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2009 Update of the NREL biomass-to-ethanol biochemical process design report

IEA Bioenergy Conference
Vancouver

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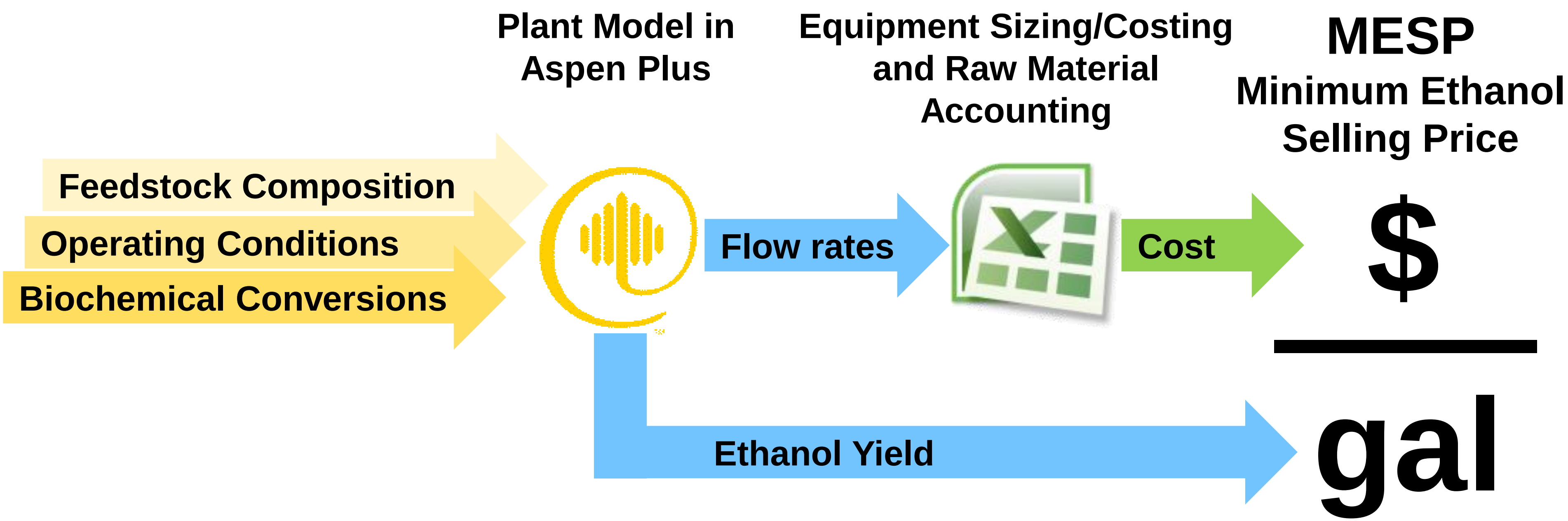
with Harris Group, Inc.

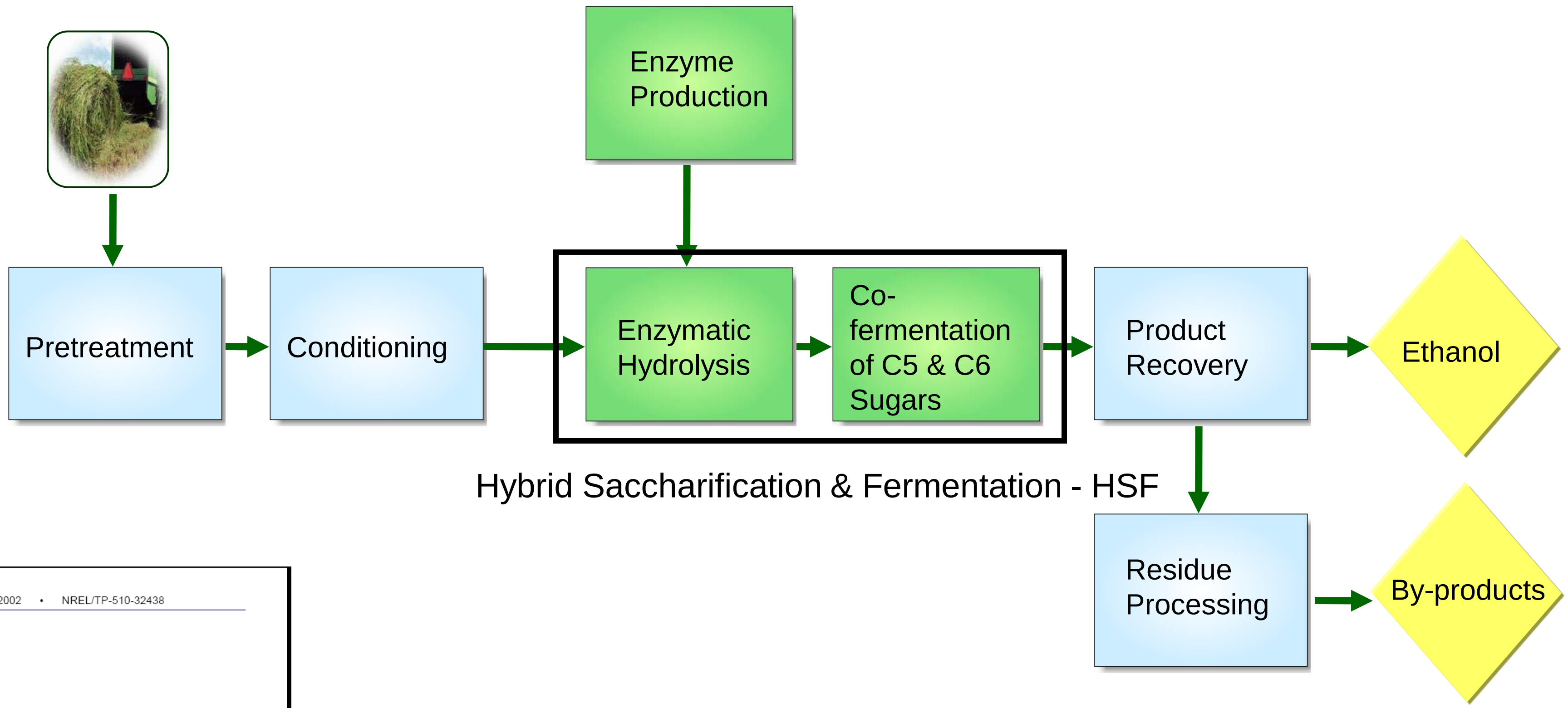
August 25, 2009

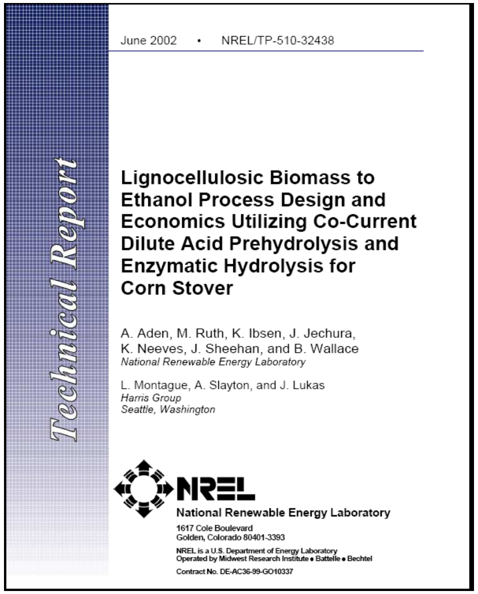
Technoeconomic Modeling



- Modeling is rigorous and detailed with clear and transparent assumptions
- Assumes *n*th-plant equipment costs
- Discounted cash-flow ROR calculation includes (e.g.) return on investment, equity payback, and taxes
- Determines the minimum ethanol selling price required for zero NPV at plant end-of-life (MESP > COP)

2002 Biochemical Design Report





June 2002 • NREL/TP-510-32438

Technical Report

Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover

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- Conceptual design of a 2,200 dry ton/day commercial plant
- Documents one possible technology package for cost-effective ethanol
- Establishes a benchmark for comparison of other technology options
- Quantifies economic impact of research progress and helps set goals
- Permits better industrial collaboration
- Has been reviewed by industry, academia, and government

Motivation for the 2009 design report update

- Incorporate recent research learning into 2012 model
- Optimize design
  - Water reduction and power utilization
  - Consider different configurations
- Update equipment decisions
  - Detailed vendor quotes for key unit operations
  - New costs for standard equipment in 2009$
- Revisit major assumptions
- Improve model stability and usability

- ***Significant changes made to all process areas***

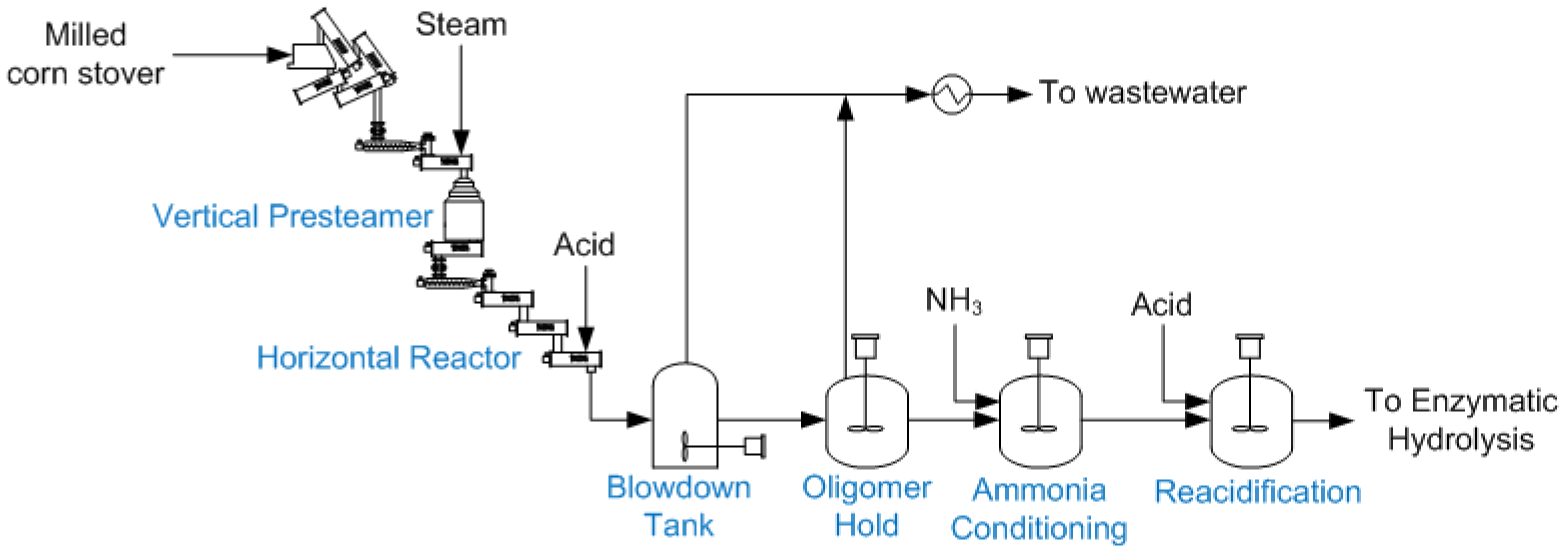
Corn stover feedstock composition

- 2002 feedstock composition was an average of 9 samples from two batches
- Glucan was determined to be too high based on a 2007-2008 round-robin study
- 2009 composition is based on a single sample
- Economic implications
  - Less total sugar = lower yield of 81.5 gal/ton vs 90 in 2002
  - Lower lignin = smaller electricity credit
  - Extractives component is essentially inert in the model

Component Dry wt%	*2002*	*2009*
Glucan	37.4	33.12
Xylan	21.1	20.64
Lignin	18	11.62
Ash	5.2	4.78
Acetate	2.9	2.77
Protein	3.1	1.45
Extractives	4.7	17.88
Arabinan	2.9	3.87
Galactan	2	1.53
Mannan	1.6	0
Unknown Soluble Solids	1.1	2.35
Total	100	100

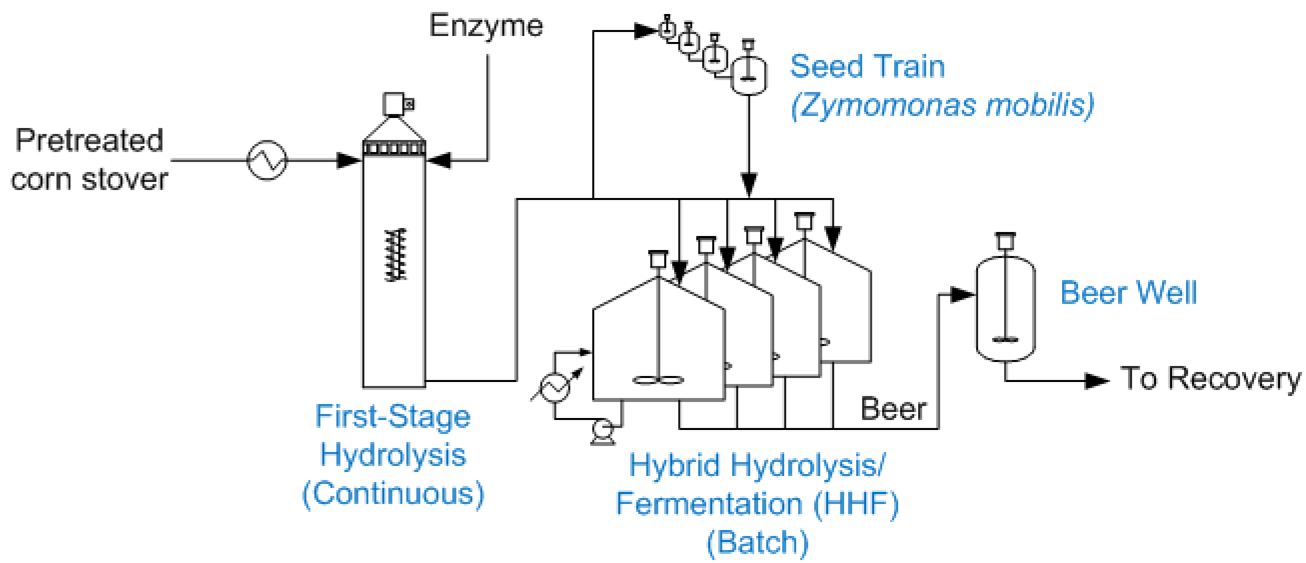
Feedstock cost is $50.90/dry ton, including all handling and transport to pretreatment

Dilute-acid pretreatment



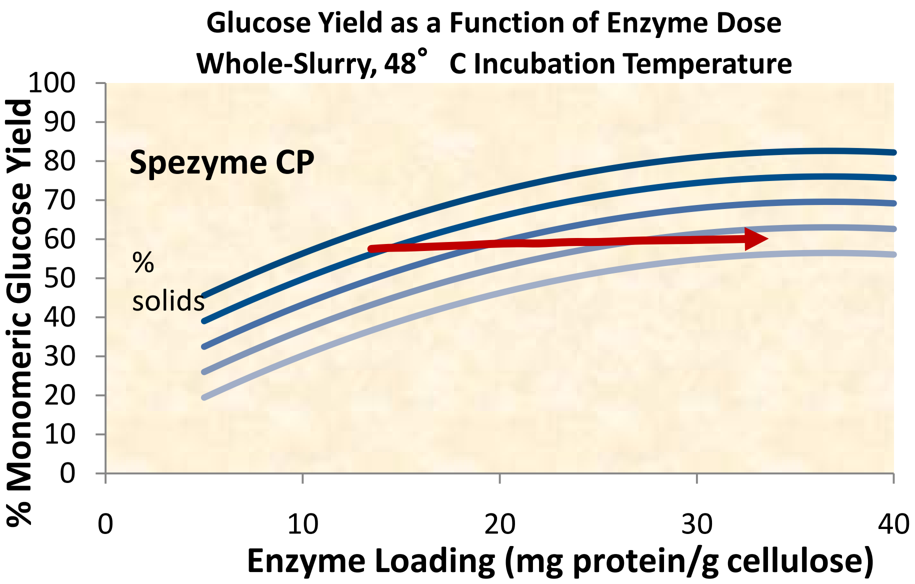
- **2002:**
  - Anco-Eaglin reactor design (based on a rendering unit)
  - Solid/liquid separation of pretreated material with lime conditioning on the liquid only
- **2009:**
  - Purpose-designed reactor from Andritz, Inc.
  - Whole-slurry conditioning with ammonia
  - Secondary hold step converts xylose oligomers to monomers

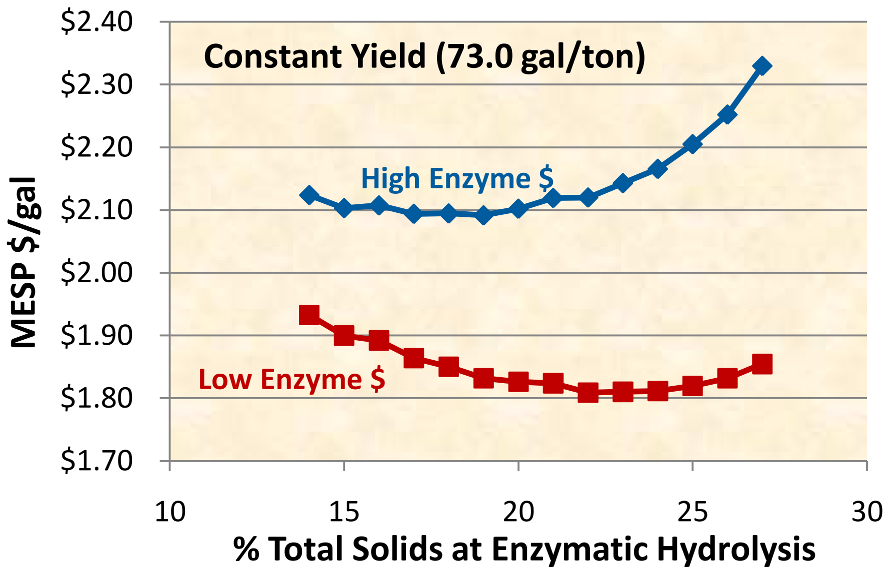
Enzymatic hydrolysis & fermentation



- **2002:**
  - Separate hydrolysis and fermentation in a continuous train
- **2009:**
  - High-solids first-stage hydrolysis reactor (targeting 20 wt% total solids)
  - Hydrolysis continues in a batch reactor
  - Fermentation is initiated in the same reactor before hydrolysis is complete (hybrid SHF/SSF)

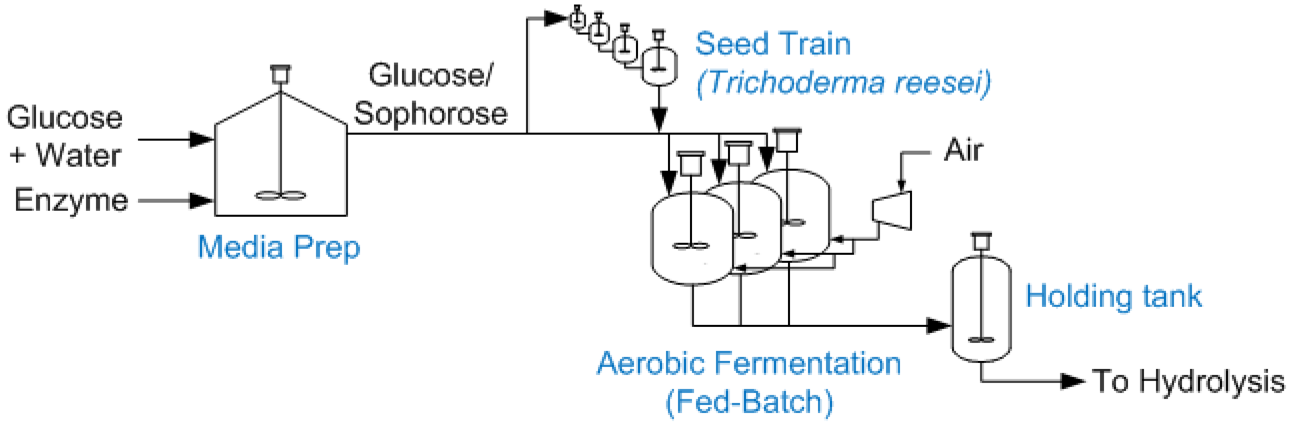
Solids loading at enzymatic hydrolysis





- There is an economic benefit to performing hydrolysis at higher solids loading
- Enzyme activity falls off at higher solids loading but enzyme dose can be increased to overcome lower conversion
- For a constant ethanol yield, there is an optimum %solids that depends on the enzyme price
- Lower enzyme prices (i.e. 2012 DOE target prices) push the hydrolysis optimum operating regime toward “high solids” loading (>20%)

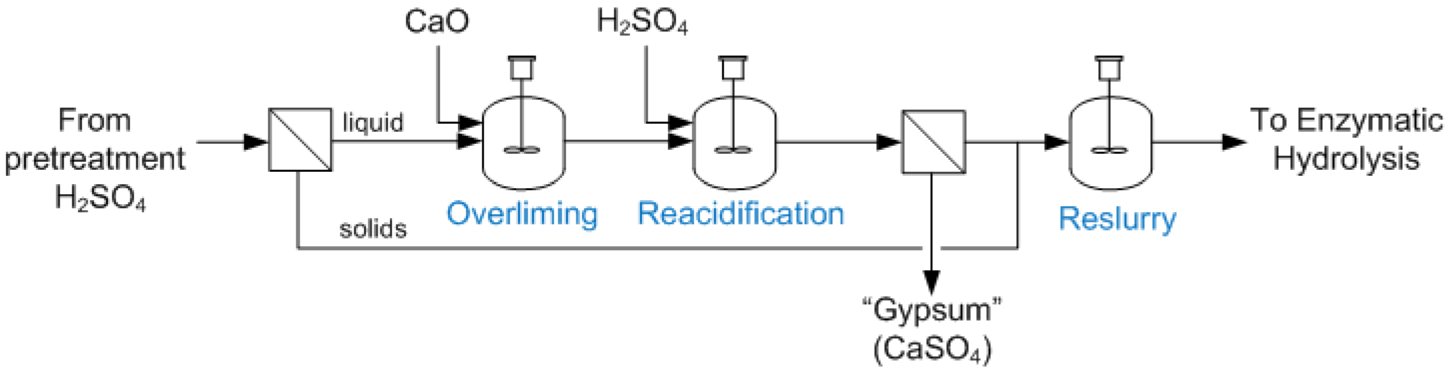
On-site enzyme production



- **2002:**
  - Purchased enzyme model with fixed cost contribution ($0.12/gal)
- **2009:**
  - Detailed model of a smallish enzyme production facility
  - Aerobic growth of *T. reesei* on glucose substrate
  - Genencor's economic sophorose conversion step is assumed
  - Provides more transparency on the actual economics of enzyme production

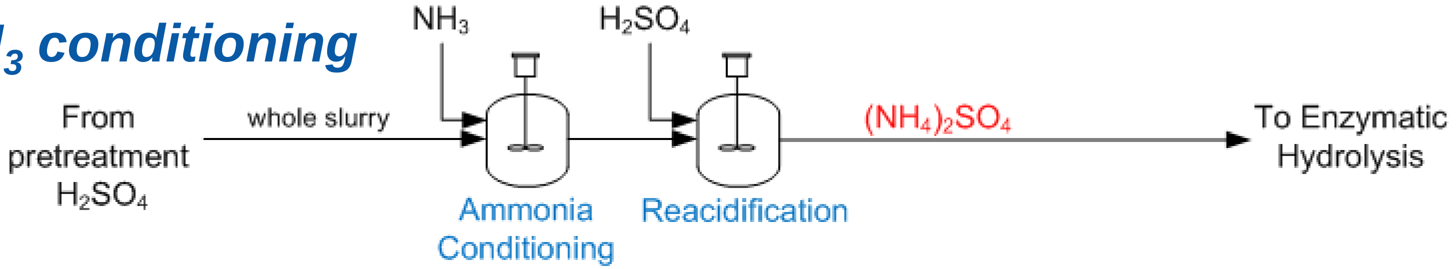
Changes and challenges in the back-end

Overliming



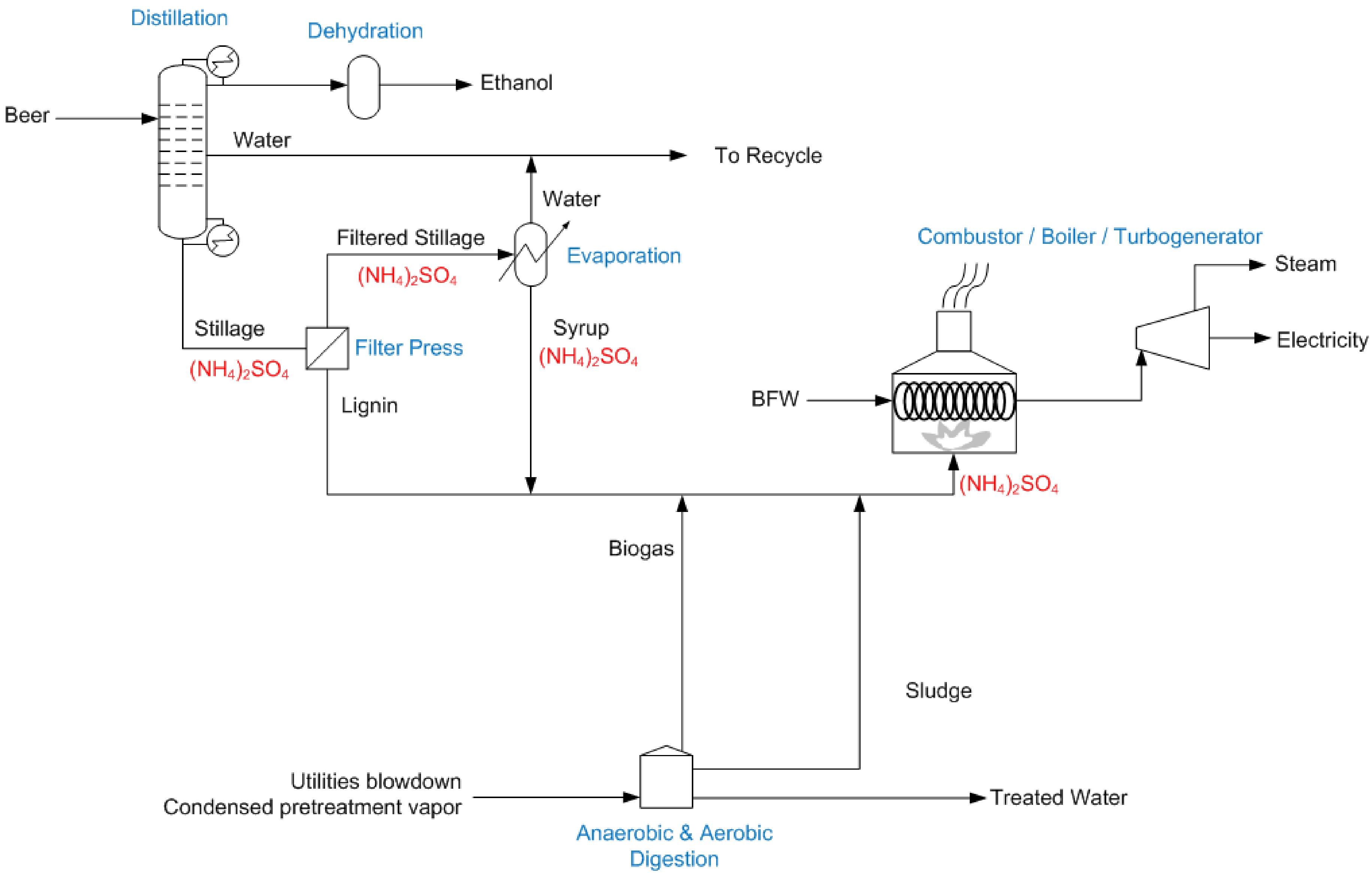
- Inorganic compounds are removed as a wet solid
- Significant xylose sugar is lost with the solid
- This solid is probably toxic and would require remediation before disposal

Whole-slurry NH_3 conditioning

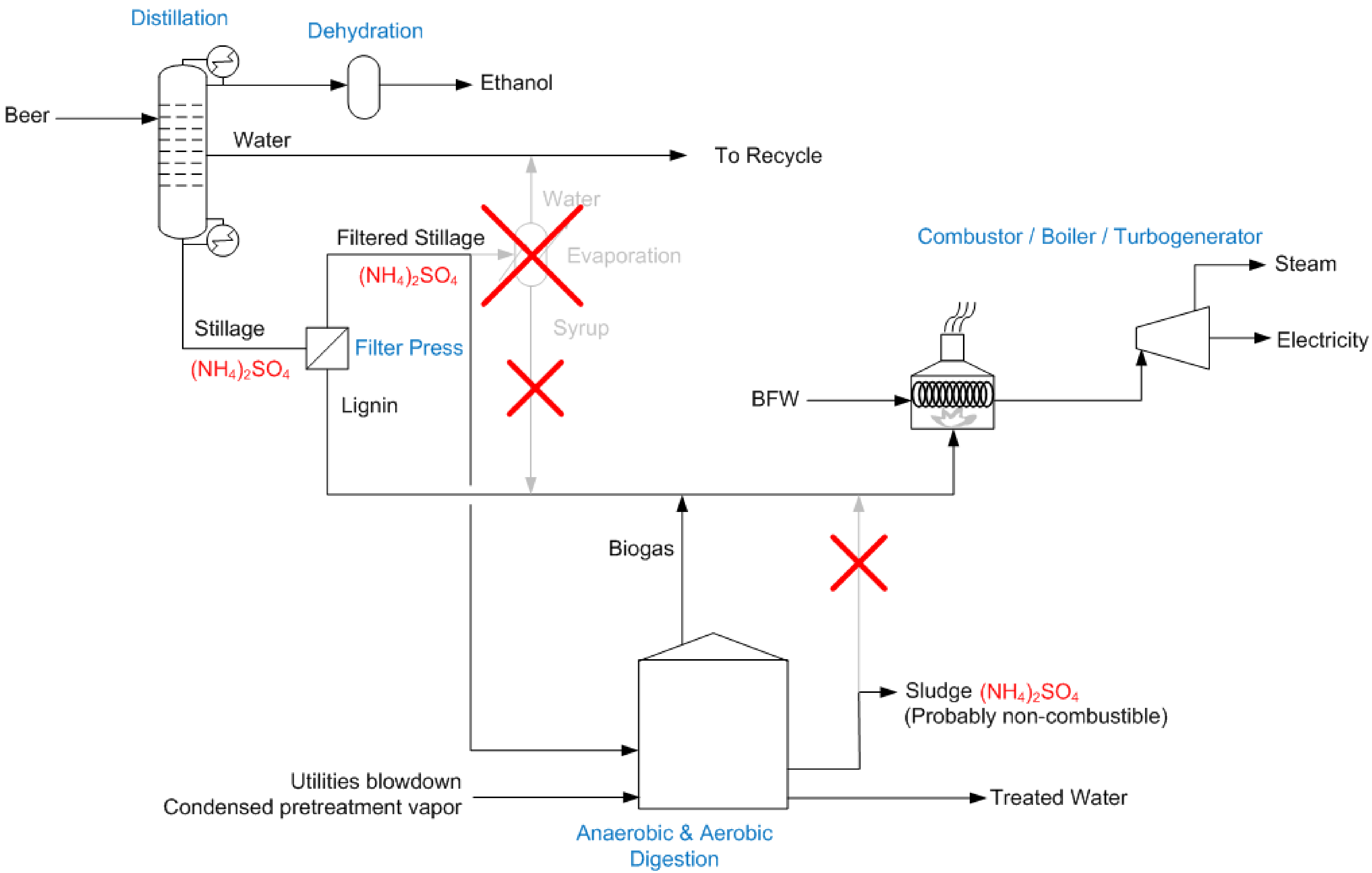


- Much simpler process; no solid-liquid separations required
- Minimal sugar losses
- Ammonia is expensive compared to lime
- Inorganic compounds stay in the process and wind up in the boiler

Existing back-end process



New back-end process



Water demand reduction

- 2002 Water usage was ~6 gal/gal
  - High compared to corn dry mill and thermochemical ethanol
  - We feel an obligation to reduce this where possible
- >50% of water losses are from the cooling tower
  - Elimination of the evaporator system is a significant savings
- Other water-saving process changes have been identified
  - Elimination of condensing turbine (=lower electricity credit)
  - Air-cooled exchangers for major cooling water users
- 2 gal/gal has been demonstrated using all known water-saving measures
- The most economic of these measures will be implemented
- Sustainability metrics will be a focus of the design report ("LCA-ready")

Work remaining and timeline

- Oct 08 – Aug 09: Aspen model updated, Harris obtained quotes for major process equipment
- 8/4/09: Held a meeting with researchers and internal stakeholders to present the new process and get agreement on key design assumptions
  - Some significant changes were required in Aspen as a result
  - No additional non-standard equipment items
- Aug – Sep 09: Finish the Aspen, get remaining costs
- Sep 09: Report writing
- Oct – Nov 09: Peer review (reviewers needed)
- Dec 09: Issue NREL technical report

Acknowledgements

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http://www.eere.energy.gov/biomass

NREL Biorefinery Analysis Team

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References:

Feedstock: http://www.inl.gov/bioenergy/uniform-feedstock