NREL/PO-510-31788
March 2002

Project Goal

Objective

Develop and demonstrate economical bioethanol technology based on ***enzymatic cellulose hydrolysis***

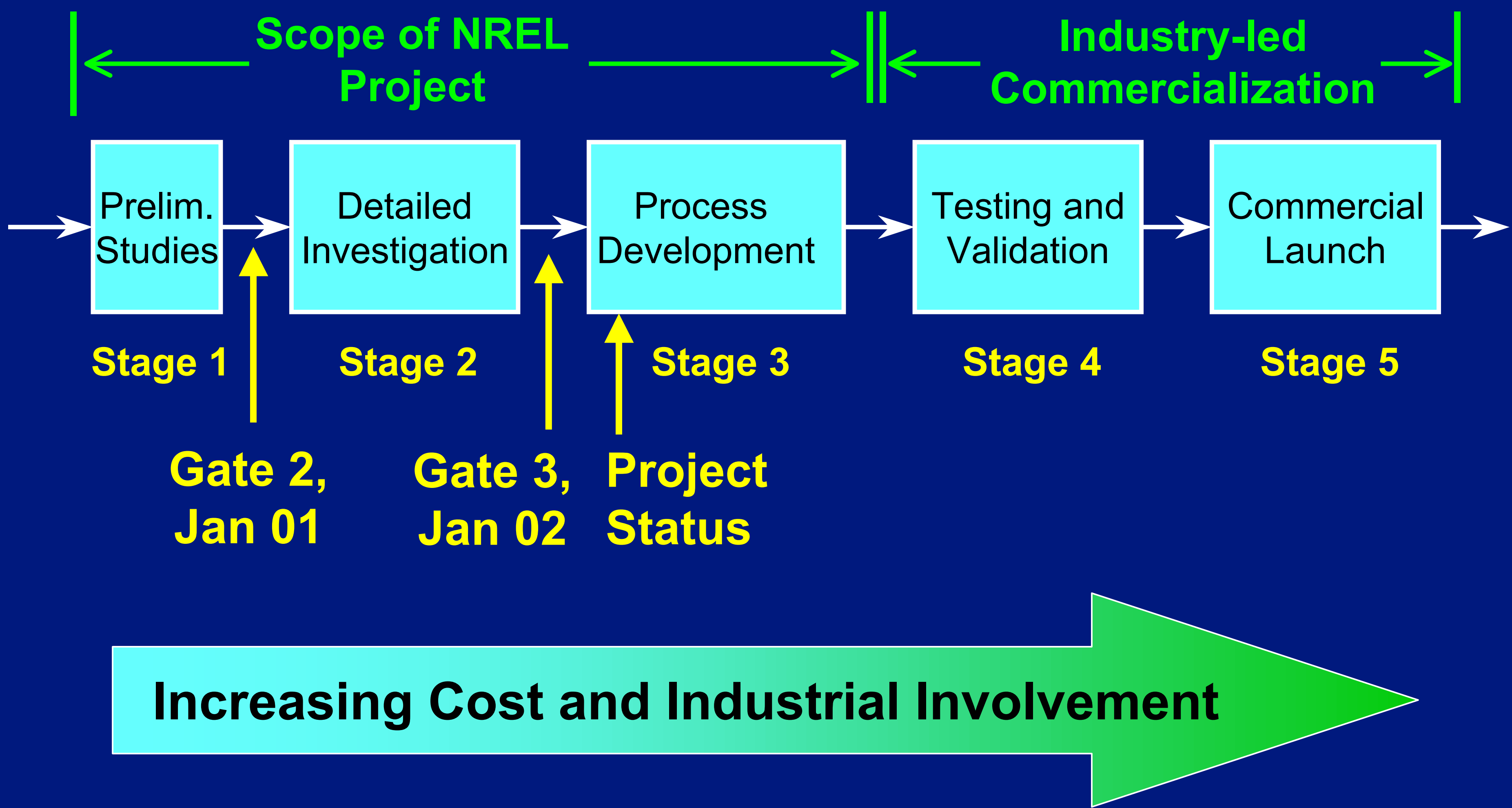
Production Volume Goal

Develop the technology for an abundant biomass resource that can support production of at least ***3 billion gallons*** of ethanol per year

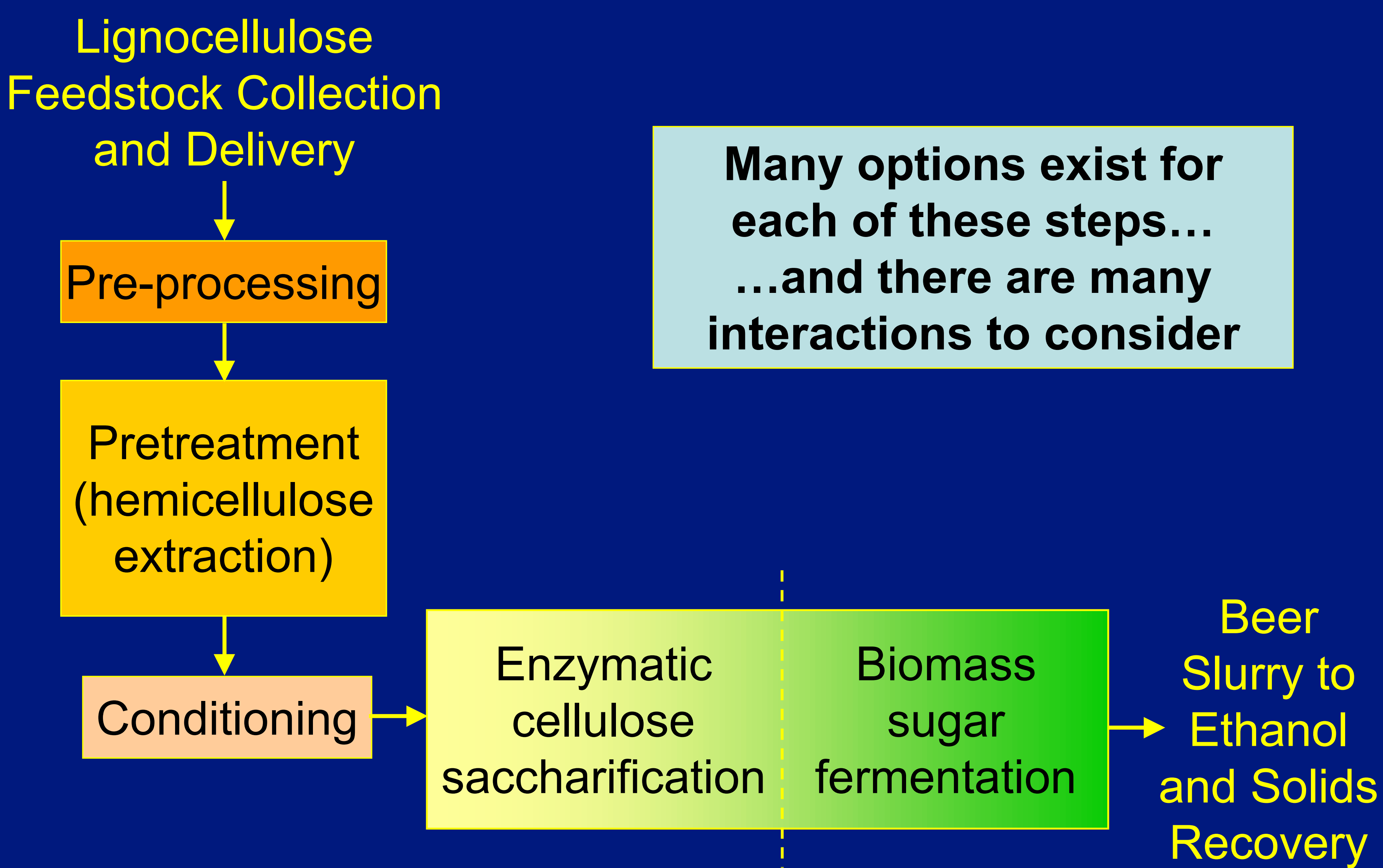
Strategic Fit

- This project plays a central role in the USDOE's Bioethanol Technical Plan
  - Largest and most integrated project
  - Builds on other major program efforts
  - Enables core biorefinery technology
  - Demonstrates environmental "life cycle" benefits
- Success of niche pioneer plants will build a commercial experience base and reduce risk
- Success of enzyme developers currently working to reduce enzyme cost will provide the key enabling technology

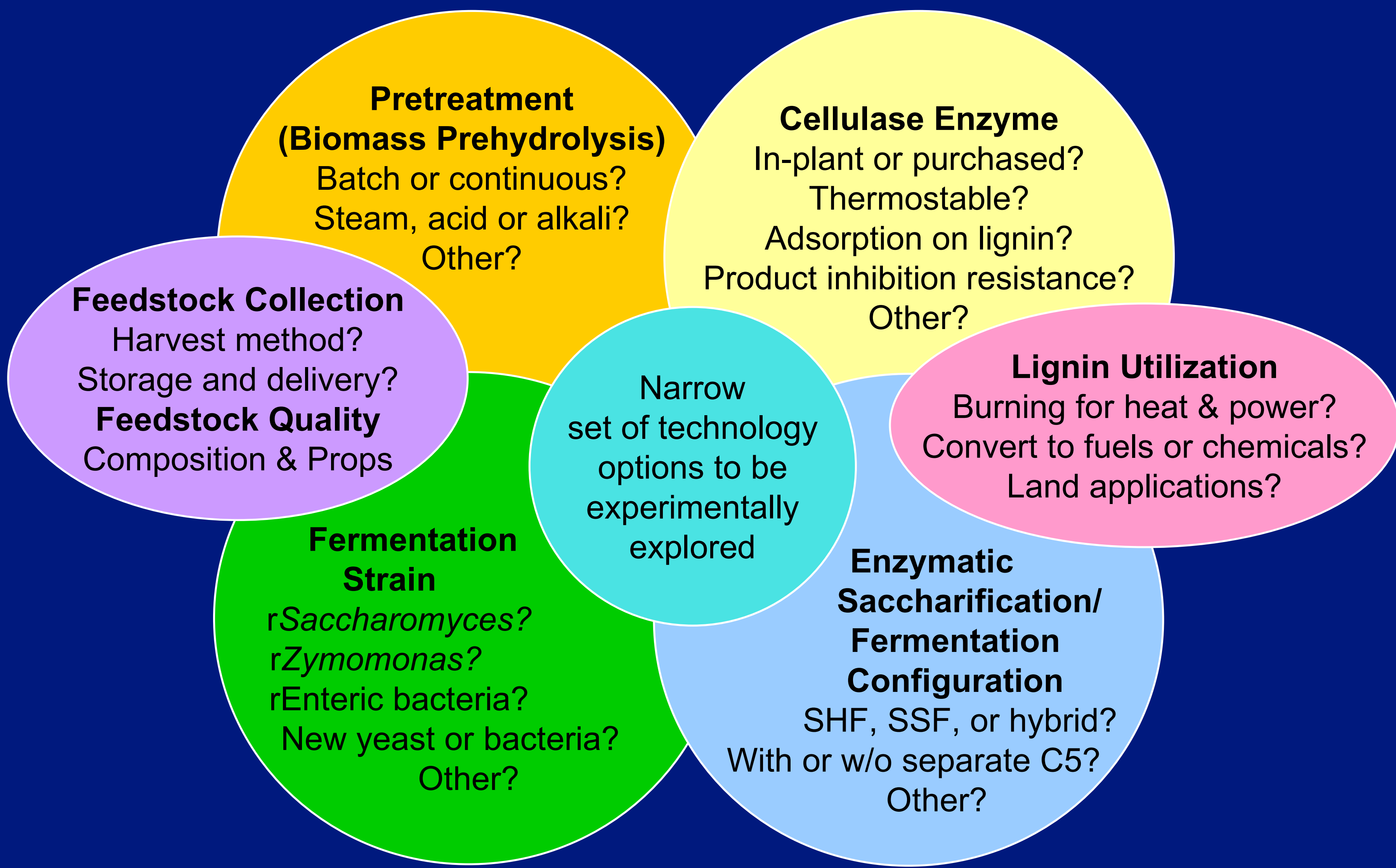
Project Scope



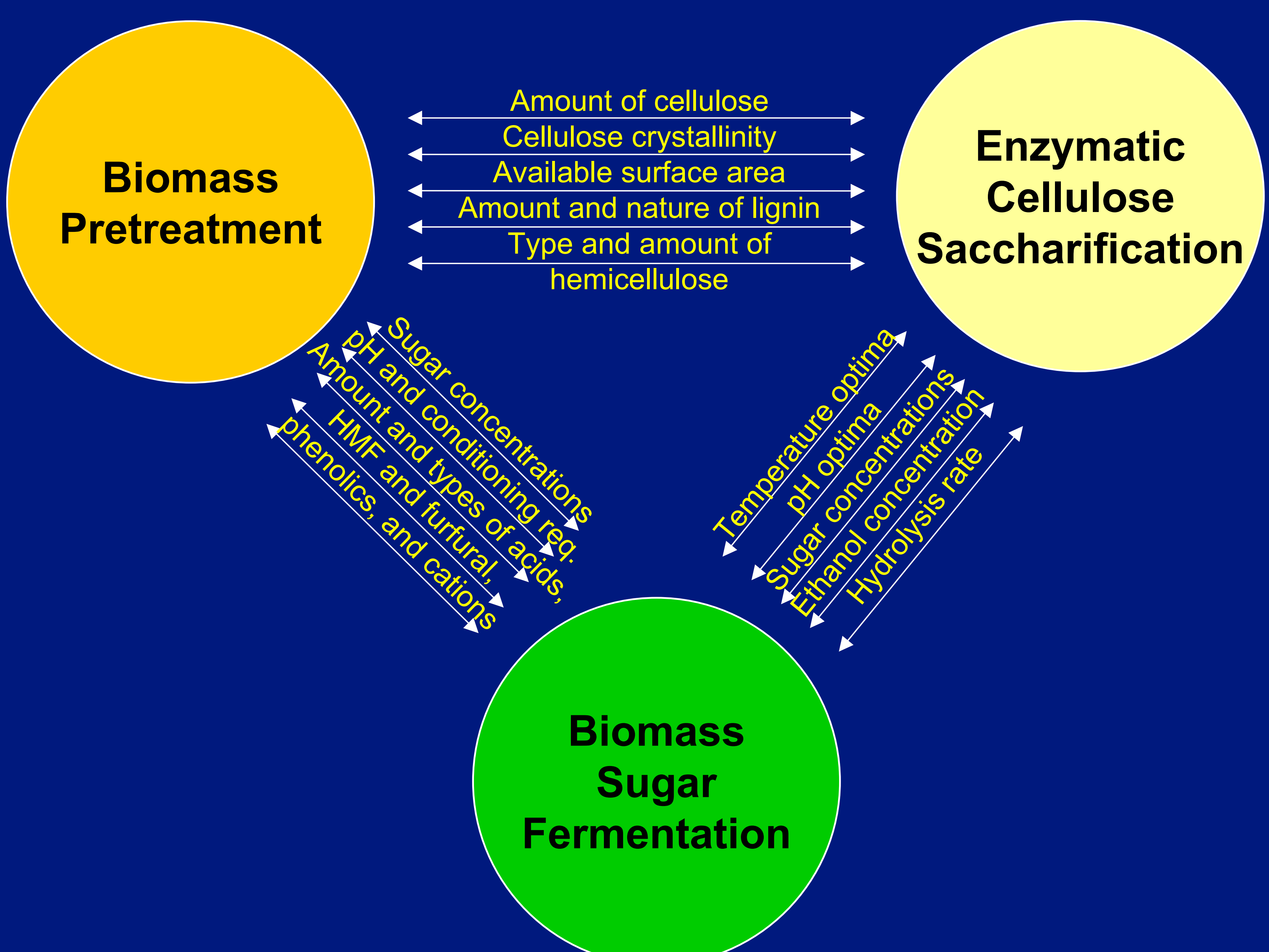
Major Steps in an Enzymatic Process



Many Process Development Options!



Key Process Interactions



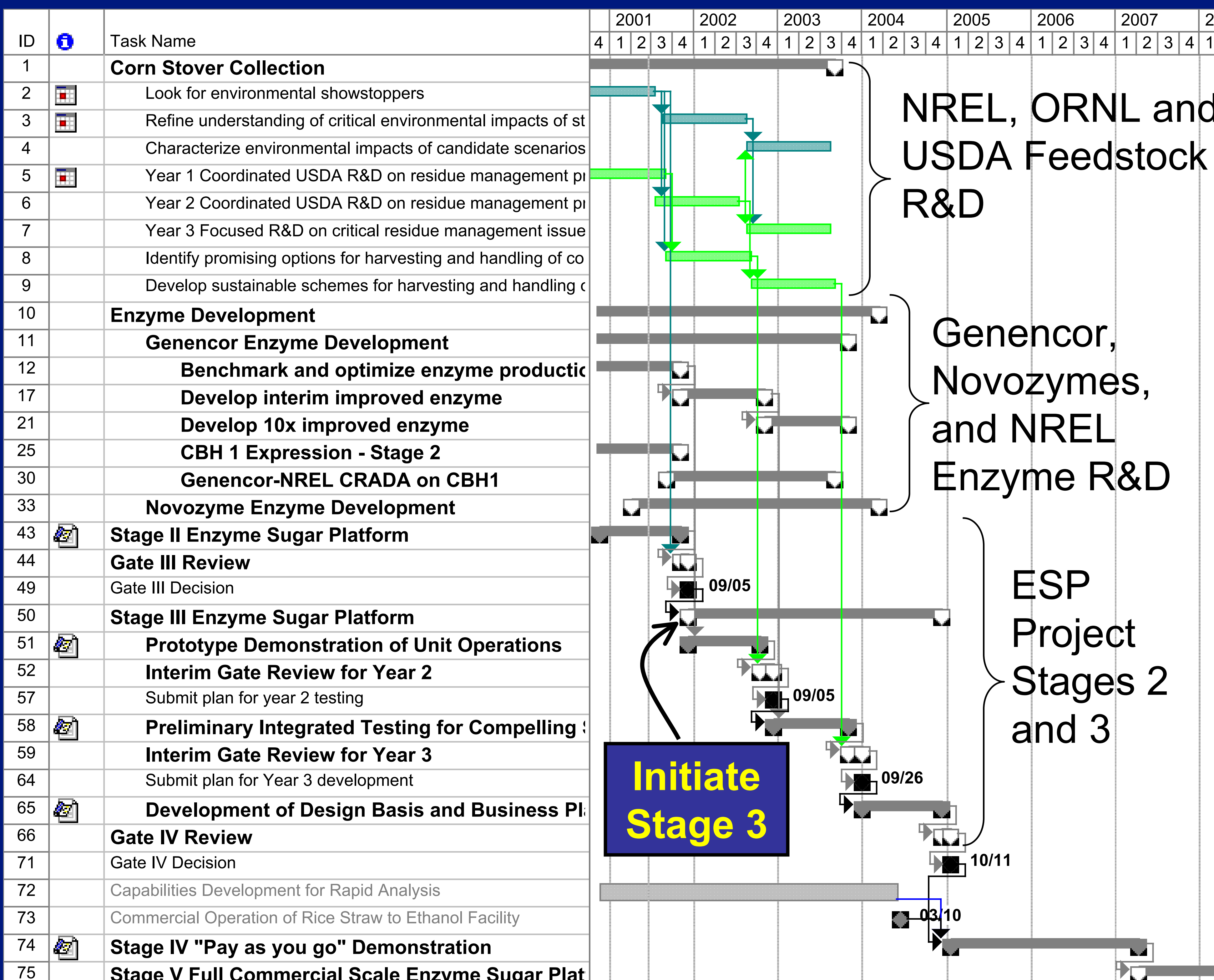
Approach — Feedstock

- Select corn stover as the ***model*** feedstock
  - Most abundant, concentrated domestic biomass resource
  - Leverage the existing corn harvesting and ethanol production infrastructure (starch-based)
- Leverage USDOE and nascent USDA-sponsored efforts to develop a feedstock collection infrastructure
  - Determine how much corn stover can be removed
    - Critical to maintain soil quality/health
  - Study collection logistics and reduce costs
    - Critical to minimize the cost of delivered feedstock

Approach — Conversion

- Utilize low cost enzymes now being developed by Genencor International and Novozymes Biotech through cost-shared subcontracts from the USDOE.
  - Genencor effort, 3 years, DOE share $13.6 Million
  - Novozymes effort, 3 years, DOE share $11.8 Million
  - The first generation of significantly lower cost enzymes should be available in 2003–2004
- Conversion technology should be adaptable to other lignocellulosic feedstocks, esp. agricultural residues

Timeline



ID
Task Name
2001
2002
2003
2004
2005
2006
2007
1 Corn Stover Collection
2 Look for environmental showstoppers
3 Refine understanding of critical environmental impacts of st
4 Characterize environmental impacts of candidate scenarios
5 Year 1 Coordinated USDA R&D on residue management pı
6 Year 2 Coordinated USDA R&D on residue management pı
7 Year 3 Focused R&D on critical residue management issue
8 Identify promising options for harvesting and handling of co
9 Develop sustainable schemes for harvesting and handling c
10 Enzyme Development
11 Genencor Enzyme Development
12 Benchmark and optimize enzyme productic
17 Develop interim improved enzyme
21 Develop 10x improved enzyme
25 CBH 1 Expression - Stage 2
30 Genencor-NREL CRADA on CBH1
33 Novozyme Enzyme Development
43 Stage II Enzyme Sugar Platform
44 Gate III Review
49 Gate III Decision
50 Stage III Enzyme Sugar Platform
51 Prototype Demonstration of Unit Operations
52 Interim Gate Review for Year 2
57 Submit plan for year 2 testing
58 Preliminary Integrated Testing for Compelling
59 Interim Gate Review for Year 3
64 Submit plan for Year 3 development
65 Development of Design Basis and Business Pl
66 Gate IV Review
71 Gate IV Decision
72 Capabilities Development for Rapid Analysis
73 Commercial Operation of Rice Straw to Ethanol Facility
74 Stage IV "Pay as you go" Demonstration
75 Stage V Full Commercial Scale Enzyme Sugar Plat
09/05
09/05
09/26
10/11
03/10
NREL, ORNL and USDA Feedstock R&D
Genencor, Novozymes, and NREL Enzyme R&D
ESP Project Stages 2 and 3
Initiate Stage 3

What Constitutes Success?

- Demonstrating integrated conversion technology with robust performance that has compelling economics and a favorable outlook for commercialization
  - Success is industry taking the lead in technology development efforts, beginning with Stage 4 process testing and validation

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Critical Success Factors

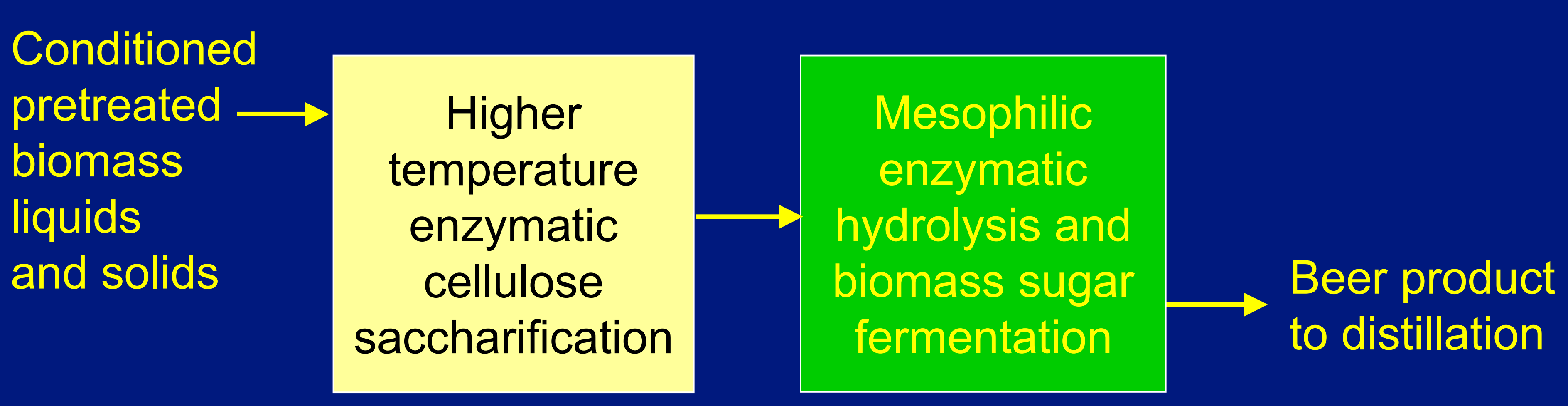
- Sufficient quantities of corn stover must be available at an acceptable cost.
  - Policies and infrastructure must be developed to collect, store, transport, and deliver feedstock.
- Cost-effective cellulases must be available for process development and scale up (i.e., to support work in Stages 3-5).
- The integrated process must be demonstrated to perform at levels commensurate with attractive economics.

Stage 2 Technology Selection

- Focus was on pretreatment and fermentation strains… since final enzyme characteristics aren't yet known
- Applied 2-step screening methodology
  - 1º screen: Reported efficacy
  - 2º screen: Quantitative performance and technology readiness

Outlook Favors Hybrid Configuration

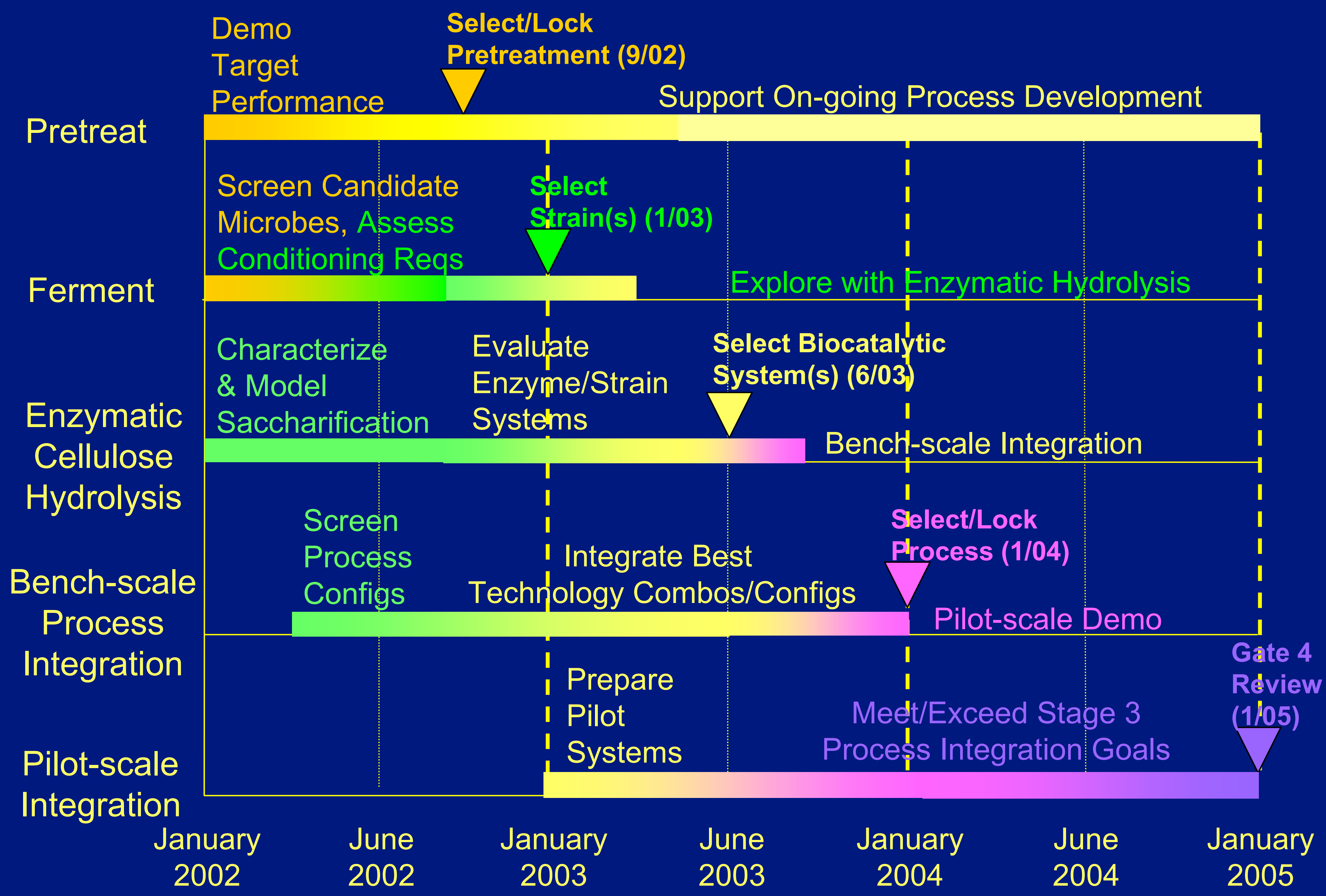
- Anticipate using a hybrid hydrolysis and fermentation (HHF) process configuration that begins with a separate hydrolysis step and ends with simultaneous hydrolysis and fermentation.



Hybrid Hydrolysis and Fermentation (HHF)

$\Rightarrow$*Economics will determine the route selected.*

High-level Stage 3 Plan

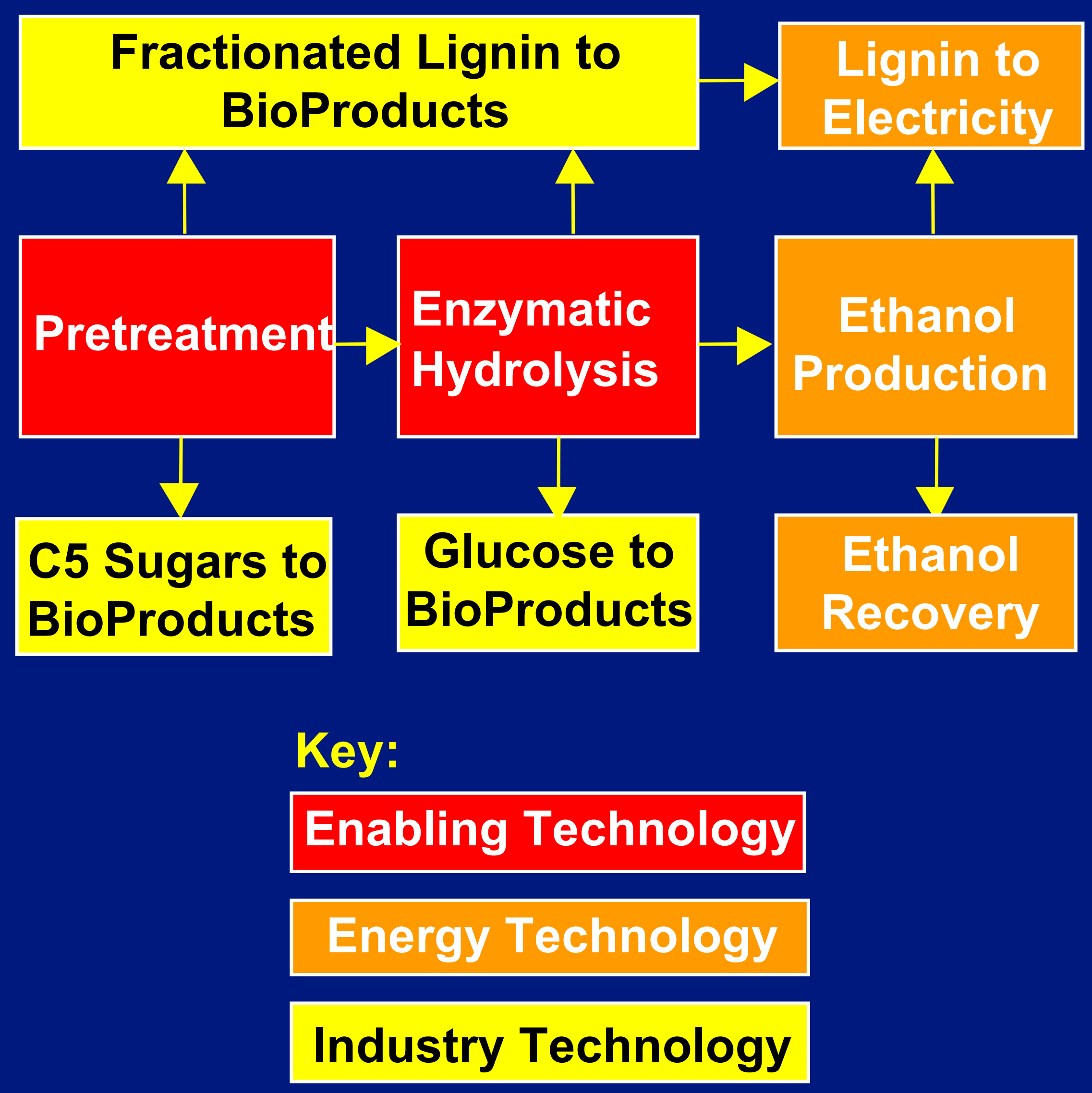


Feedback from Gate 3 Review

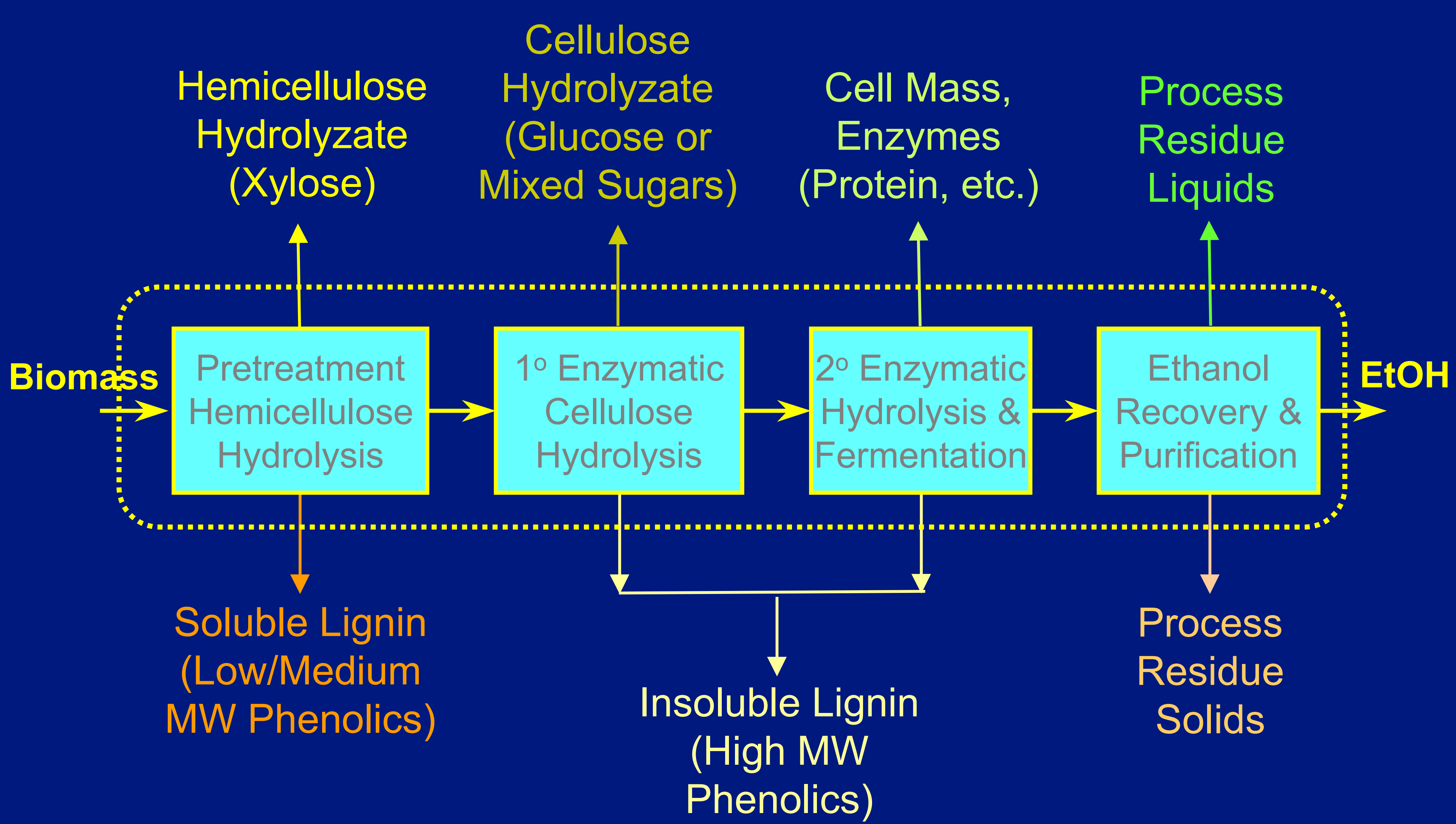
- Passed Gate 3 review 1/31/02
- Review panel charge:
  - Focus on core technology development, particularly pretreatment and enzymatic cellulose hydrolysis
  - Timeline overly aggressive for available resources and should be revised/ lengthened
- Initial Stage 3 work is focused on core technology development

Strategic Fit: Enabling Lignocellulose Biorefineries

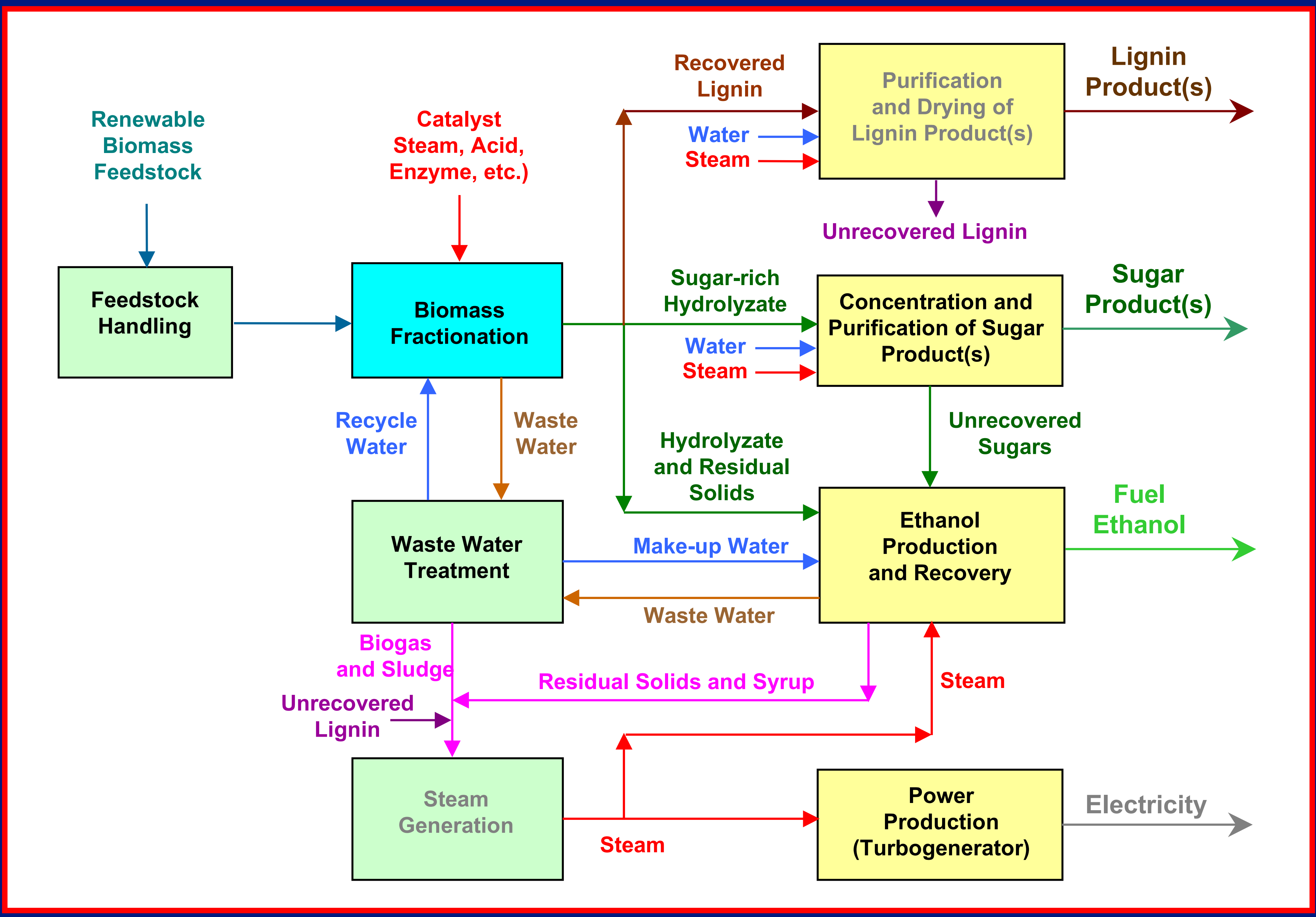
- The project demonstrates enabling technology for a lignocellulose-based biorefinery
- The project focuses on the core steps needed to produce sugars, fractionated lignin, and ethanol
- Industry is focusing on the application of this technology to make new products



Potential Process Co-products



Sugar and Lignin Platform Biorefinery



Acknowledgment

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