



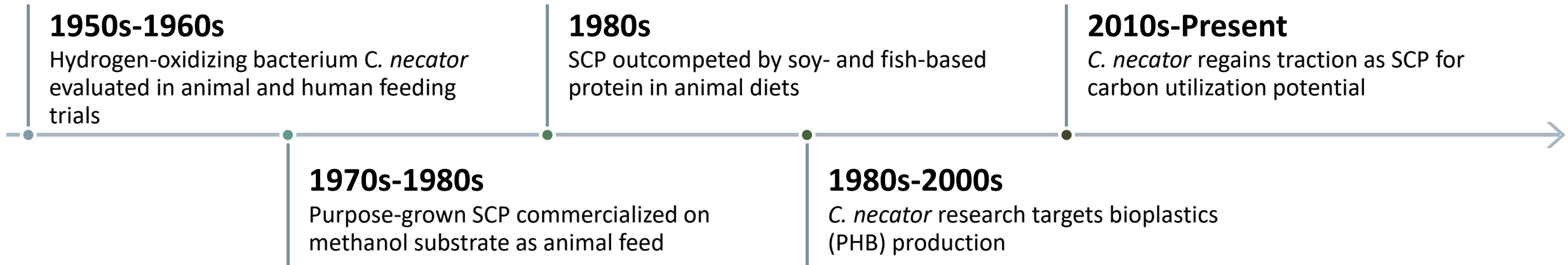
CO₂ upgrading to single cell protein: a comparative assessment of conventional fermentation and emerging pathways

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Cupriavidus necator (*C. necator*) has a long history as a single cell protein (SCP) candidate



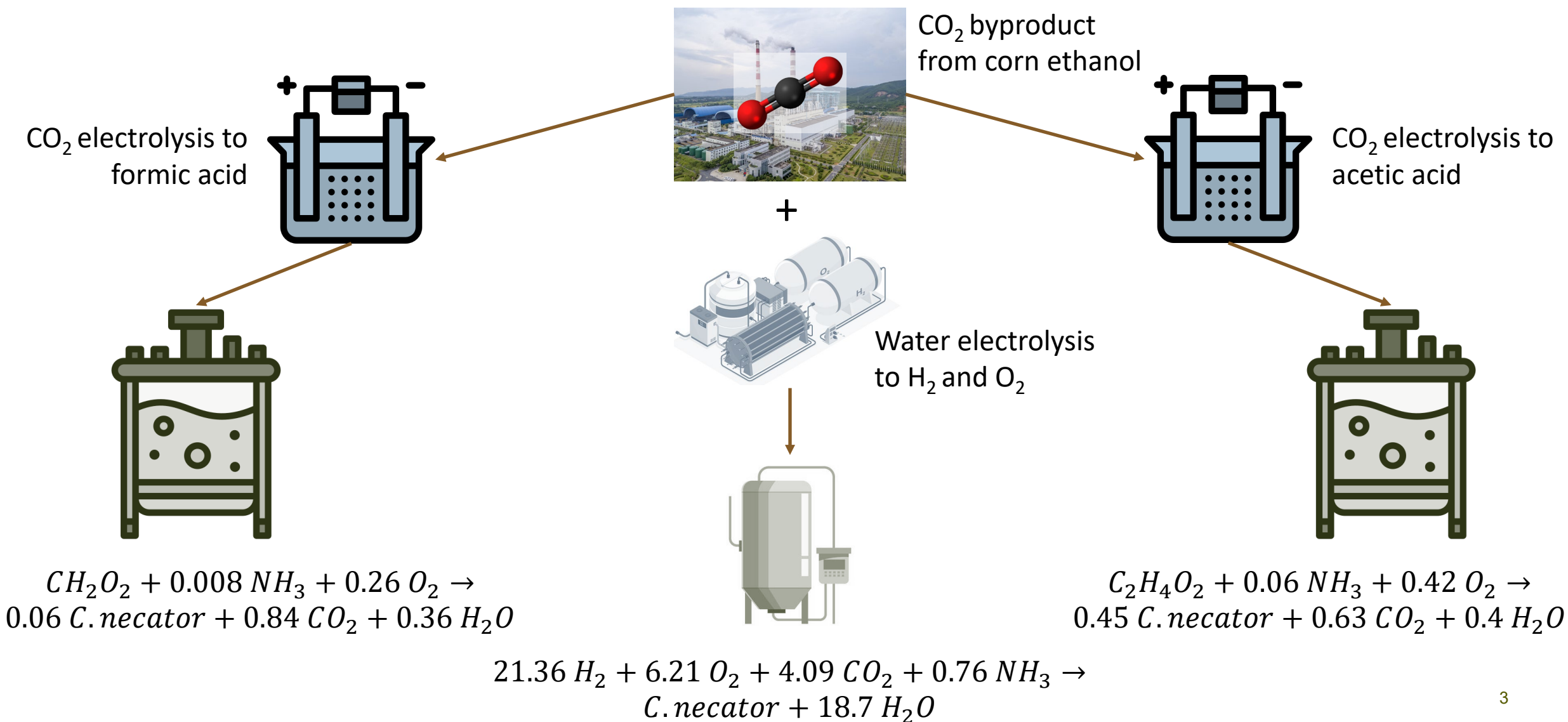
Advantages

- 50%-80% protein content
- Near-complete amino acid profile
- Metabolic flexibility
- Existing commercialization and regulatory framework

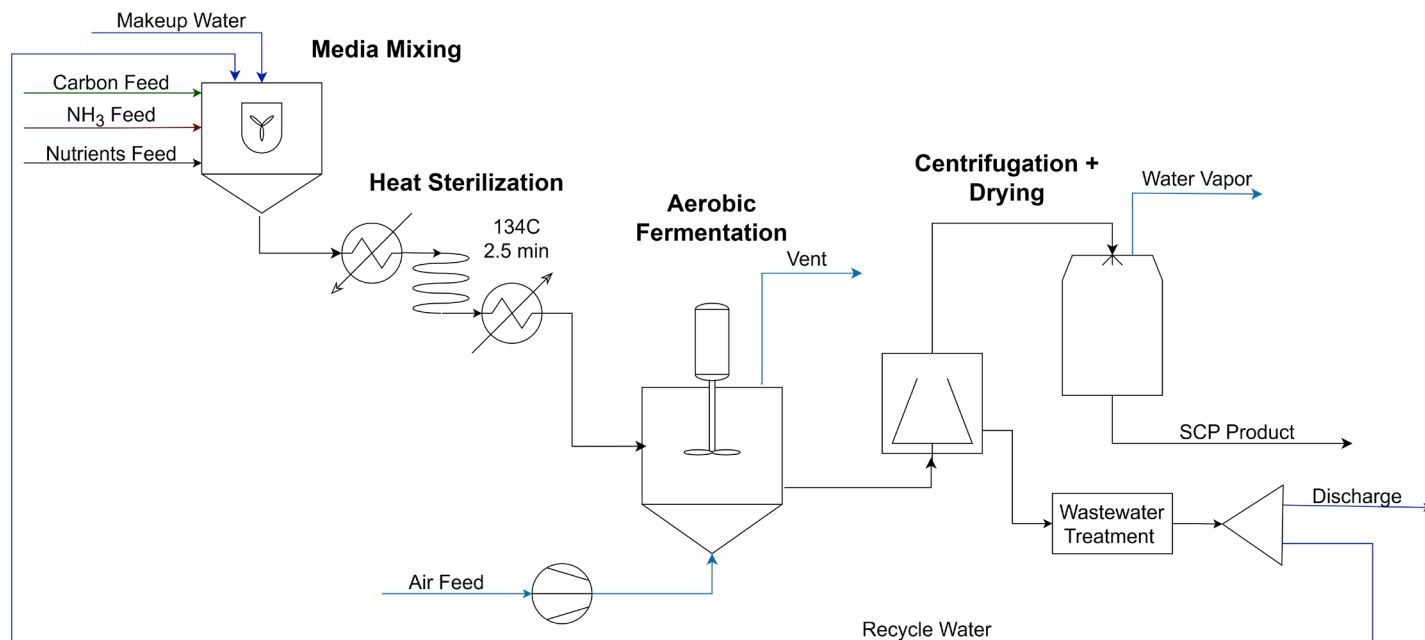
Challenges

- Unresolved economic viability
- Substrate delivery bottlenecks
- Nucleic acid content
- Protein vs. bioplastic production optimization
- Consumer acceptance

A shared fermentation platform enables comparison of alternative pathways for CO₂ utilization



Aerobic fermentation pathways evaluated in similar system models with route-specific chemistry and kinetics



Shared Parameters

- Production target: 25,000 MT/yr
- Nutrients feed: 0.39 g/g biomass
- Operating hours: 7752 h/yr
 - 2 restarts/line/yr
- Fermentation
 - 30°C
 - $D = 0.8\mu_{\max}$
 - $\varepsilon = 0.9$
- Centrifuge recovery: 95%
- Recycle fraction: 75%

Fructose

Baseline Comparison

- $\mu_{\max}$: 0.22 h⁻¹
- $Y_{x/s}$: 0.32 g/g
- Target Titer: 24 g/L

Acetic Acid

Electrolysis Limited

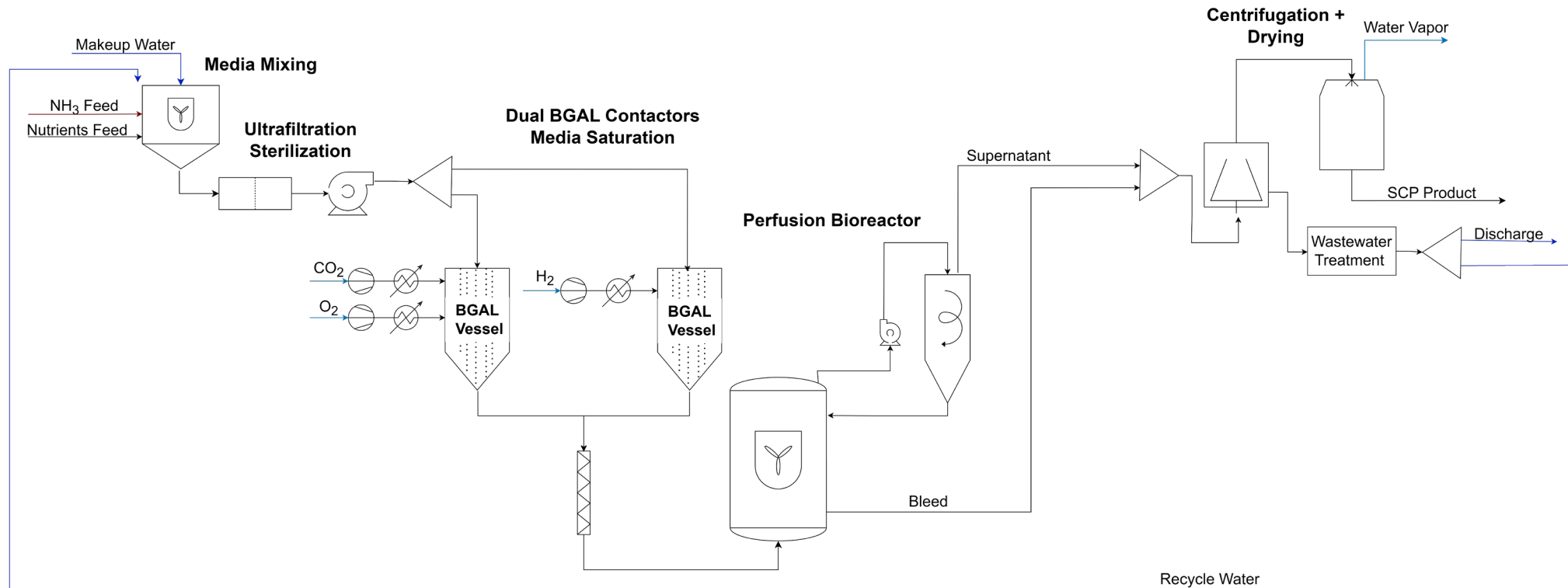
- $\mu_{\max}$: 0.15 h⁻¹
- $Y_{x/s}$: 0.45 g/g
- Target Titer: 11 g/L

Formic Acid

Growth Limited

- $\mu_{\max}$: 0.18 h⁻¹
- $Y_{x/s}$: 0.06 g/g
- Target Titer: 1.6 g/L

Explosion hazards and solubility limitations necessitate a novel approach for gas fermentation route



Dual Bulk Gas-to-Atomized Liquid (BGAL) Contactors

Explosion Hazard + Mass Transfer Limitations

- H₂ Concentration: 0.0051 g/L
- O₂/CO₂ Concentration: 0.1 g/L
- High mass transfer rate = low residence time

Perfusion Bioreactor

Low Dissolved Gas Concentration

- $\mu_{\max}$: 0.12 h⁻¹
- $Y_{X/S}$: 2.26 g/g H₂
- Solids retention time (10h) vs. Hydraulic retention time (0.4h)
- Cell density ceiling: 0.01 g/L → 0.25 g/L

Techno-economic and life cycle assessment used to evaluate four pathways

Goal and scope

- Cradle-to-gate
- Functional unit: 1 kg SCP product
- Production Basis: 25,000 MT/yr *C. necator* SCP

TEA methodology

- Process modeling and TEA: BioSTEAM
- Capital Costing: Bare-module method ($FCI = 1.18 \sum C_P F_{BM}$)
- Financial basis: 2025 USD
- Key result metric: Minimum Selling Price

LCA methodology

- Inventory assessment: BioSTEAM
- LCA: OpenLCA
- Impact assessment method: ReCiPe 2016 (Midpoint H)
- Primary KPI: Global warming potential
- Data sources: LCA commons, literature LCAs
- Capital goods: 20 yr amortization
- CO₂ Assumptions: Biogenic point source with ultimate release

	Feed Cost (\$/kg)
Fructose	1.16
Electrolytic Acetic Acid	0.65
Electrolytic Formic Acid	0.35
Electrolytic H ₂	4.83

	GWP (kg CO ₂ -eq/kg)
Fructose	1.5
Electrolytic Acetic Acid	5.6
Electrolytic Formic Acid	3.3
Electrolytic H ₂	0.39

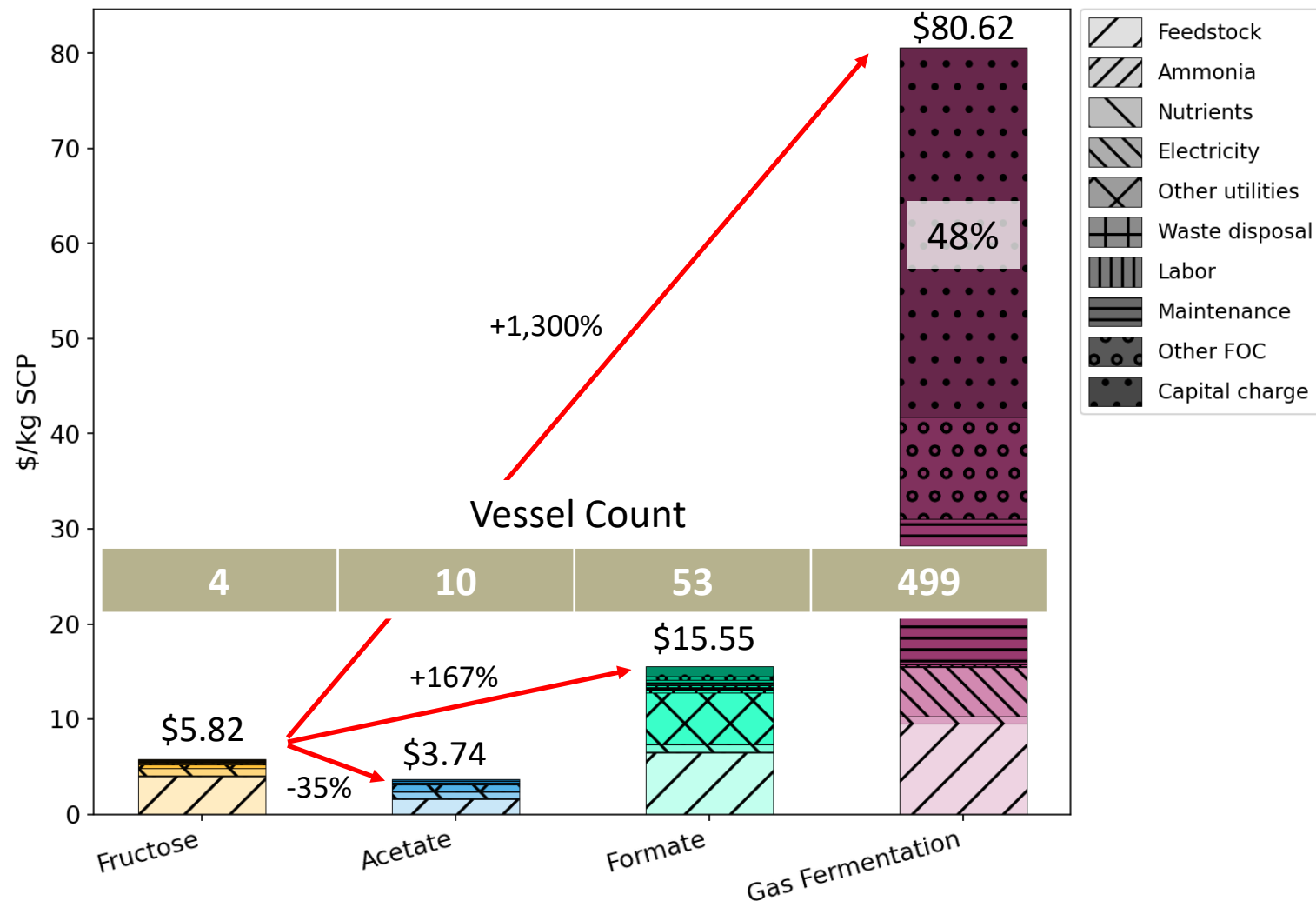
Acetate pathway shows economic advantages over traditional sugar fermentation

Liquid Routes

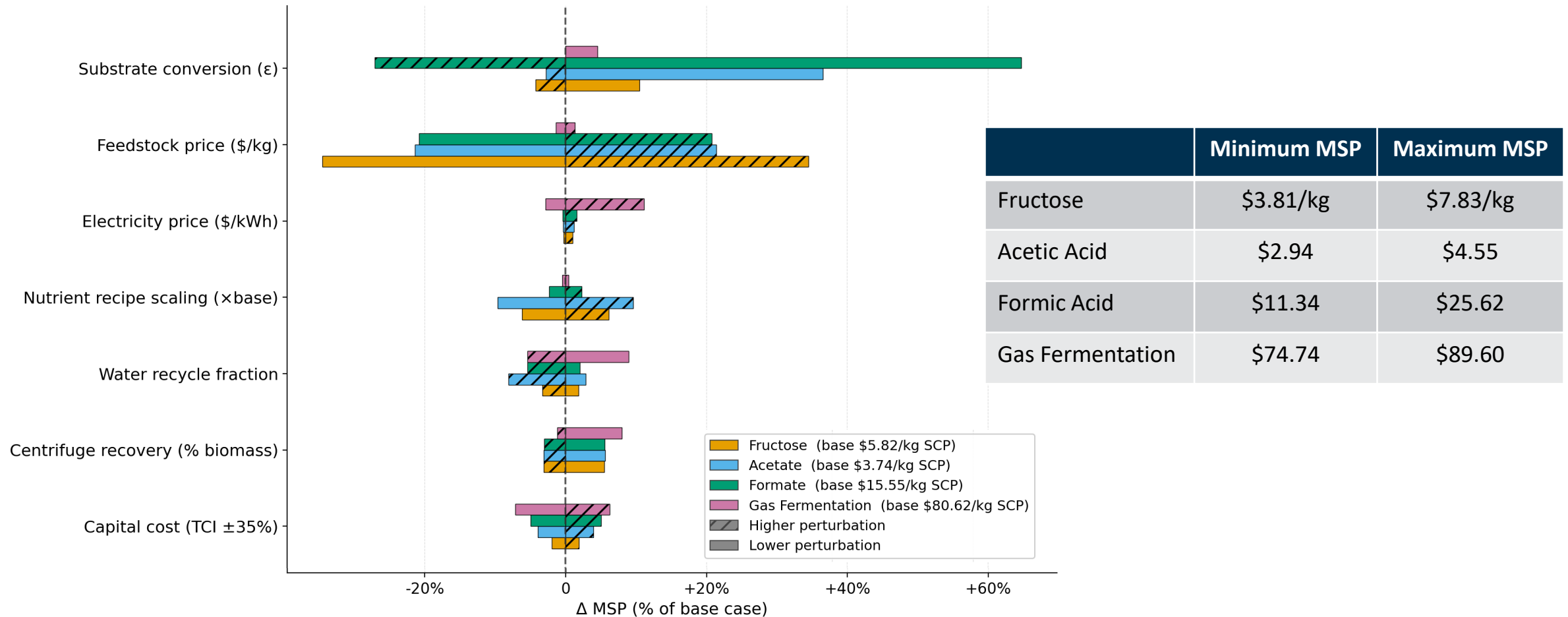
- Vessel count scales inversely with achievable titer
- OPEX dominated
- Heat sterilization adds financial burden

Gas Fermentation

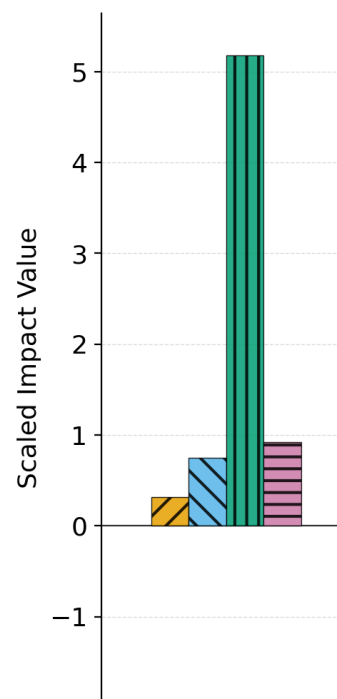
- Large vessel count – low gas solubility
- Droplet columns require parallel scaling
 - H_2 : 143
 - O_2/CO_2 : 31
- CAPEX dominated
- Heat sterilization infeasible – ultrafiltration alternative



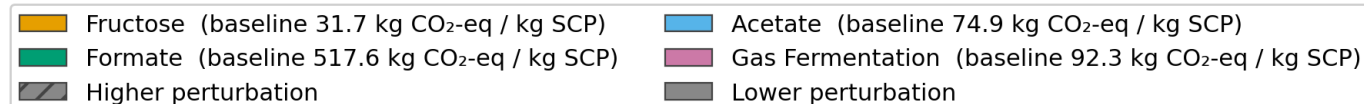
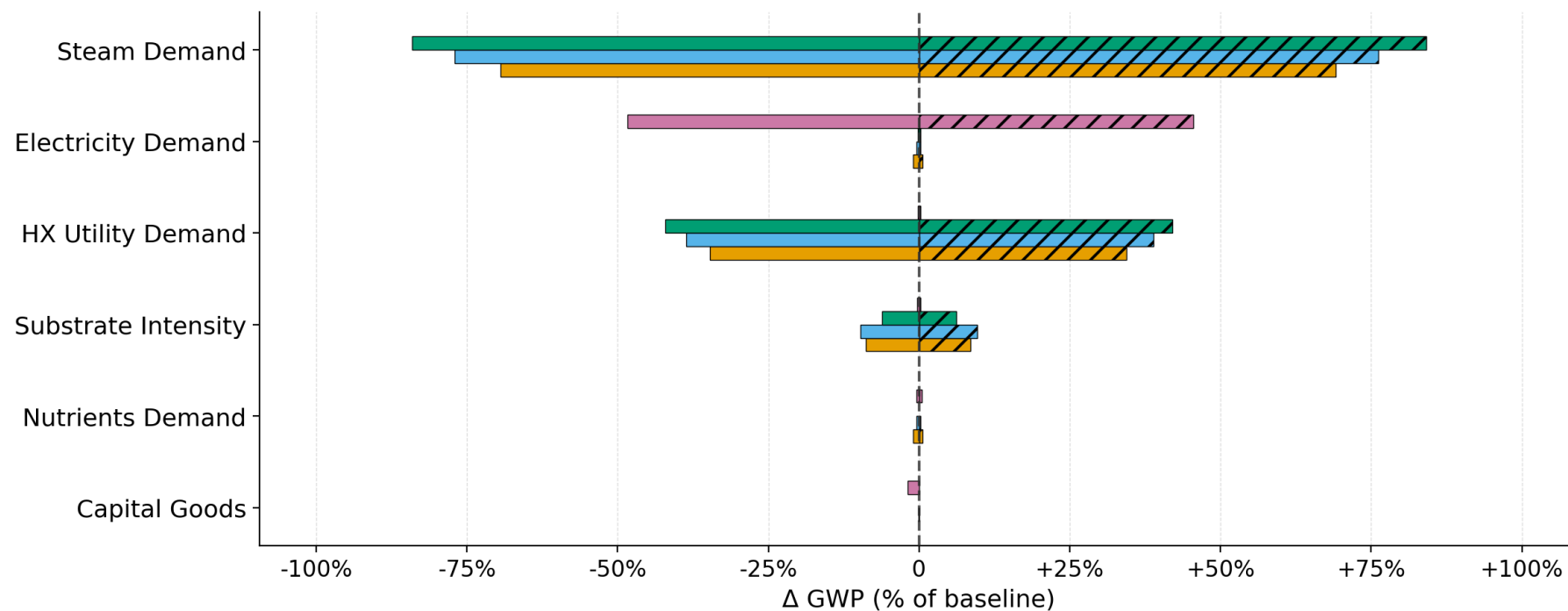
Liquid pathways are feedstock price and conversion dominated; gas fermentation does not indicate much potential for cost reduction



Global warming impacts largely driven by heat sterilization thermal inputs



Global Warming
kg CO₂eq (x10²)



No single pathway shows superiority across all performance metrics

Fructose

- MSP: \$5.82/kg
- GWP: 32 kg CO₂-eq/kg

Acetic Acid

- MSP: \$3.74/kg
- GWP: 75 kg CO₂-eq/kg

Formic Acid

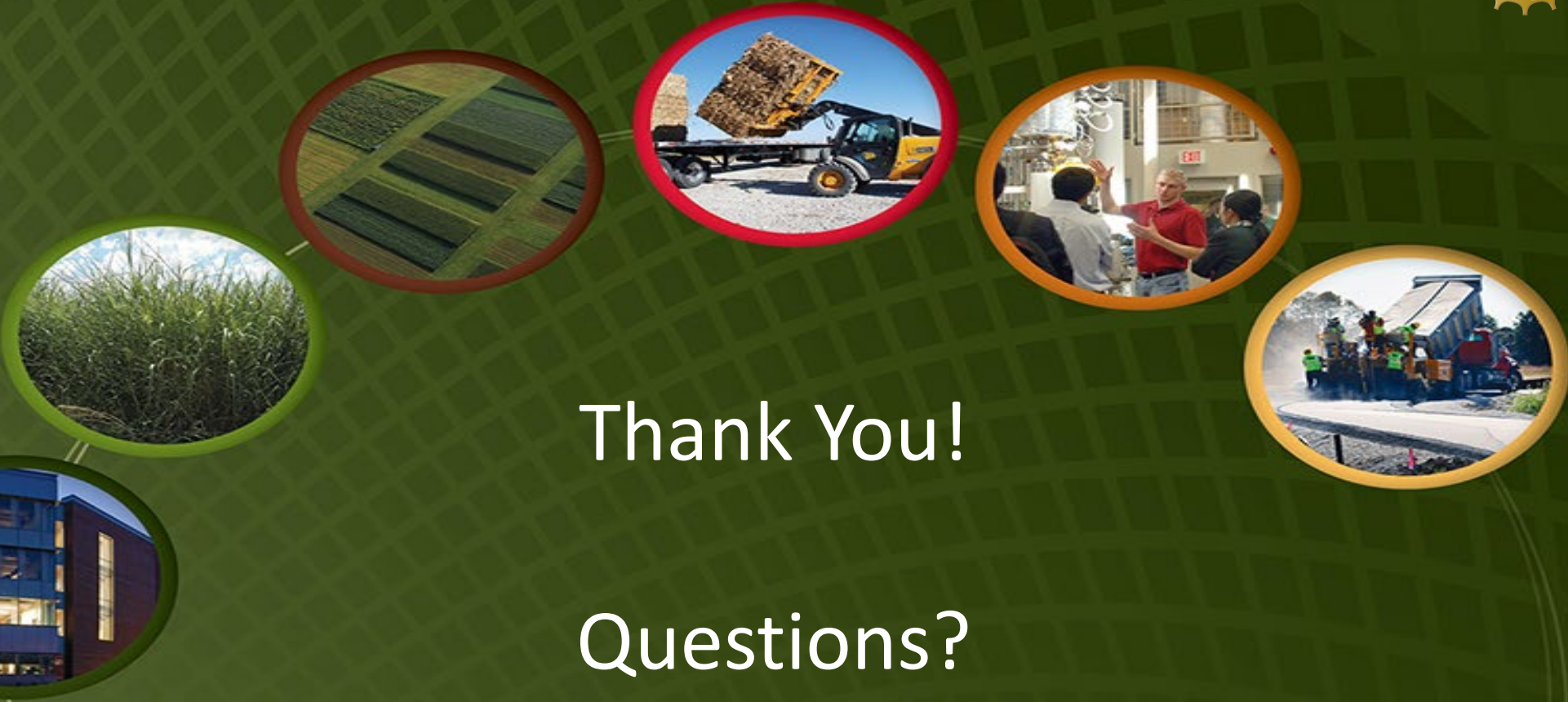
- MSP: \$15.55/kg
- GWP: 518 kg CO₂-eq/kg

Gas Fermentation

- MSP: \$80.62/kg
- GWP: 92 kg CO₂-eq/kg

Identified research priorities:

- Examine heat sterilization alternatives
- Perform energy integration
- Expand CO₂ electrolysis capacity
- Increase substrate conversion of alternative carbon feeds
- Improve cellular resilience in high-concentrations of alternative carbon feeds
- Examine bioplastics as alternative product pathway within existing framework



Thank You!

Questions?