Techno-economic analysis and life-cycle assessment of emerging technologies for bioprocessing separations

Lauren Valentino and Jennifer B. Dunn *– Argonne National Laboratory*

Eric C.D. Tan *– National Renewable Energy Laboratory*

Charles J. Freeman *– Pacific Northwest National Laboratory*

William Kubic *– Los Alamos National Laboratory*

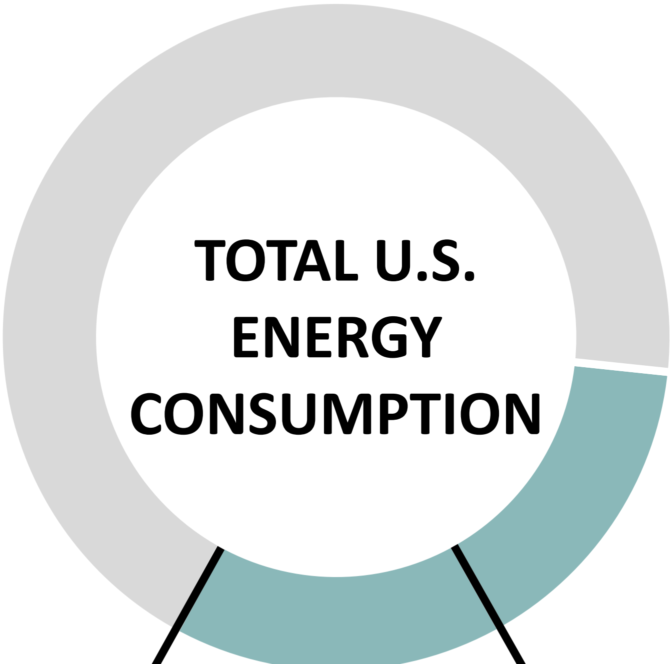
Alex Rosenthal *– inCTRL Solutions*

U.S. DEPARTMENT OF ENERGY

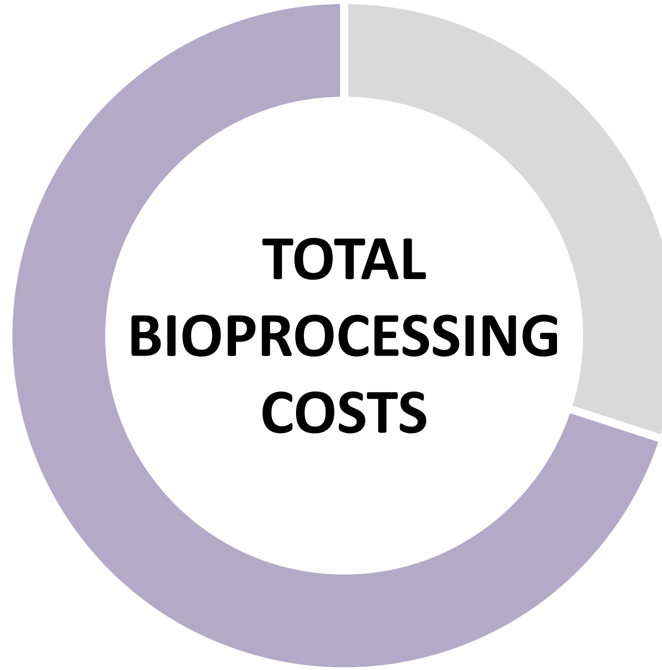
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

2020 AIChE Annual Meeting

The challenge: separations



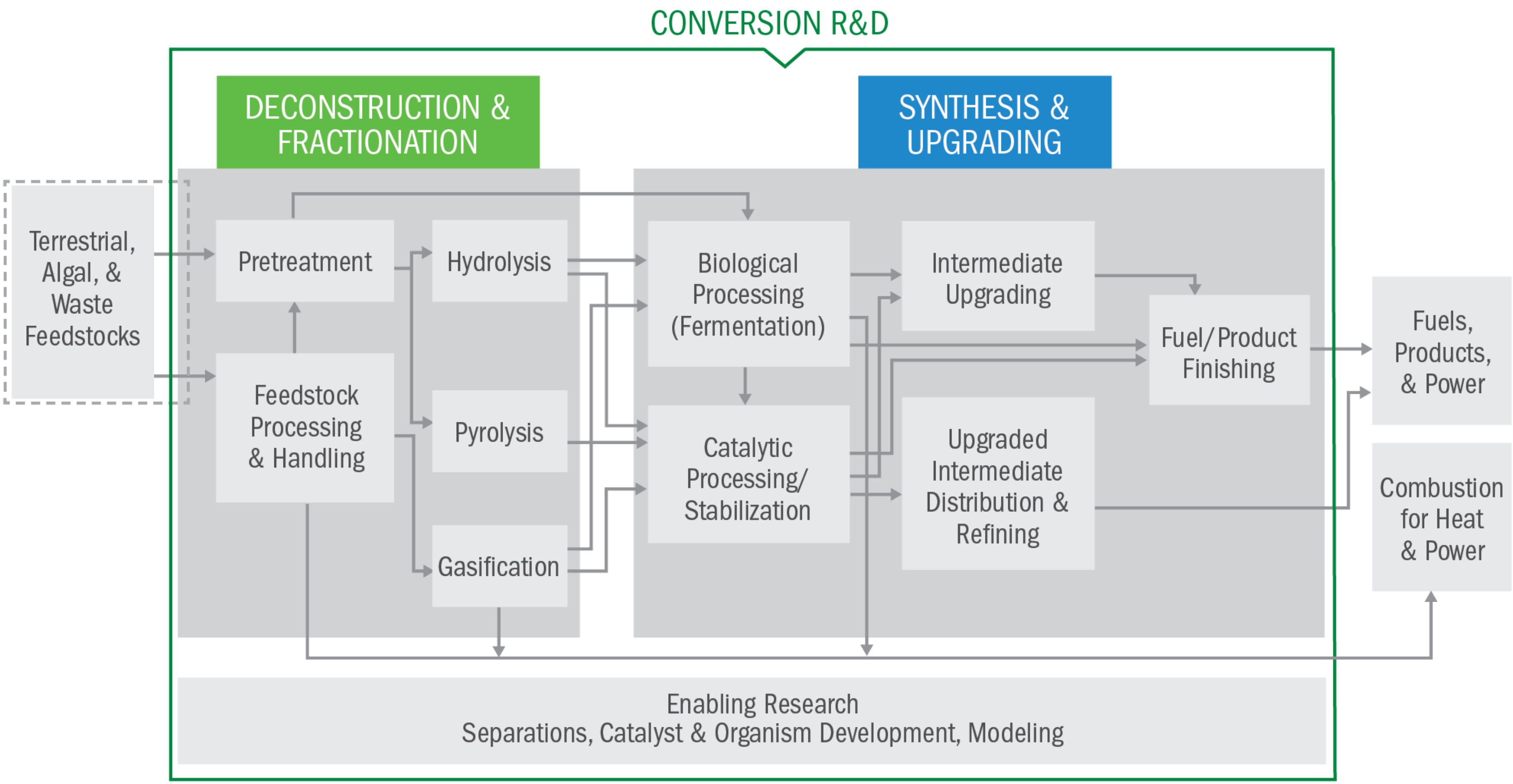
Separations account for 45 - 55% of **industrial** energy use and 10 - 15% of **TOTAL** energy consumption



60 - 80% of **BIOPROCESSING COSTS** are associated with **separations**

Sholl and Lively 2016, Ragauskas et al. 2006

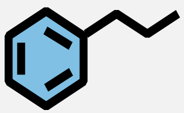
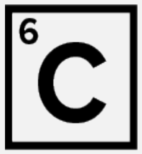
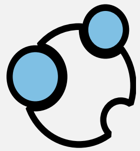
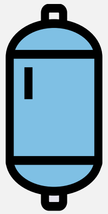
Conversion pathways



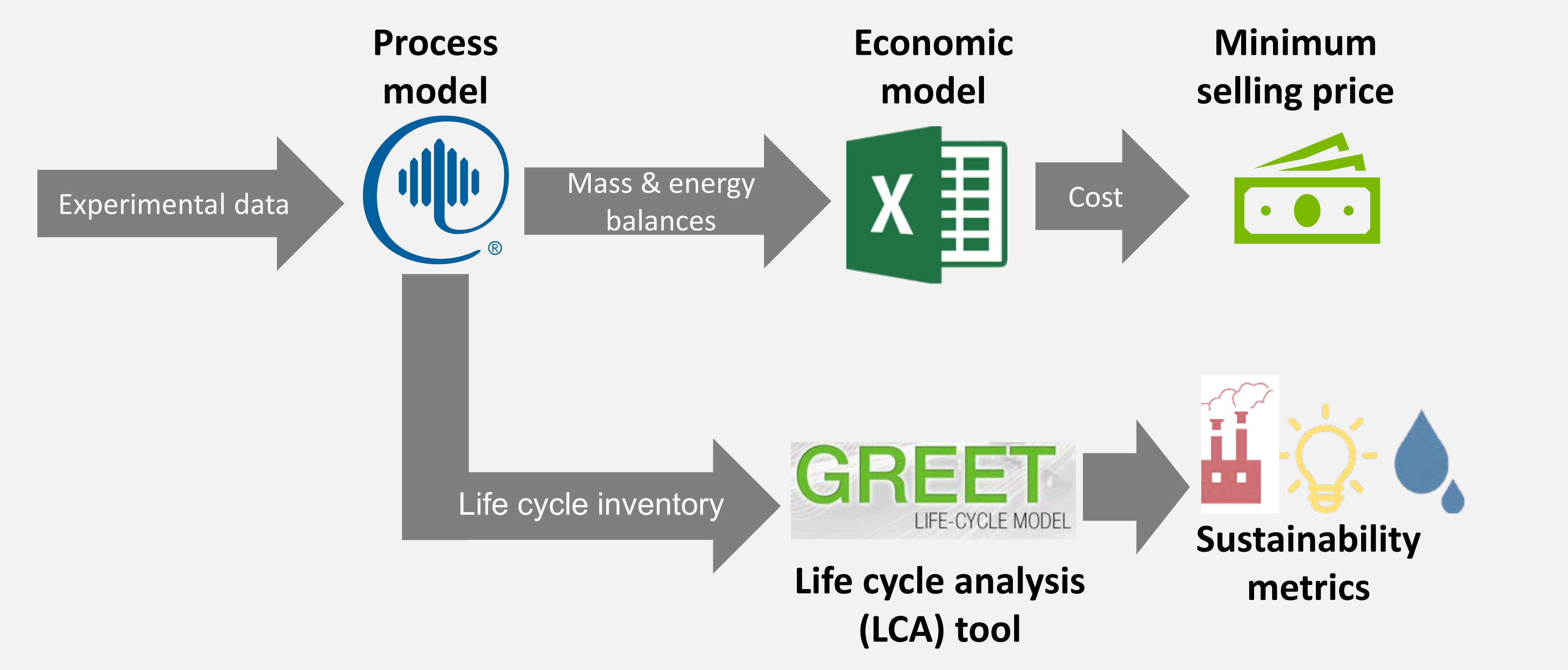
Separations are costly and complex regardless of conversion pathway

Challenges are related to upstream and downstream separations

Major bioprocessing separation challenges

Lignin fractionation and valorization	Lignin fractionation enables conversion to valuable co-products that can enhance process economics and sustainability.	
Recover carbon from dilute aqueous streams	Increasing carbon efficiency of processes from recovery of valuable co-products can lead to improved process economics.	
Remove catalyst poisons from feedstocks and fermentation broth	Poisons and foulants like carbonyls limit the lifetimes of upgrading catalysts and biocatalysts. Selective removal strategies to eliminate them will extend catalyst life and decrease processing costs.	
Process intensification	Reducing the number of processing steps associated with separations, including through reactive fermentation and in-situ product recovery, reduce process energy intensity and costs.	

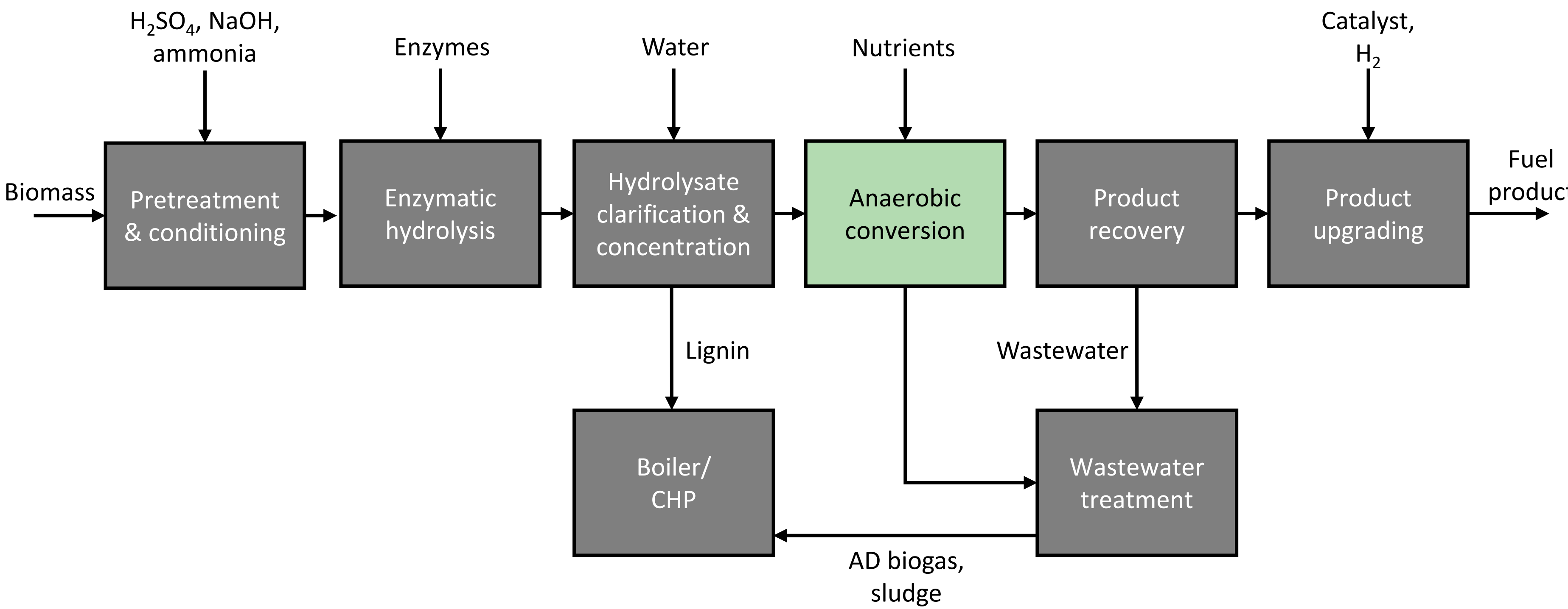
Integrated analysis approach



GREET™: Greenhouse gases, Regulated Emissions and Energy use in Transportation

Analysis for separations strategies

Biochemical conversion example



Anaerobic production of carboxylic acids was identified as a strategy to produce biological intermediates that could be further upgraded to a hydrocarbon fuel via chemical catalytic conversion

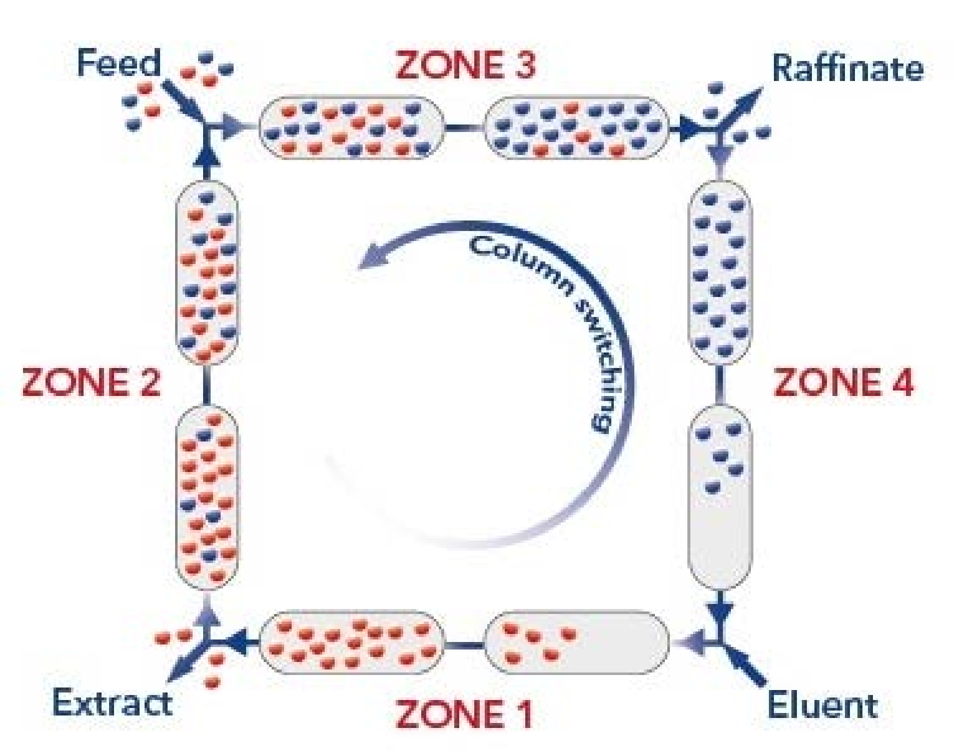
Analysis methodology

SOT description / Baseline case	State-of-the art commercial technology Establish benchmarks Starting point for model design basis
Economic viability analysis of both SOT and novel separations	Incorporate innovative technologies Assess how new technologies affect performance and cost Evaluate and develop performance and cost targets
Environmental impact assessment of both SOT and novel separations	Incorporate innovative technologies Assess how new technologies affect sustainability Evaluate and develop sustainability targets
Sensitivity analysis	Identify input parameters with high impact on model outputs Establish priorities for technology development

State of technology – Simulated moving bed

Simulated moving bed (SMB)

- SOT for single product isolation
- Limited to A/B separations
- Stationary phase is expensive
- Solvent recycling is complicated in reverse phase

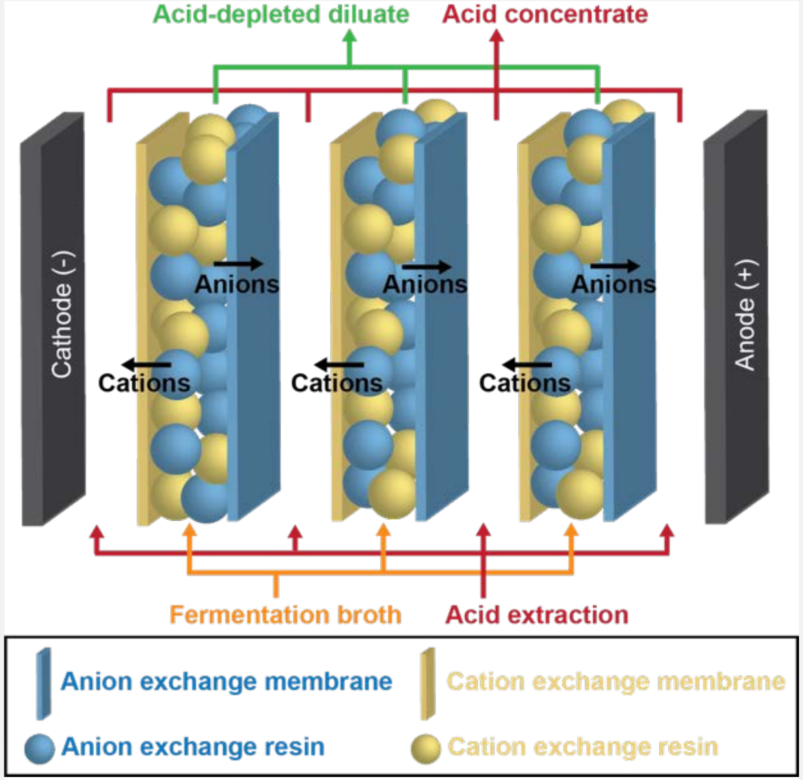


AZoM 2017 (https://www.azom.com)

Consortium technology - Electrodeionization

Electrodeionization (EDI)

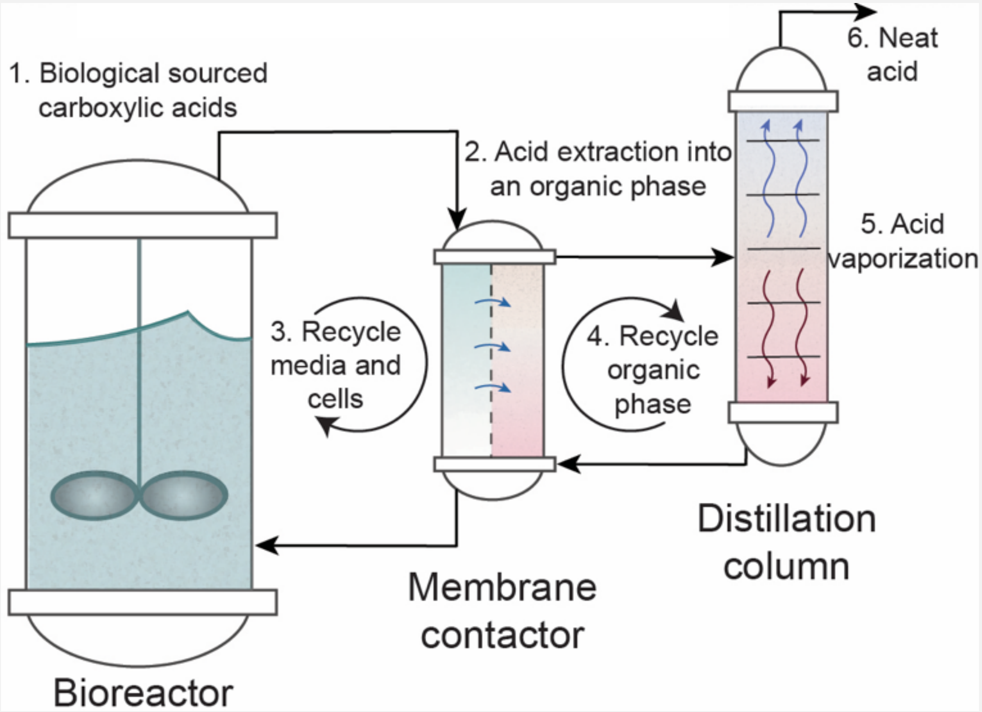
- Electrically driven separation
- Ion transport across membranes
- Incorporates ion exchange
- Continuous process with no need for resin regeneration
- In-situ pH control decreases dependence on influent characteristics



Consortium technology – Membrane extraction (pertraction)

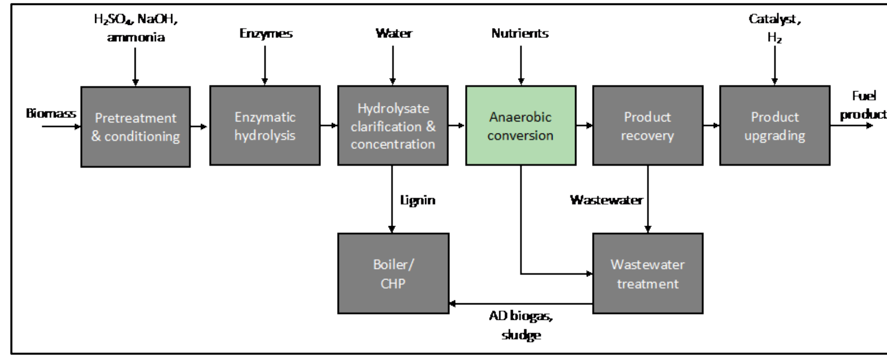
Pertractive *in-situ* product recovery

- Liquid-liquid membrane extraction system
- Carboxylic acid and solvent separation/recovery via distillation of organic phase
- Increases end-product titer, rate, and yield by avoiding cell inhibition

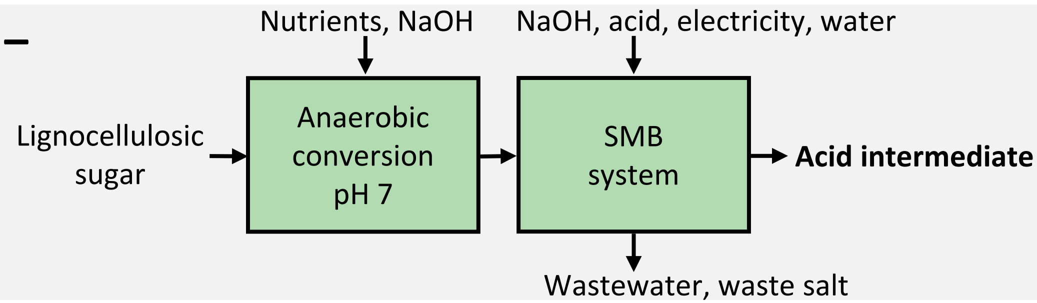


Saboe et al. 2018

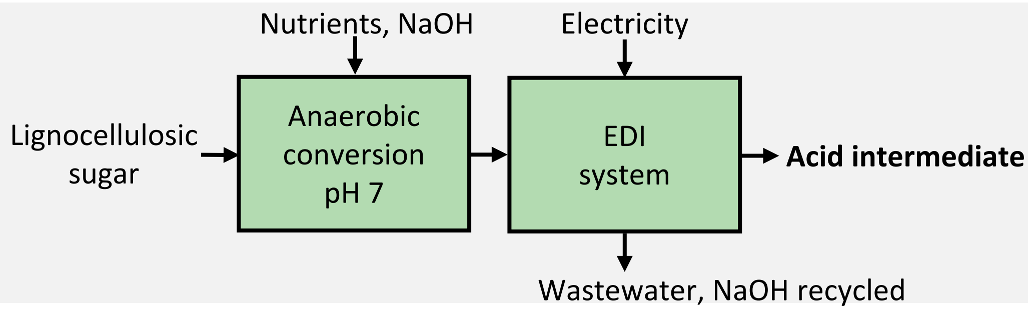
Analyses for separations strategies



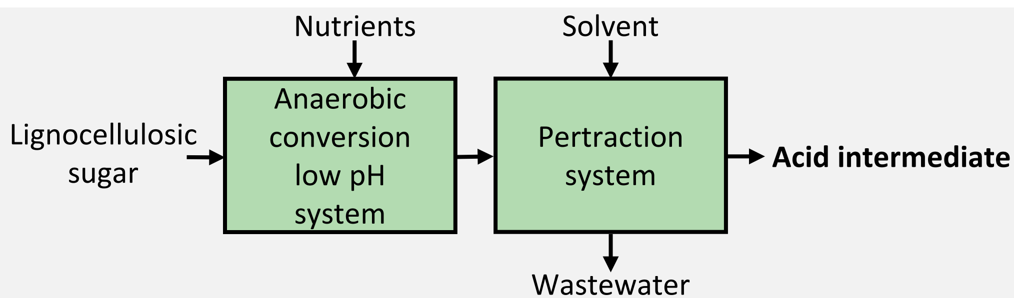
Simulated moving bed (SMB) – Off-the-shelf technology



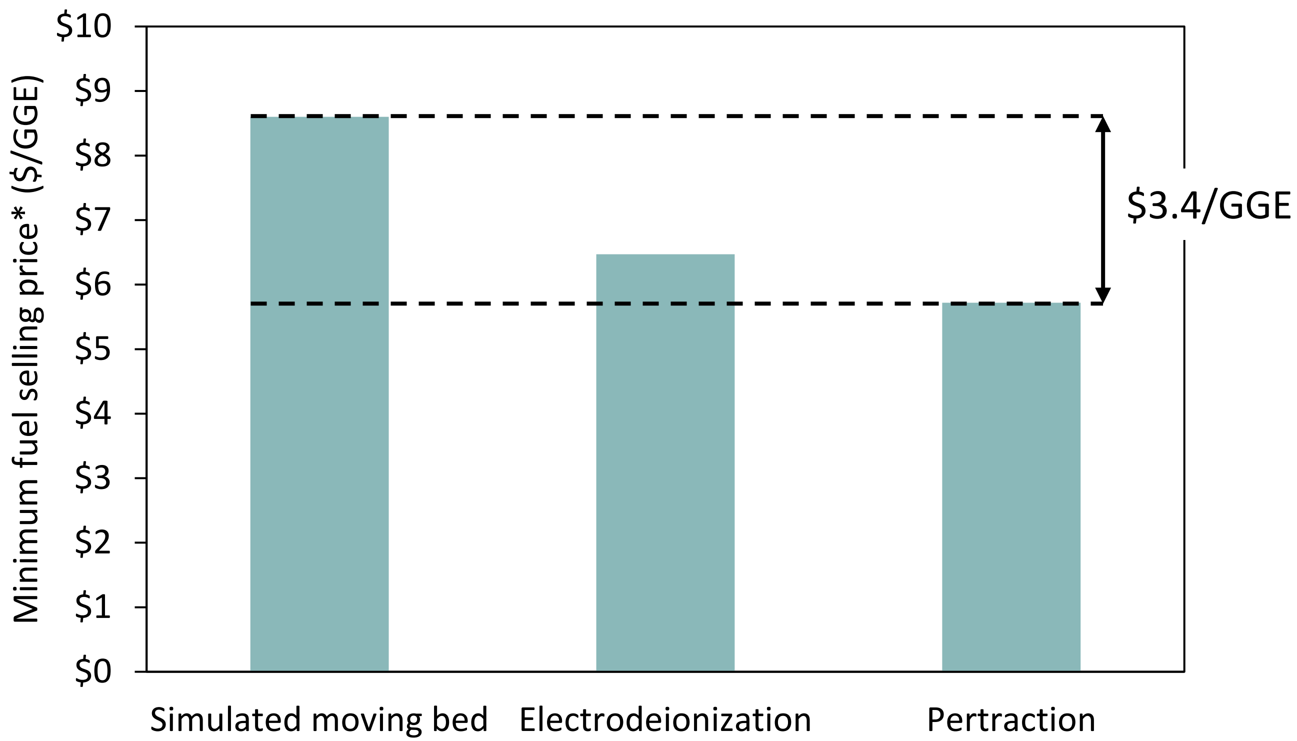
Electrodeinoization (EDI) – SepCon technology



Pertraction – SepCon technology



TEA to estimate minimum selling price

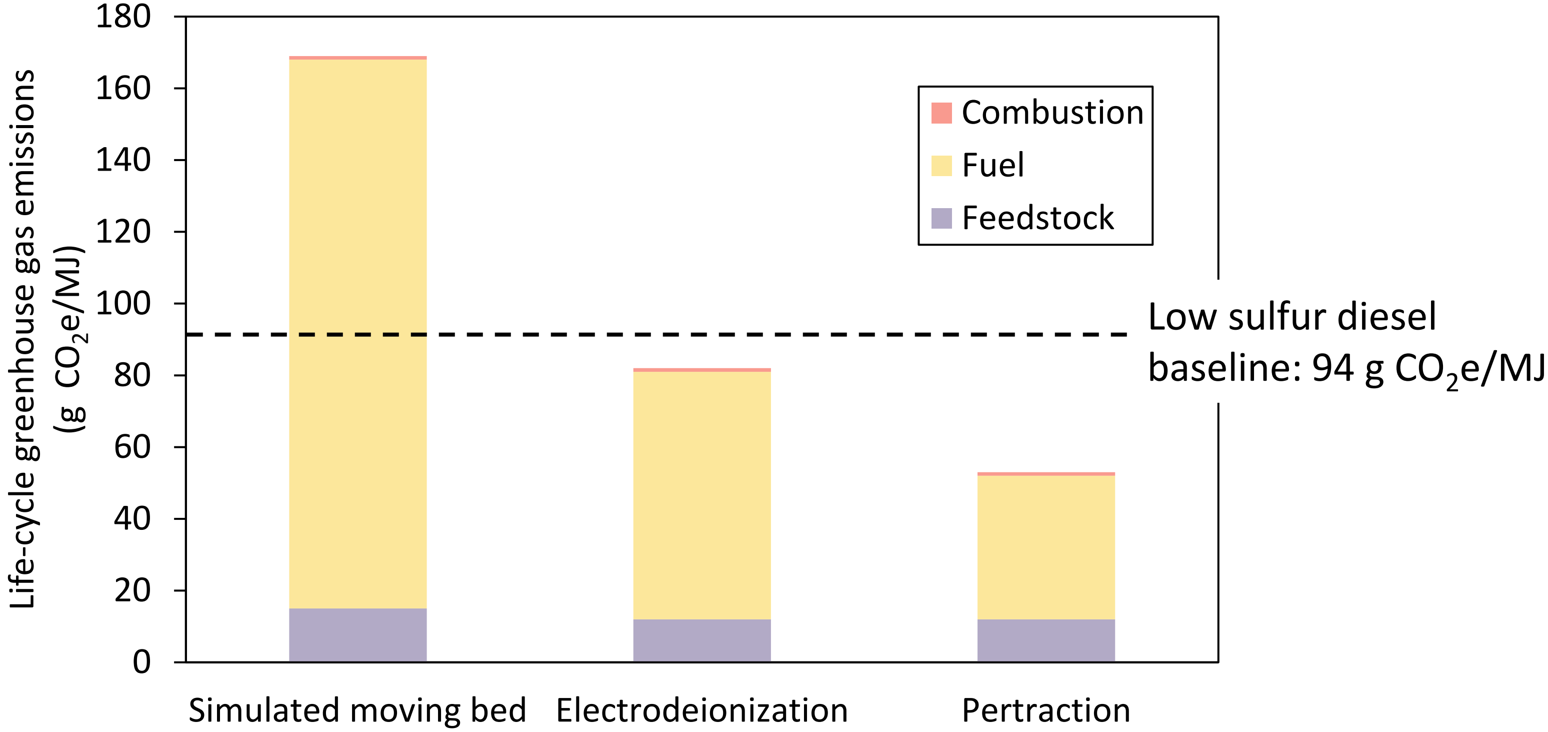


** Lignin co-products not considered*

Differences in overall MFSP are attributed to the separation technology

Compared to baseline technology, EDI and pertractive separations the potential to lower separations costs

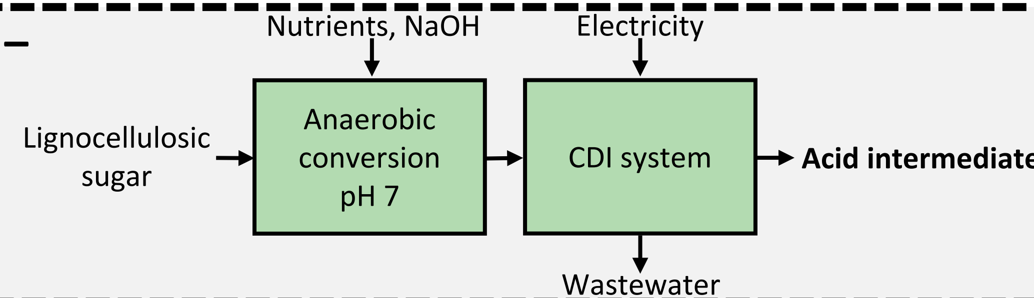
LCA to estimate GHG emissions



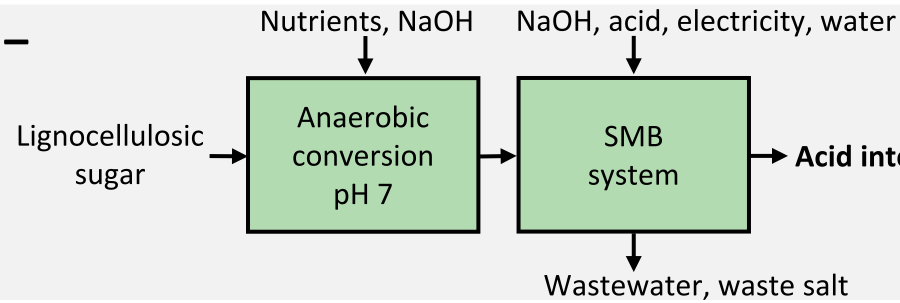
Compared to baseline technology, EDI and pertractive separations result in lower life-cycle GHG emissions for renewable diesel produced

NaOH consumption is key driver for GHG emissions

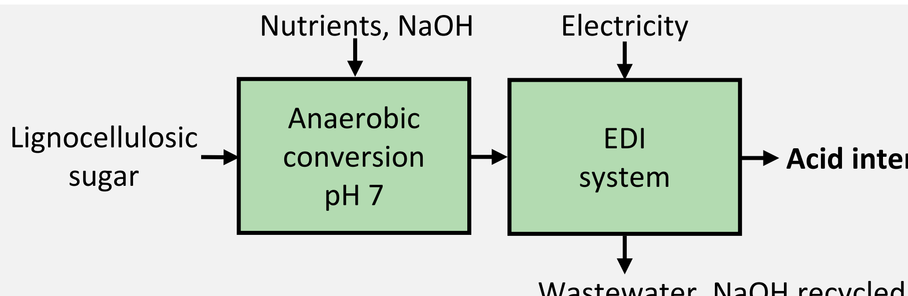
Capacitive deionization (CDI) – Consortium technology



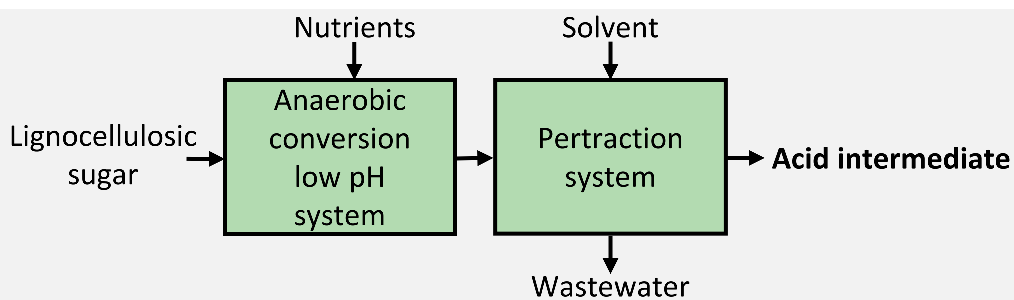
Simulated moving bed (SMB) – Off-the-shelf technology



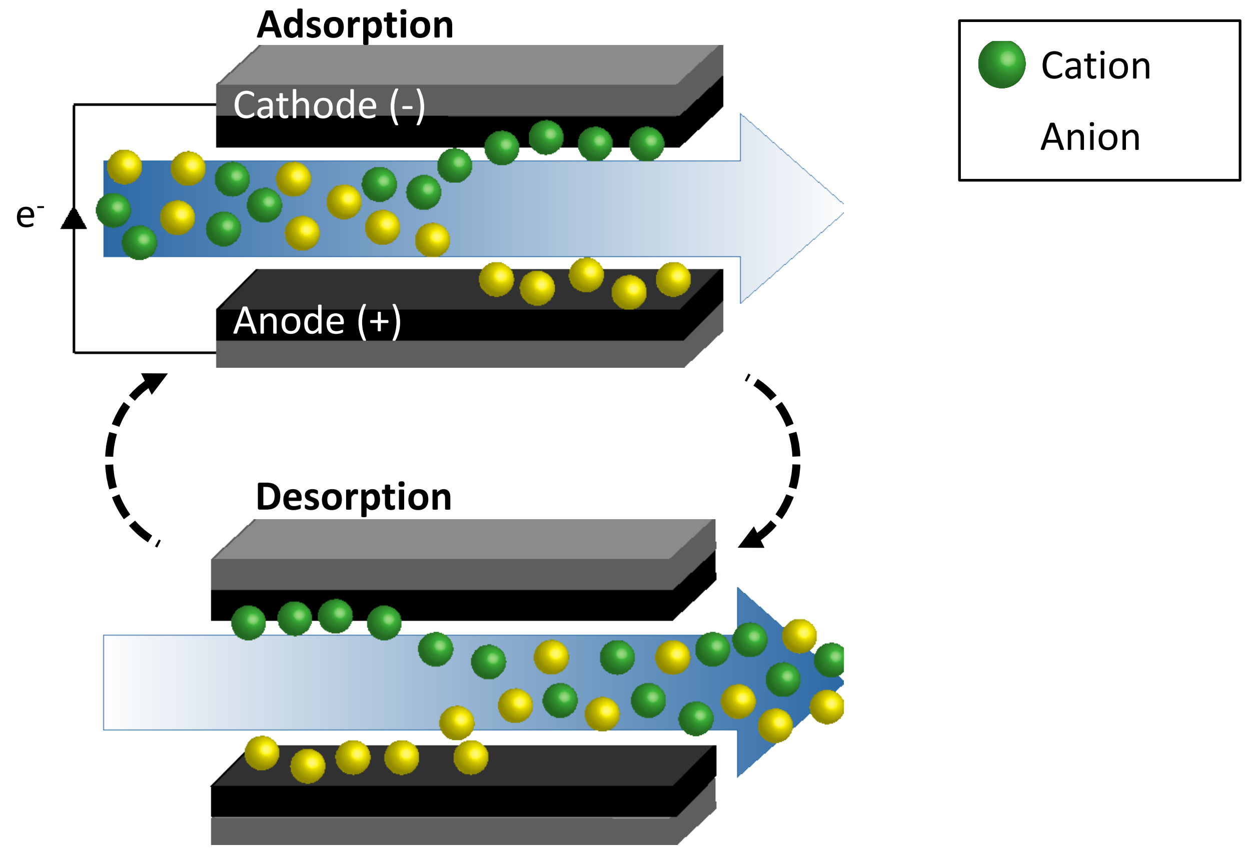
Electrodeinoization (EDI) – Consortium technology



Pertraction – Consortium technology

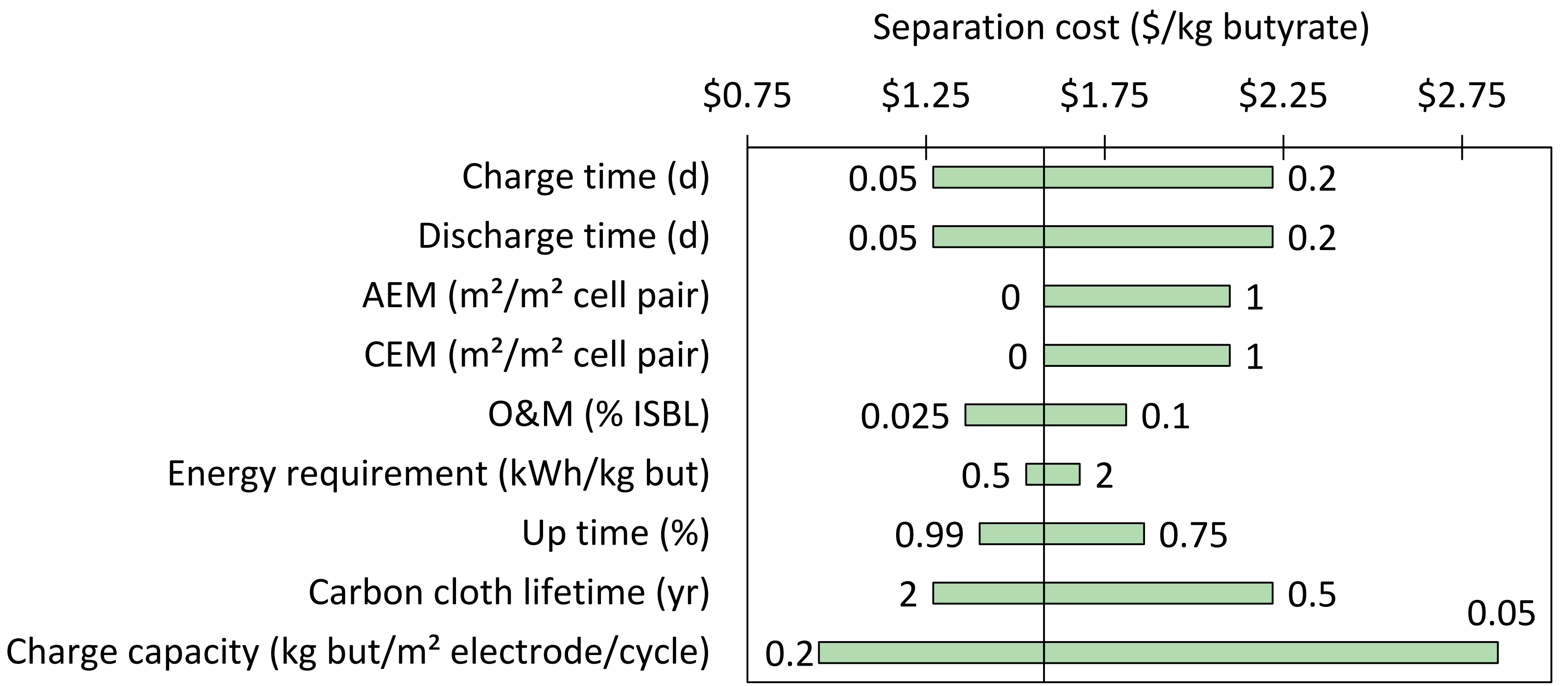


Capacitive deionization



Electric potential drives ion transport towards the electrodes where the ions are stored (adsorption) until the electric potential is reversed or removed resulting in the release of ions (desorption)

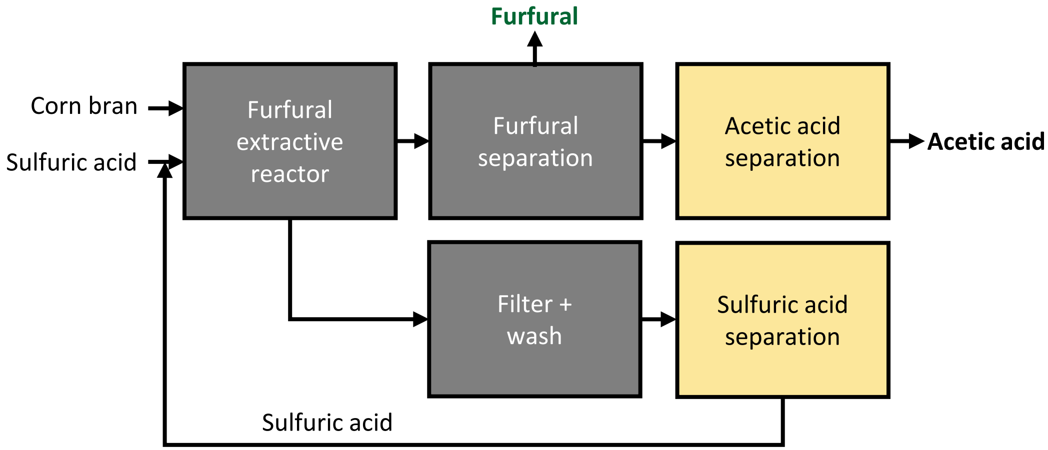
Sensitivity analysis for CDI system performance



Capacity and cycle time (charge + discharge time) are key cost drivers with CDI for separation of butyrate

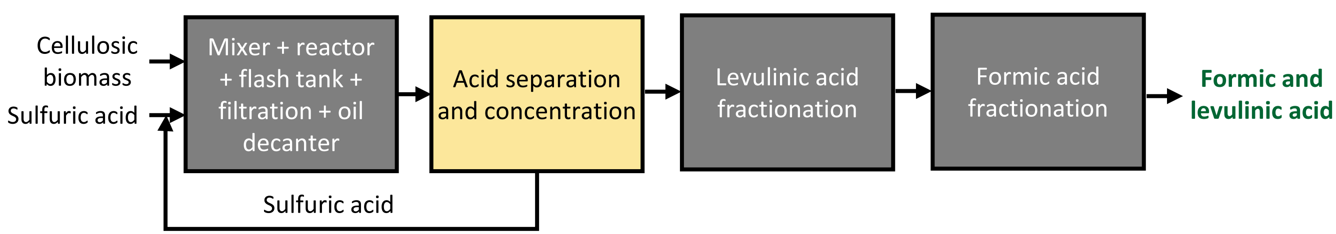
Other applications for electrochemical technologies in bioprocessing

Conventional furfural process



Electrochemical technology reduces minimum furfural selling price from $1460/MT to $1325/MT

Levulinic acid production



Elimination of LLE and evaporation could reduce levulinic acid selling price by 3x

**Block flow diagrams are simplified*

Integrated analysis to drive R&D

Assess technical, economic, & environmental feasibility of bioproduct/biofuel conversion processes

- Detailed process analysis with rigorous mass and energy balances
- Identify data needs and further R&D need to improve overall cost and efficiency
- Assess environmental impacts (greenhouse gas emissions, fossil fuel consumption, and water consumption)

Challenges

- Data availability and quality
- Uncertainty of capital cost for new and novel technologies
- Ensuring rigor of separations process modeling, particularly when considering scale-up

Acknowledgements

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Gayle Bentley, Nichole Fitzgerald, Ben Simon, Clayton Rohman

Argonne NATIONAL LABORATORY

- YuPo Lin
- Phil Laible
- Ed Barry

BERKELEY LAB

- Ning Sun
- Eric Sundstrom

OAK RIDGE National Laboratory

- Aimee Church
- Michael Hu (retired)

Los Alamos NATIONAL LABORATORY EST. 1943

- Taraka Dale
- Jim Coons
- Bill Kubic

NREL NATIONAL RENEWABLE ENERGY LABORATORY

- Gregg Beckham
- Eric Karp
- Eric Tan
- Mary Biddy (now at BP)

Pacific Northwest NATIONAL LABORATORY

- Mike Thorson
- Charlie Freeman
- Vanda Glezakou
- Sue Jones (retired)

Thank you for your attention!

Contact: lvalentino@anl.gov