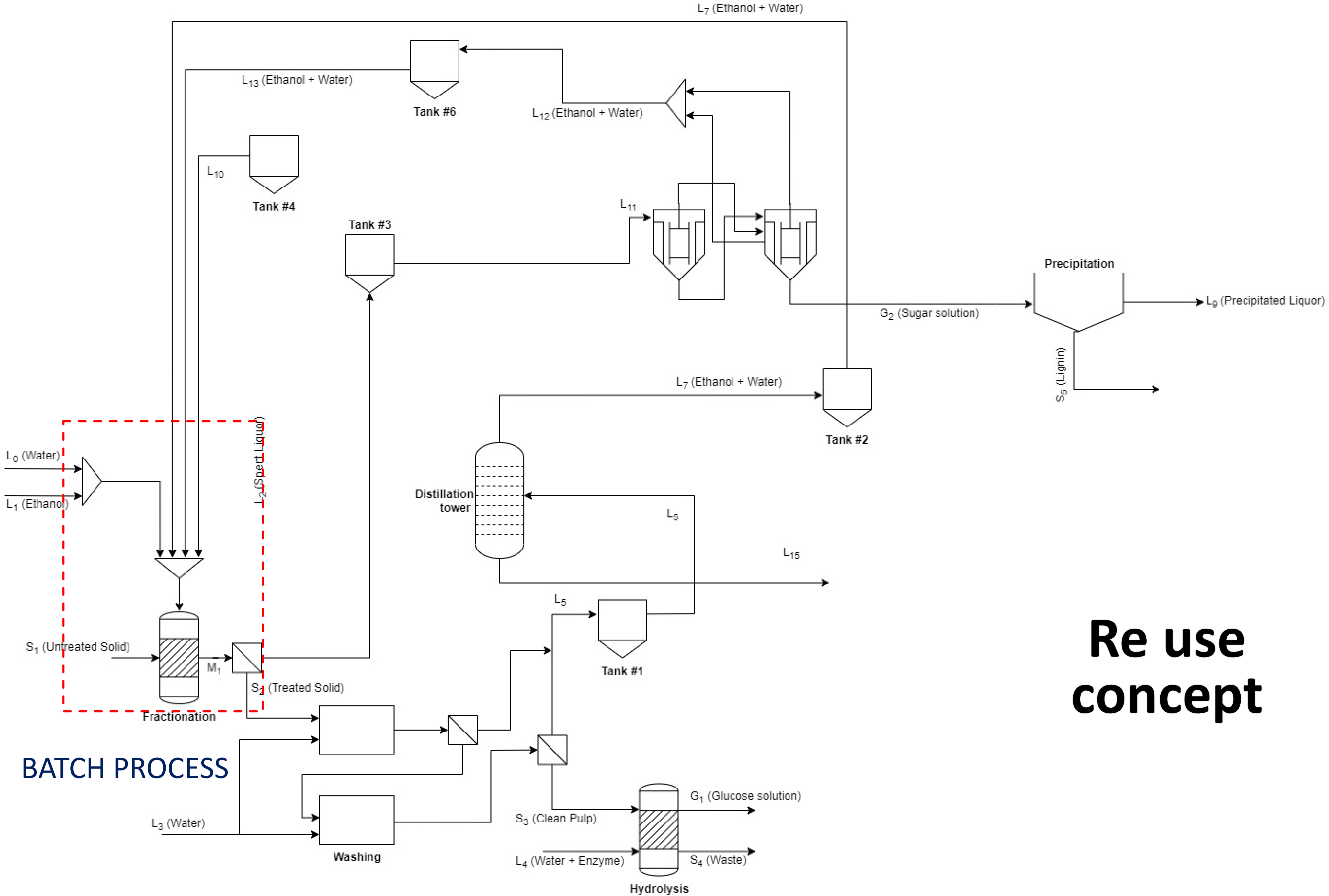
Chemical reactions

- Pretreatment
  - CELLULOSE (s) + H2O (l) → GLUCOSE (aq)
  - XYLAN (s) + H2O (l) → XYLOSE (aq)
  - LIGNIN (s) → LIGNIN (aq)
  - XYLAN (s) → FURFURAL (aq) + 2 H2O(l)
  - CELULOSE (s) → HMF (aq) + 2 H2O(l)
  - ARABINAN (s) + H2O (l) → ARABINOSE (aq)
  - ACETYL GR. (s) → ACETATE (ac)
  - ASHES (s) → ASHES (ac)

Conversion fraction	
DSA	EW
0,1476	0,1438
0,8256	0,8259
0,2882	**0,5731**
0,018	0
0,0024	0
0,9752	0,8414
0,8209	0,7656
0,8	0,8

- Enzymatic hydrolysis
  - CELULOSE (s) + H2O (l) → GLUCOSE (ac)

0,752	0,767



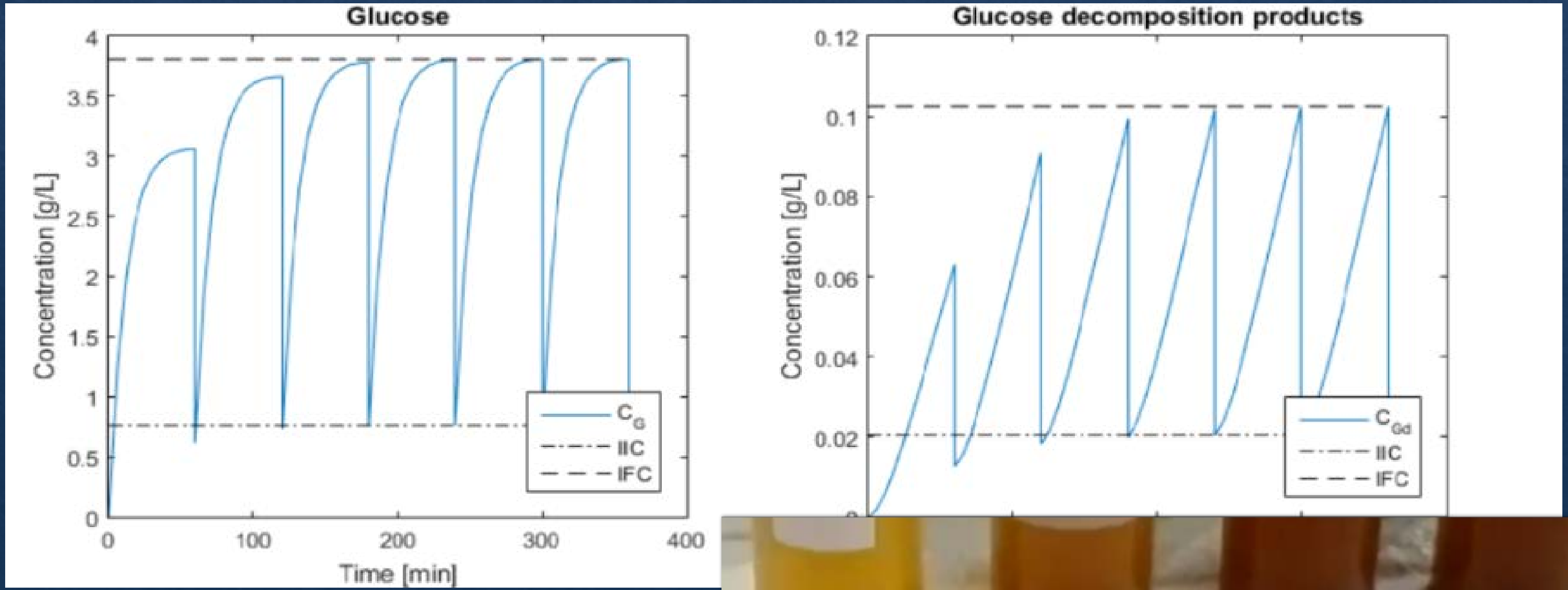
BATCH PROCESS

Re use concept

Re-use strategy in batch operation

Re-use strategy in batch operation

- Energy, water, and solvent savings
- Consecutive cycles will have different initial conditions

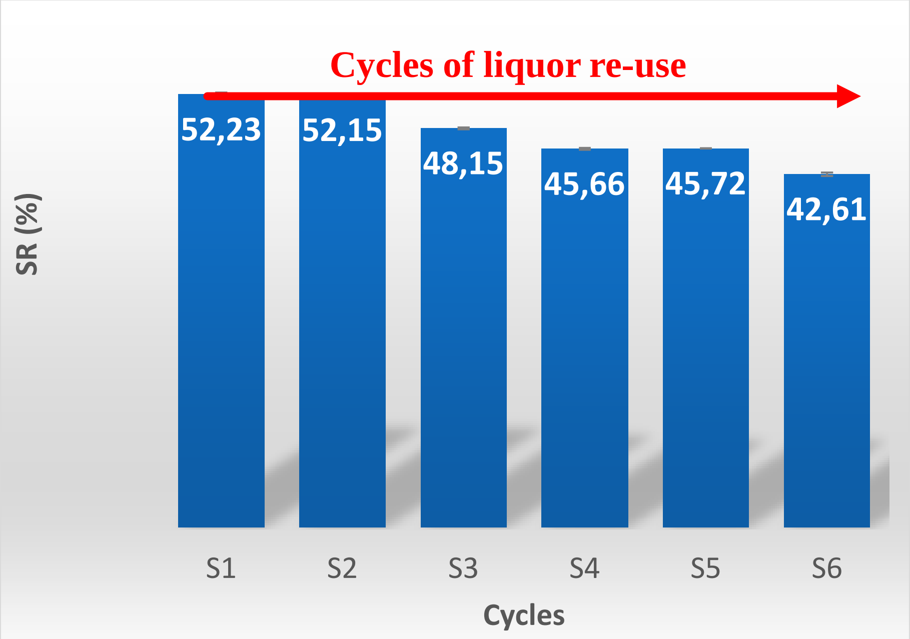


Liquor re-use drawbacks

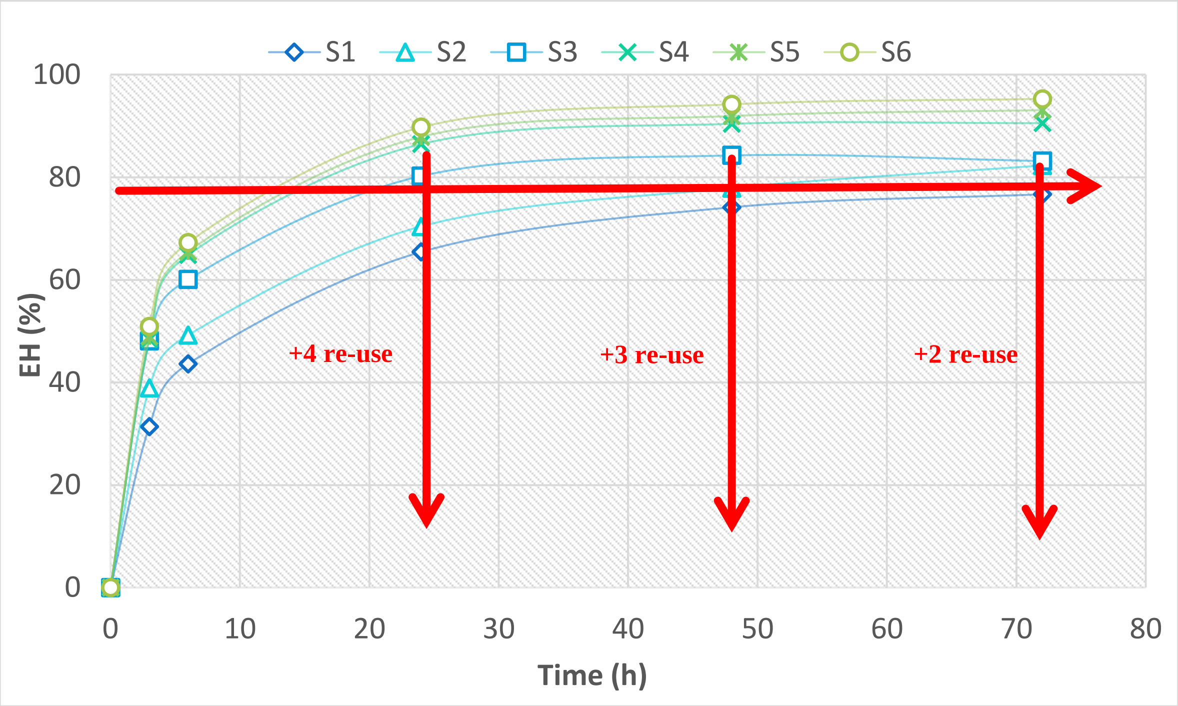
- Liquor will spend more and more time in the batch reactor. Undesirable reactions like sugar degradation will occur to a greather degree
- Liquor will concentate in sugars but also in inhibitor compounds, so they could cause enzymatic inhibition
- The dynamic nature of this process make the re-use difficult to model and include in a simulation for mass integration.

Re- use experimental data_previous work

Vergara et al (2018) Biores.Technol. 256, 178-186



The recovery of solids (SR) decreases as the number or cycles increases (higher glucan solubilization)



Enzymatic Hydrolysis (EH) occurs faster and in a greather extent.

These two opposing effects compensates and the glucose after enzymatic hydrolisis has similar concentration among re-uses

Chemical reactions_EWR conversion factors

- Pretreatment
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  - XYLAN (s) + H2O (l) → XYLOSE (aq)
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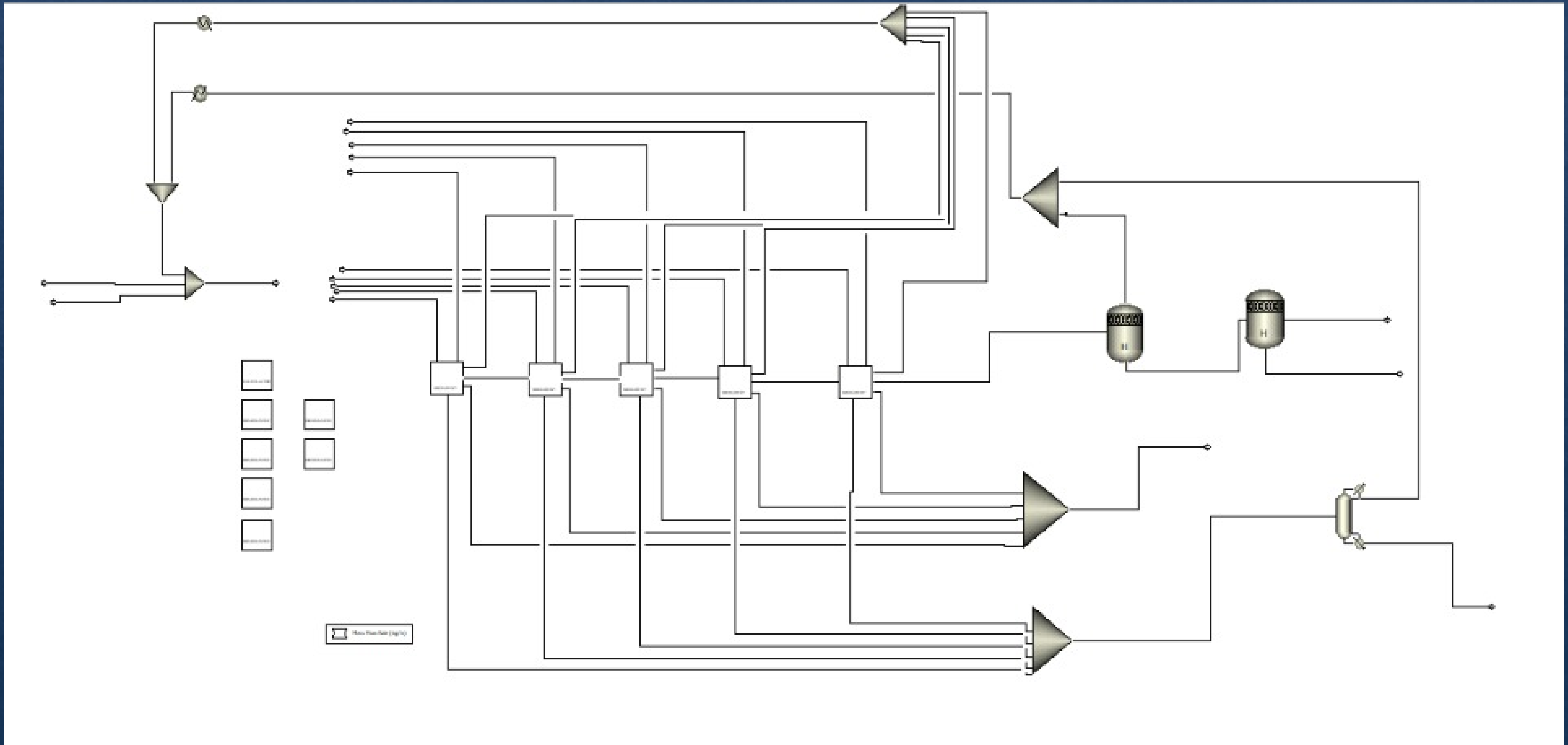
  - ACETYL GR. (s) → ACETATE (ac)
  - ASHES (s) → ASHES (ac)

Conversion fraction- RE-USE			
#1	#2	#3	#4
0,1432	0,1997	0,2043	0,2306
0,8335	0,8443	0,8513	0,8650
0,5515	0,5742	0,5673	0,5569
0,028	0,0457	0,0643	0,0767
0	0,0076	0,0048	0,0058
0,8435	0,8575	0,8703	0,8798
0,795	0,8731	0,9086	0,9037
0,8	0,8	0,8	0,8

- Enzymatic hydrolysis
  - CELULOSE (s) + H2O (l) → GLUCOSE (ac)

0,823	0,832	0,907	0,938

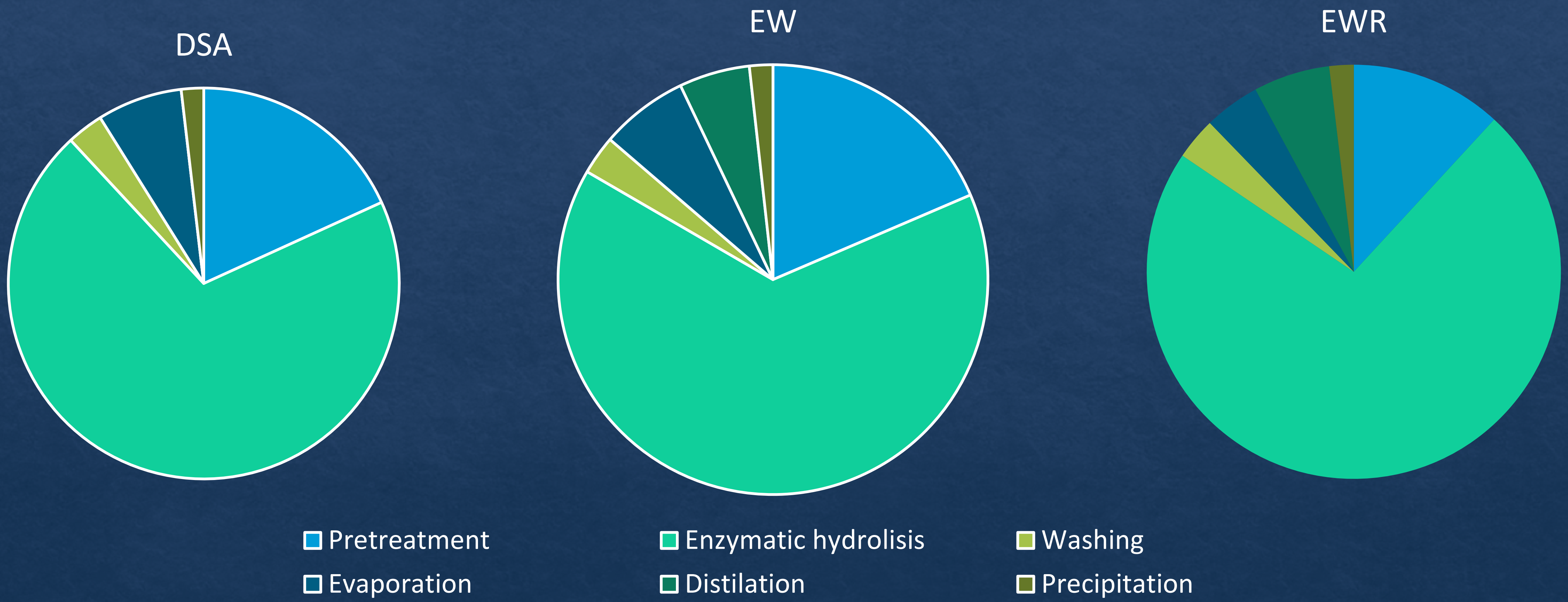
Re-use set up



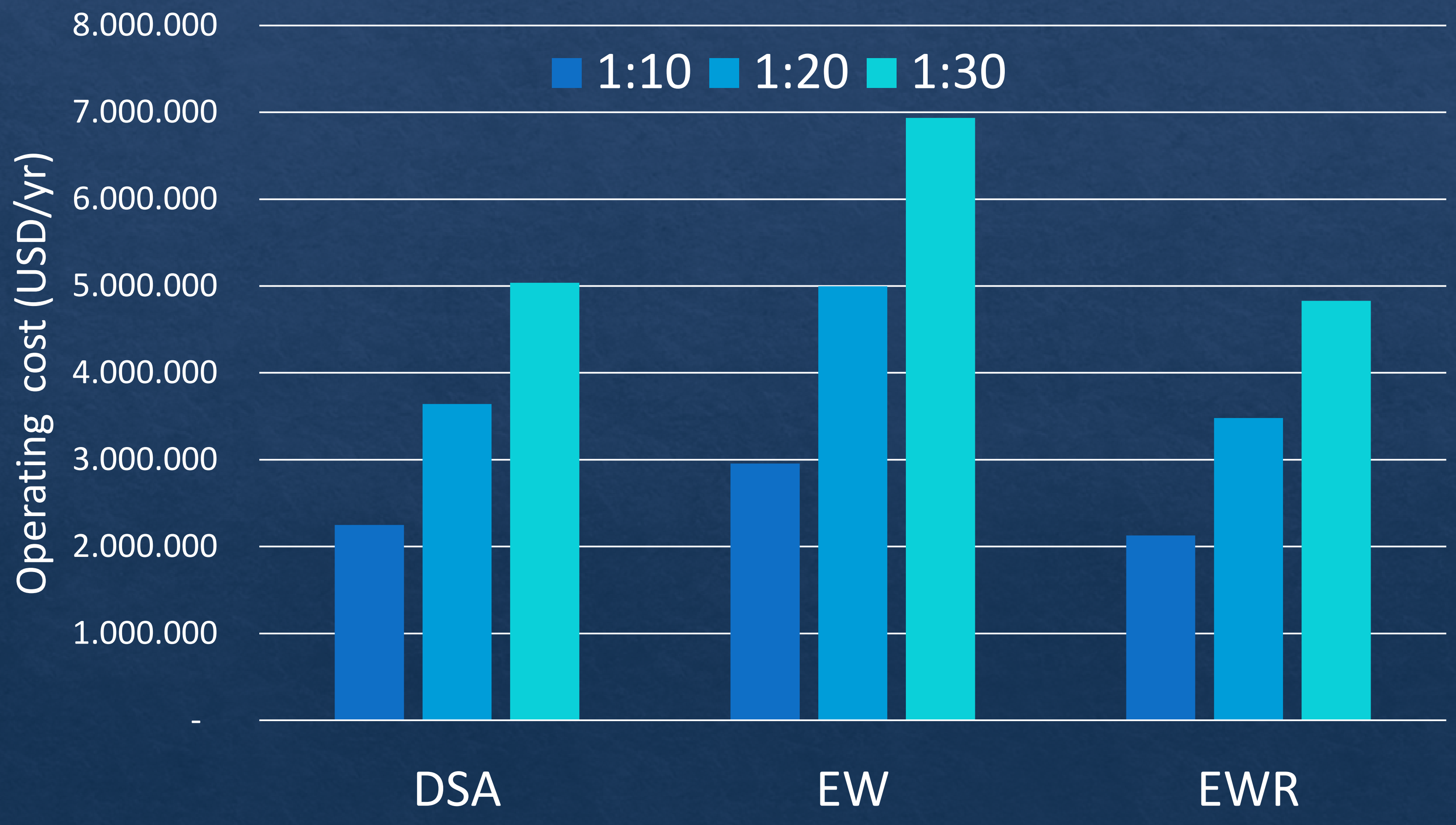
Process costs

- Only capital and operating costs (utilities, water and etanol) have been considered. Other costs were considered similar for all alternatives
- Costs are not included upstream (stocking and handling of raw materials), nor downstream (use of the sugars obtained)
- Equipment cost has been annualized considering 10 years life Project

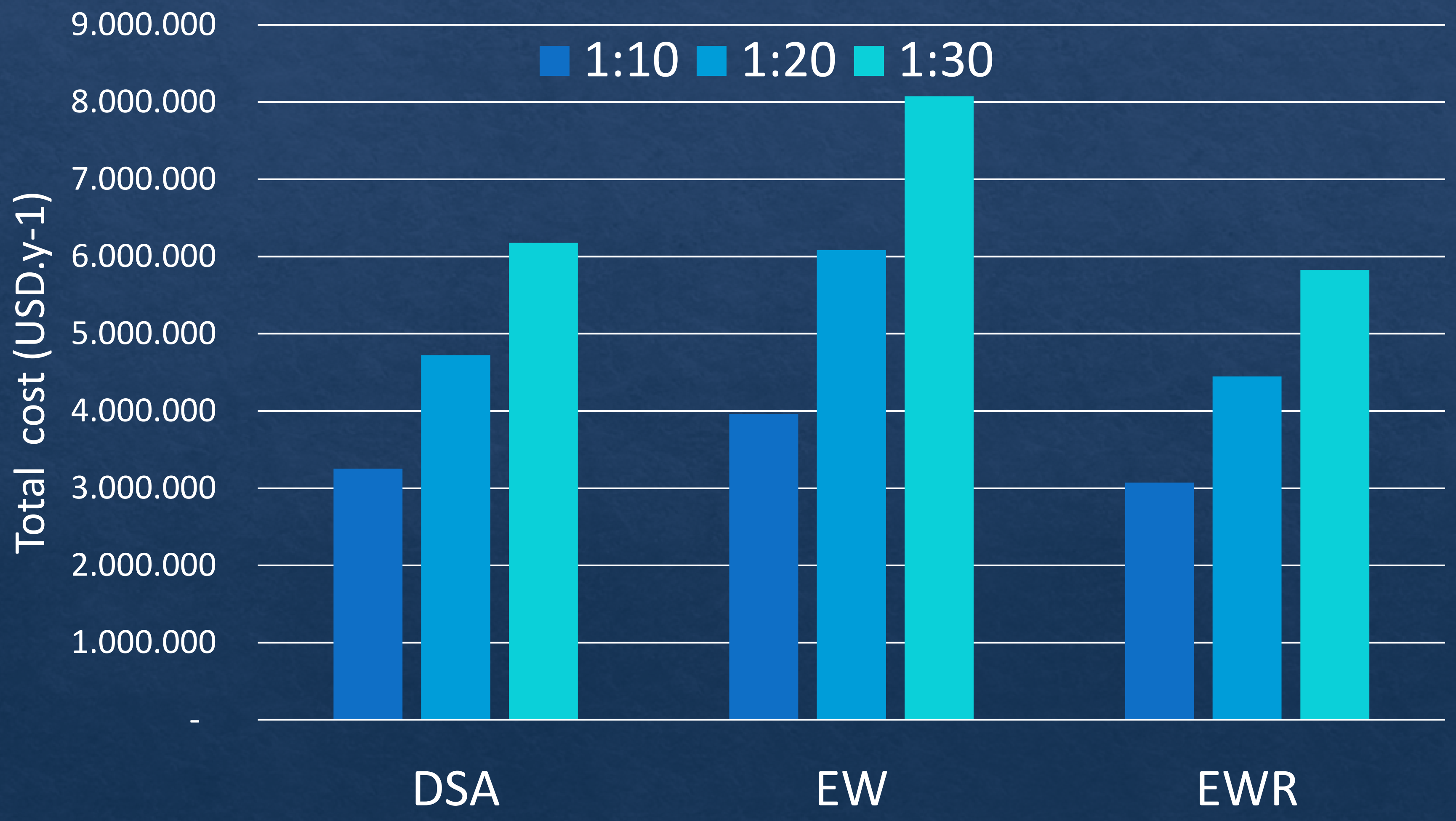
Results_ annualized investment costs L/S 20:1



Results_ operating costs



Results_ total costs



Results_ L/S ratio

		Facilities, Equipment		Operating Costs ($/yr)			Total Operating cost	
		($/yr)	**Ratio**	Utilities	Water	Ethanol	($/yr)	**Ratio**
DSA	1:10	1.005.510	**1**	1.304.028	945.212	0	2.249.240	**1**
	1:20	1.078.280	**1,07**	2.552.854	1.089.792	0	3.642.646	**1,62**
	1:30	1.138.770	**1,13**	3.803.263	1.234.768	0	5.038.031	**2,24**

		Facilities, Equipment		Operating Costs ($/yr)			Total Operating cost	
		($/yr)	**Ratio**	Utilities	Water	Ethanol	($/yr)	**Ratio**
EW	1:10	1.003.030	**1,00**	1.910.858	846.668	200.276	2.957.802	**1,00**
	1:20	1.083.600	**1,08**	3.749.249	951.548	296.772	4.997.570	**1,69**
	1:30	1.140.800	**1,14**	5.636.585	969.764	327.724	6.934.073	**2,34**

		Facilities, Equipment		Operating Costs ($/yr)			Total Operating cost	
		($/yr)	**Ratio**	Utilities	Water	Ethanol	($/yr)	**Ratio**
EWR	1:10	942.350	**1,00**	1.166.220	899.455	63.906	2.129.581	**1,00**
	1:20	967.470	**1,03**	2.360.794	1.012.354	106.783	3.479.931	**1,63**
	1:30	997.470	**1,06**	3.562.812	1.123.868	141.923	4.828.603	**2,27**

Conclusions

- EW is around 30% more expensive than DSA treatment
- Re-use strategy compared with DSA result in 5% savings, with a better quality lignin
- Operating cost are more tan twice as high   when L/S ratio increase from 1:10 to 1:30
- Total costs are dominated by operating costs (utilities)
- Investment costs are dominated by enzymatic hydrolisis process

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Thank you!

Questions?

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