DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

WBS 2.4.1.103 Biochemical Pilot-Scale Integration (BPSI) Project

Advanced Development and Optimization

March 6, 2019

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National Renewable Energy Laboratory

Goal

Goal:

Support BETO's and industry's mission to develop cost-effective biofuels and bioproducts by providing a **well-maintained and process-relevant, engineering-scale pilot plant** for process development and technology verification (2022 and 2030).

Biochemical Pilot Plant

Outcomes:

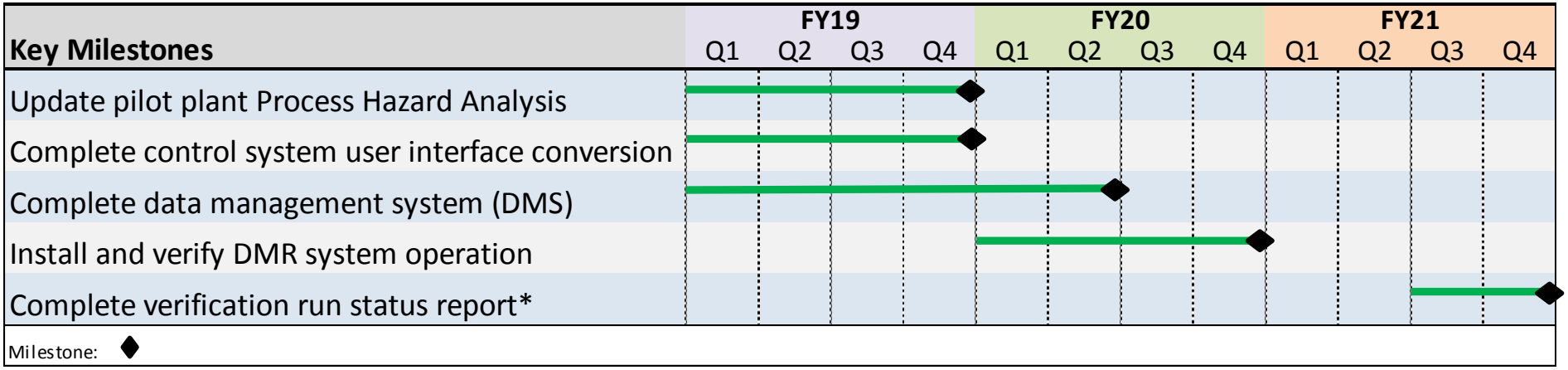
- Integrated, engineering-scale performance data
- Performance data and testing of single unit operations
- Samples and bioproducts

See additional slides for more information.

Relevance:

- Supports process development, technology selection, and verification testing
- Decreases risk and identifies and solves scale-up problems

Key Milestones



*Outlines current plant capabilities without additional funds to support verification run planning and equipment acquisition.

DMR: Deacetylation and Mechanical Refining - This pretreatment process option will be discussed later in the presentation.

Project Budget Table

	Original Project Cost (k$, Estimated)			Project Spending (k$) and Balance		Final Project Costs
Budget Periods	DOE Funding	Project Team Cost Shared Funding	Contin-gency	Spending to Date (Jan 19)	Remaining Balance	What is Needed to Complete
FY19						
- Plant Operations	900	0	0	236	664	
- New Capabilities	200	0	0	50	150	
- Material Production	200	0	0	150	50	
- DMR System Design	200	0	0	5	195	

Outyear budgets determined annually.

Quad Chart Overview

Timeline

- Start: FY19
- Merit review cycle: FY19-20
- 15% complete for this review cycle

Barriers

- ADO-A. Process Integration
- ADO-D. Technology Uncertainty of Integration and Scaling
- ADO-F. First-of-a-Kind Technology Development

Budget (M$) – All DOE Funded

Total Cost Pre FY17 (FY16)	FY17 Costs	FY18 Costs	Total Planned Funding (FY19-End of Project)
1.89	2.06	1.33	4.7

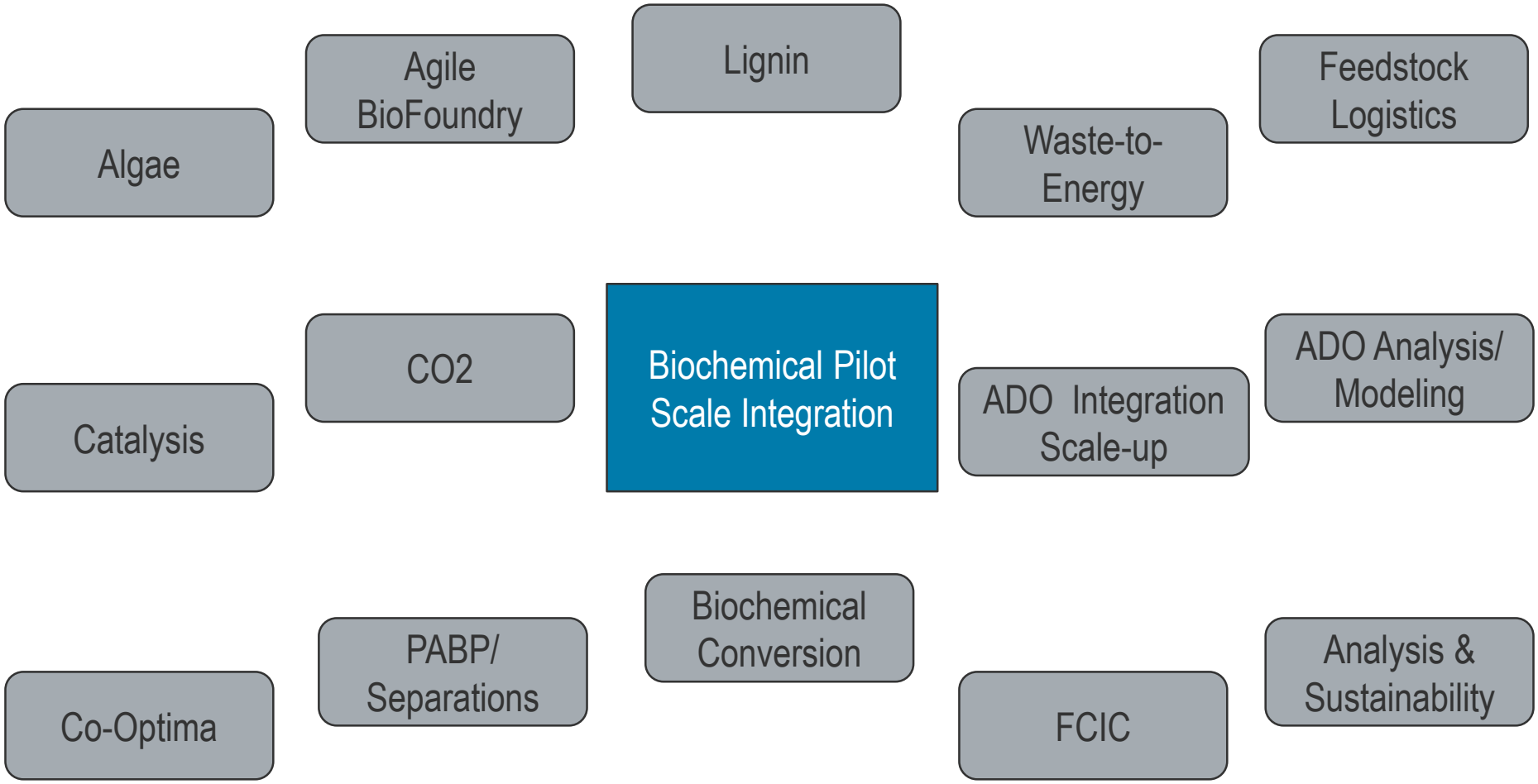
- Managed under conversion portfolio until FY19
- Current funding for maintaining readiness, materials generation, and DMR system
- Integration research eliminated in FY18
- Funding doesn't include verification work or money for new equipment

Partners

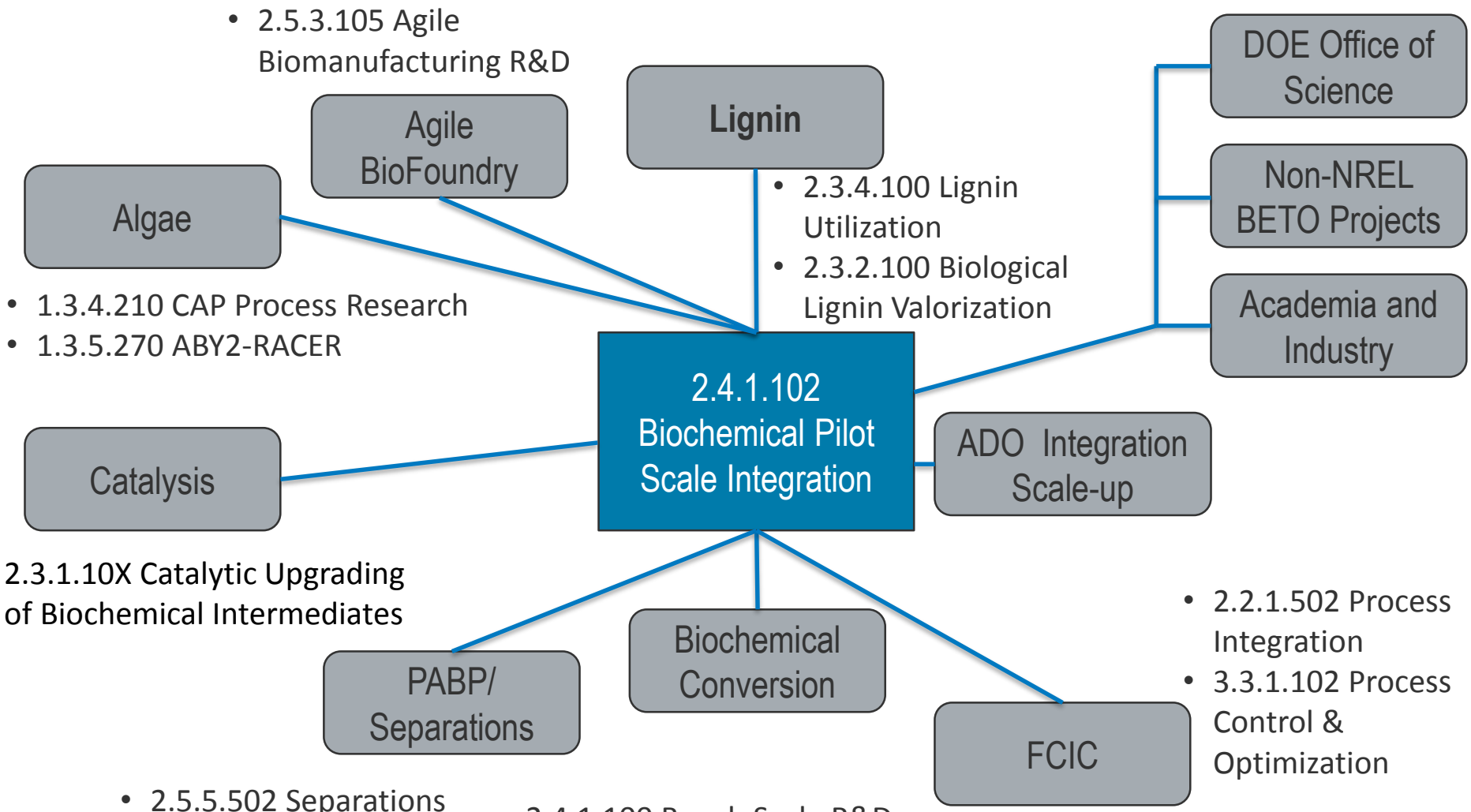
Interactions with many facility users:

- NREL BETO
- Consortiums
- Office of Science
- Industry
- Academia

NREL BETO Platform Areas



Project Interactions



Project Overview

Biochemical Pilot Plant (30+ year-old facility)

- Feed handing through fermentation and downstream processing
- Continuous (1 t/d) or batch processing
- Stand-along or integrated unit operations
- Highly instrumented and automated

What this project does (Monetary support from BETO and NREL):

- Maintains and improves facility
- Evolves facility with changes in process technology

What this project doesn't do:

- Perform research
- Solicit industry for projects

Specific Objectives:

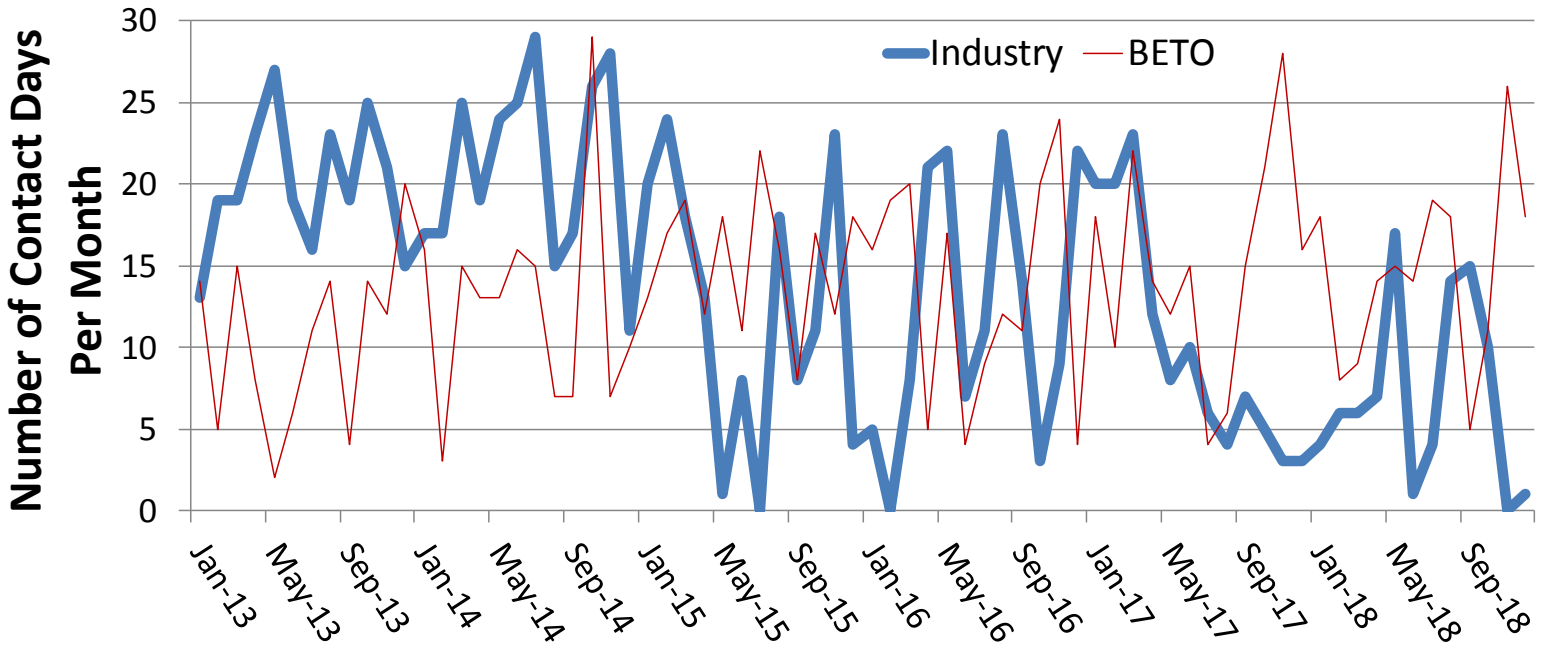
1. Maintain functional plant meeting all data quality/safety needs
2. Provide process-relevant materials for bench-scale R&D
3. Provide bioproducts for end-user and market acceptance testing
4. Acquire new capabilities to support BETO and industry

1985: First pilot plant, cellulose hydrolysis

1994: First integrated pretreatment/SSF fermentation process and labs

2011: Multiple integrated process trains, high-solids enzymatic hydrolysis

Historical Pilot Plant Use (2013-2018)



TOYOTA

HONDA
Honda R&D Americas, Inc.

DSM
BRIGHT SCIENCE. BRIGHTER LIVING.

DUPONT

VISOLIS
CARBON NEGATIVE MATERIALS

General Mills
Making Food People Love

ecopetrol
ENERGÍA PARA EL FUTURO

LYGOS

ExxonMobil
Energy lives here

AMYRIS
BIOTECHNOLOGIES

Cargill
Helping the world thrive

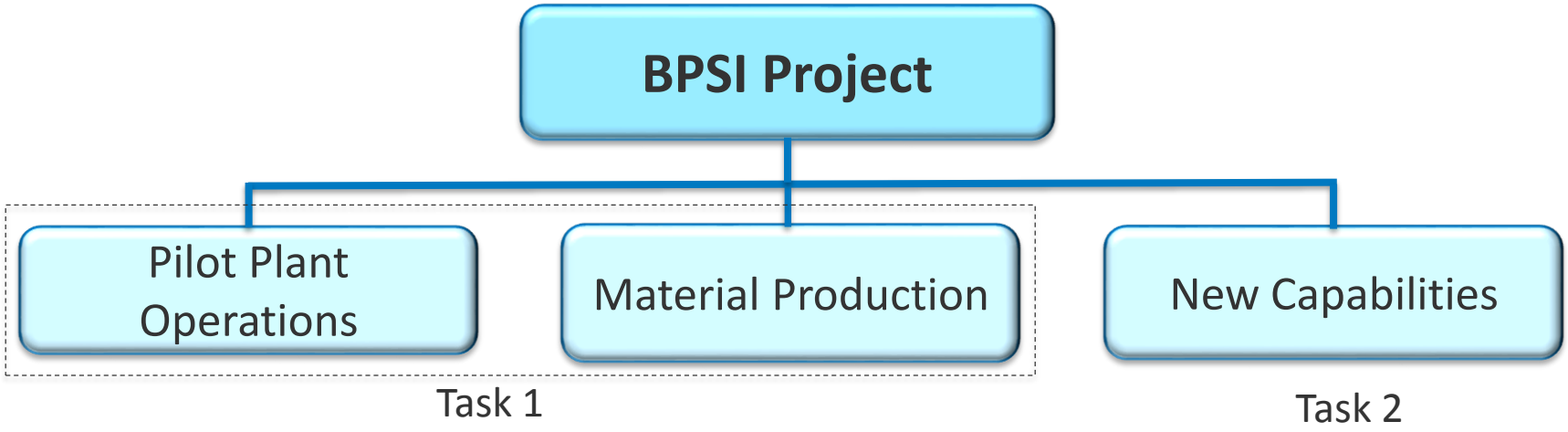
ABENGOA

novozymes
Rethink Tomorrow

"Contact Day" – On a given day, a BETO or industry (including FOAs) project used at least one piece of equipment or unit operation in the pilot plant. (Does not include routine repair and maintenance activities performed by this project. The scale and cost of the work is not represented.)

Management Approach

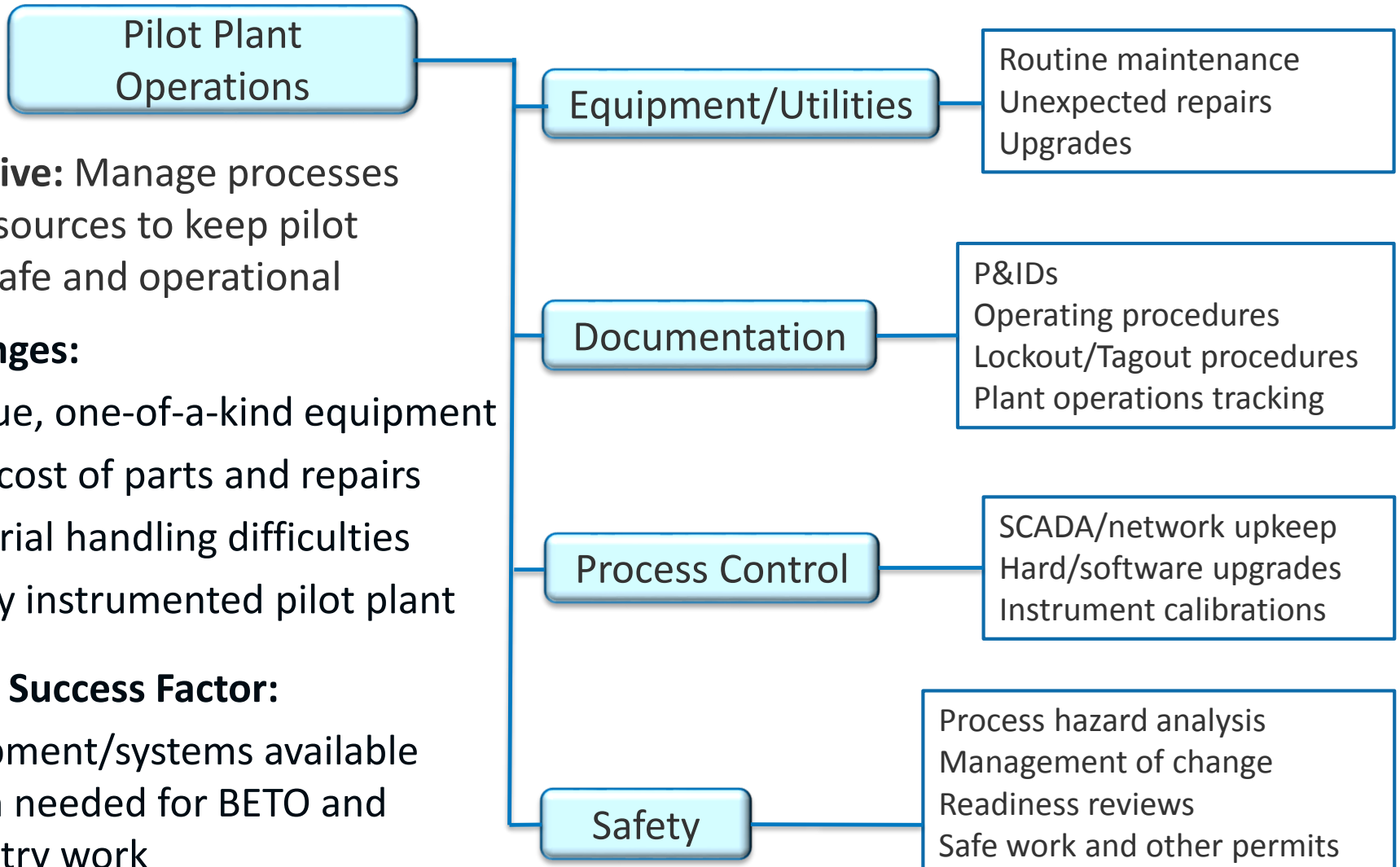
Current Project Structure (FY19- FY21):



Management:

- Milestones and Go/No-Go decisions
- Plan updated/revised yearly if needed
- Consider revising plan to 2022

Technical Approach-Pilot Plant Operations (Task 1)



Objective: Manage processes and resources to keep pilot plant safe and operational

Challenges:

- Unique, one-of-a-kind equipment
- High cost of parts and repairs
- Material handling difficulties
- Highly instrumented pilot plant

Critical Success Factor:

- Equipment/systems available when needed for BETO and industry work

*Supervisory Control and Data Acquisition System

Technical Approach-New Capabilities (Task 2)

Objective: Acquire new capabilities to support BETO's and industry needs

Technical Approach:

- Identify new needs:
  - Annual consultation with BETO and bioenergy research community
  - Interaction with industry partners
- Define/implement milestones/key decision points

Challenges:

- Enough resources to acquire new equipment
- Long implementation time

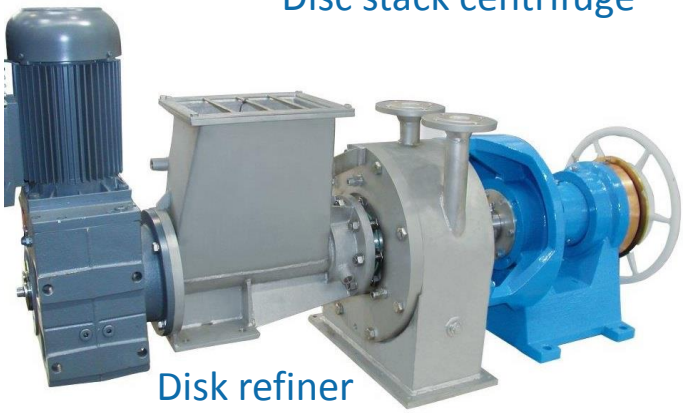
Critical Success Factors:

- Capabilities available to perform verification runs
- Support industrial projects and collaborations

Recent focus areas:

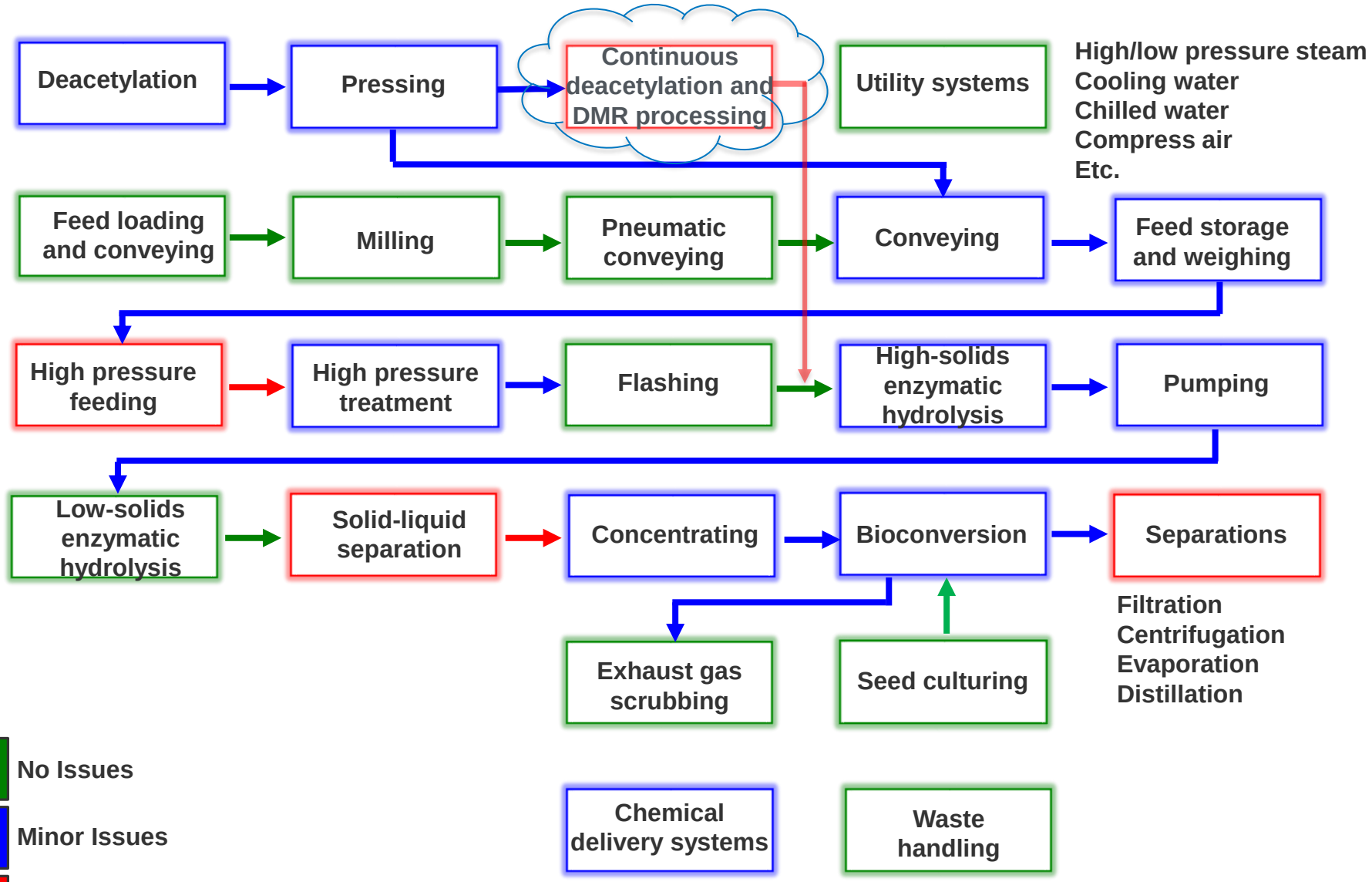
- Separations
- Alternative pretreatment option (DMR)

Disc stack centrifuge



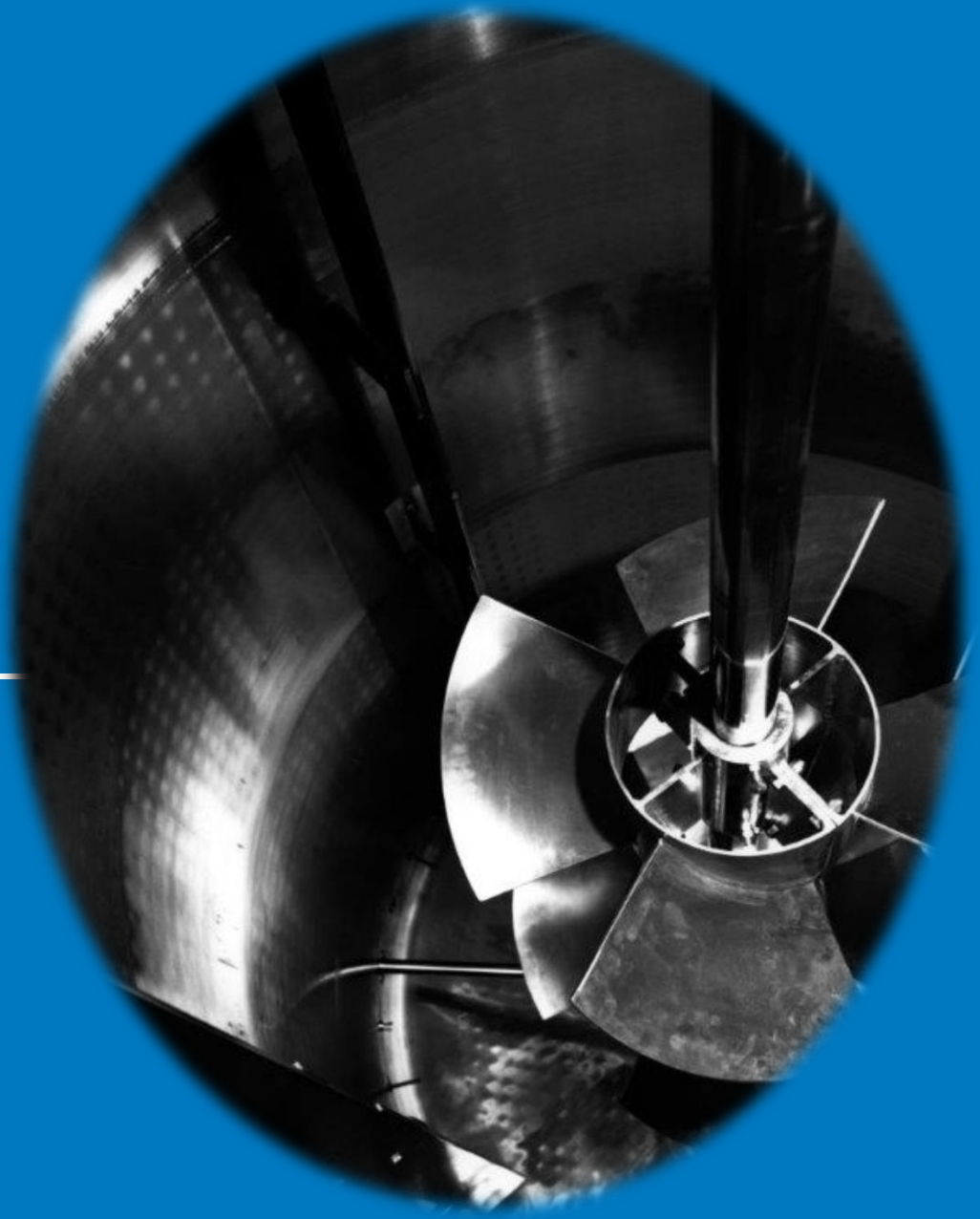
Disk refiner

Process Operations Block Diagram



Project Background and Previous Work

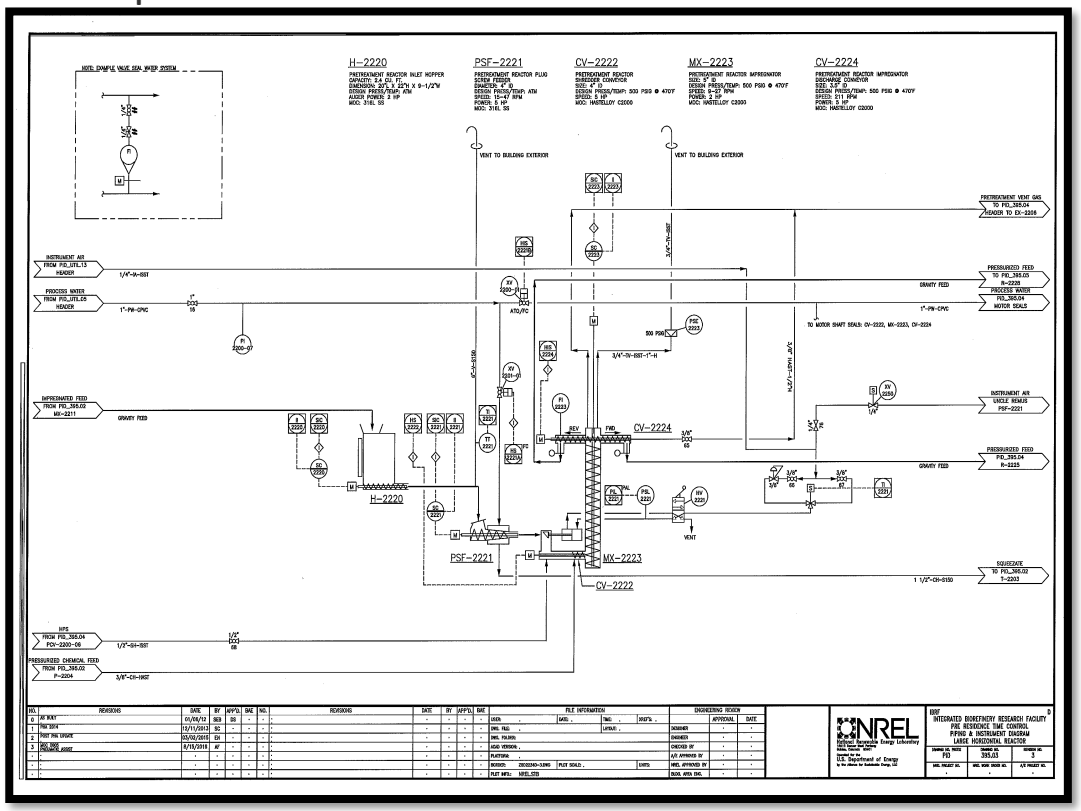
- Plant operations/Ongoing work
- New separation capabilities
- Material production



Pilot Plant Operations

Pilot Plant Scope:

- Two high bays – 27,000 ft^2
- Seven utility systems (steam, air, etc.)
- 96 Process and Instrumentation Diagrams
- ~ 400 electronic instruments
- ~ 1,100 digital control points
- 35 operator screens



Example P&ID: Horizontal pretreatment reactor front end

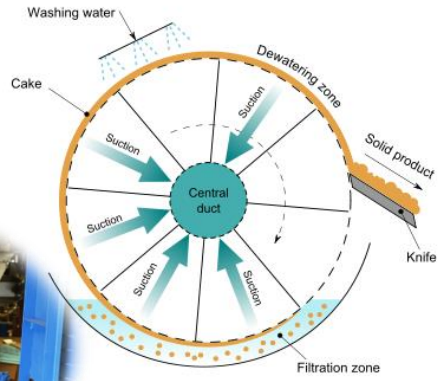
Managing Processes:

- In/Out of service
- Change management
- Calibration: Paperless calibration management program
- Parts inventory/tracking
- Key safety devices
- Repair/maintenance

Ongoing Work:

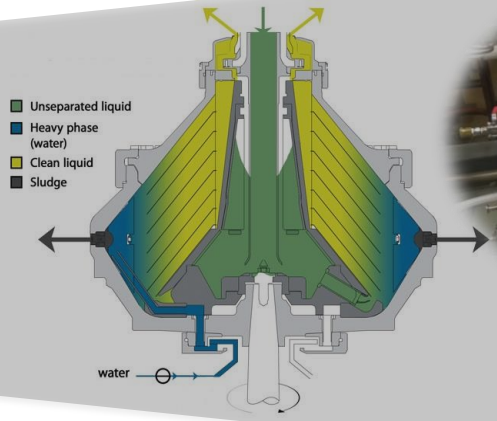
- Process hazard analysis
- Control system conversion
- Data management system

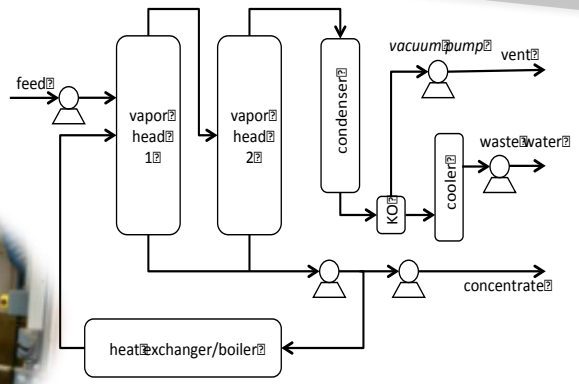
New Capabilities (FY17/18)—Separation/Concentration



Rotary Drum Filter (New equipment)—separation of solids (microfiltration) from biomass (pretreated or enzymatic hydrolysate) slurries where shear sensitivity is a problem

Disc Stack Centrifuge (New equipment)—cells recovery for cell recycle and bioproduct production technologies





Forced Circulation Evaporator (Added vacuum to existing unit)—production of concentrated sugar solutions for aerobic fed-batch fermentations

Material Production

Types of process samples include:

- Dilute-acid-pretreated corn stover
- Deacetylated and disk-refined (DDR*) stover
- Deacetylation black liquor
- Enzymatic hydrolysate from DDR stover
- Concentrated enzymatic hydrolysate from DDR stover
- Solid lignin (from enzymatic hydrolysis)

In FY18: Seven (7) BETO projects received materials from:

- 750 kg (dry) of deacetylated, dilute-acid pretreated slurry
- 600 L of raw DDR enzymatic hydrolysate
- 150 L of clarified/concentrated (> 400 g/L monomeric sugars) DDR enzymatic hydrolysate
- 80 L black liquor
- 20 kg solid lignin

During clarification of an enzymatic hydrolysate, twine used to bale stover pugged the membrane separation modules.

*Deacetylated stover disk-refined at Andritz's Springfield, OH facility

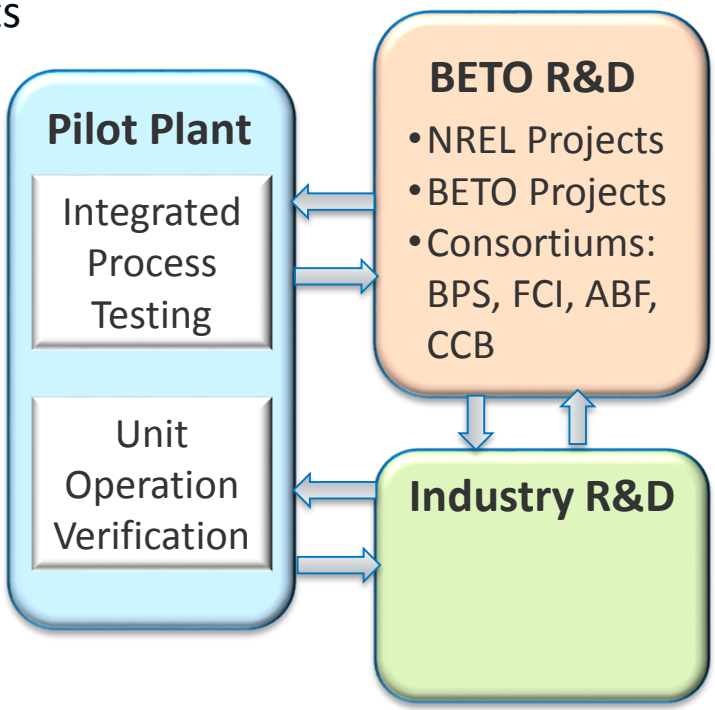
Relevance

We maintain/improve the DOE/NREL biochemical pilot plant directly supporting ADO's and industry's mission to commercialize biofuel production technology.

- Producing integrated, engineering-scale data
- Testing technical feasibility of single or multiple unit operations
- Generating process relevant materials and bioproducts

Addresses ADO strategic goals (MYP) to:

- Decrease commercialization risk
- Identity and solve scale-up issue
- Create added-value co-products
- Demonstrate innovative deconstruction approaches
- Enable high performance separations technology
- Develop technologies for utilizing waste streams
- Evaluate technology options



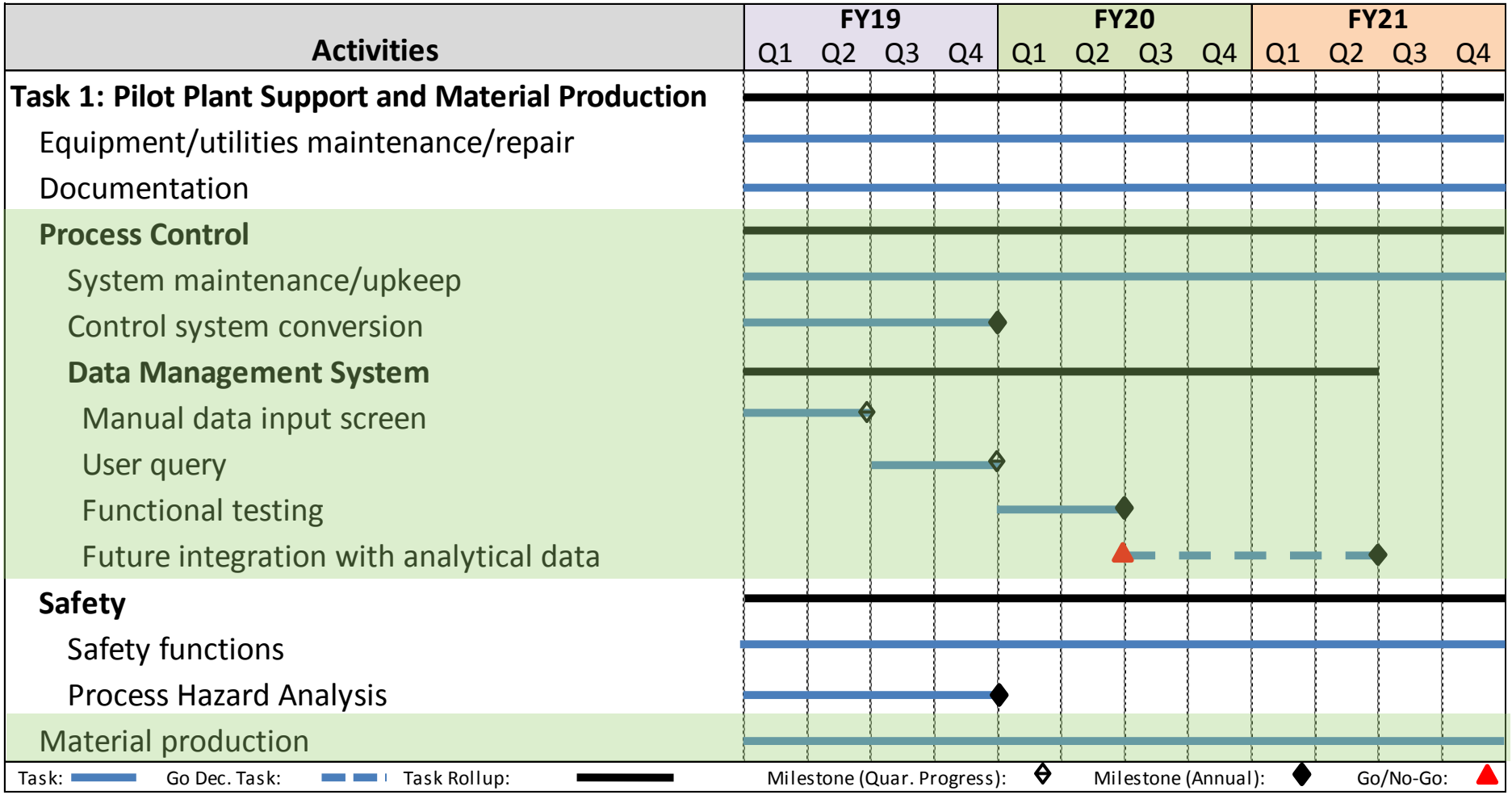
The pilot plant has a long history of working with industrial clients testing, solving, and advancing their technical objectives since 1987.

BETO Consortiums:
BPS-BioProcess Separations
FCI-Feedstock Conversion Interface
ABF-Agile BioFoundry
CCB-Chemical Catalysis for Bioenergy

Future Work

- Task 1
- Task 2
- 2022 Verification

Task 1 Future Work Plans

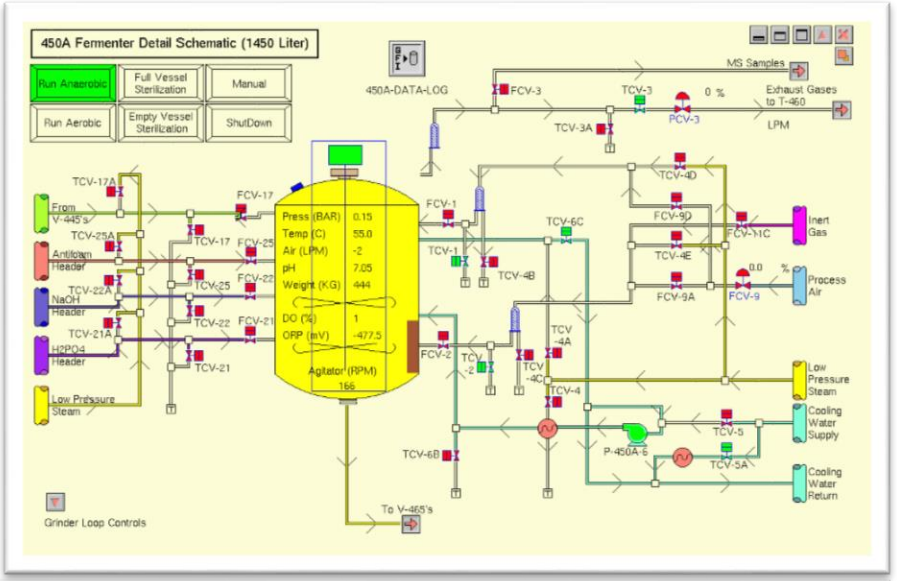


More details on items in the green shaded area are provided in following slides.

Process Control System Upgrade

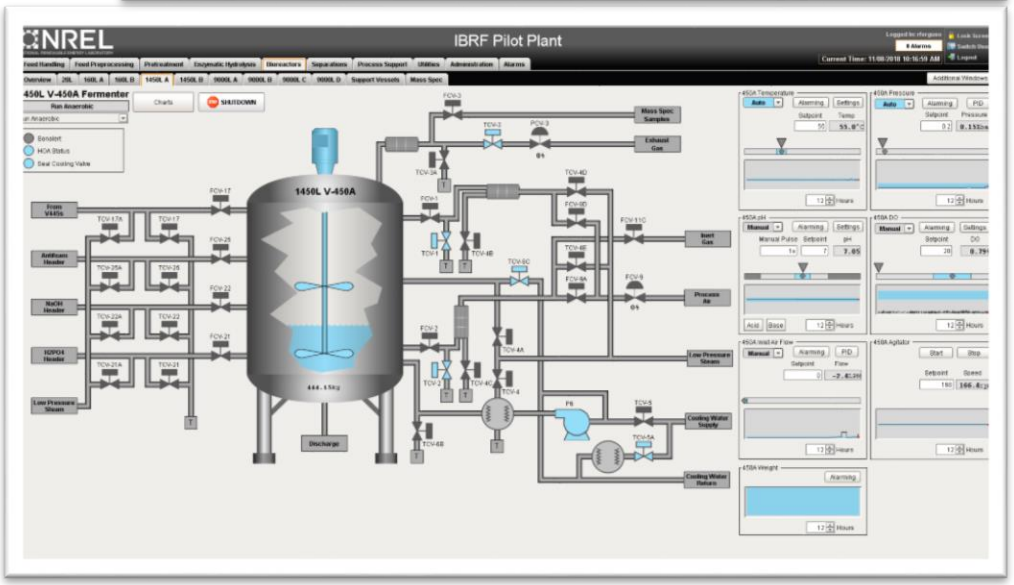
Original System (25-years old)

- Custom-coded software for data transfer
  - Not industry standard
  - Increasingly difficult to maintain
- Long-term viability of the vendor in doubt
- Expensive license fees (~$25,000/y).



New System

- Industry standard OPC communications
- License fees are about $4,000/y
- Easier to learn, program, and maintain
- Modernized user interfaces
- Complete upgrading by end of FY19



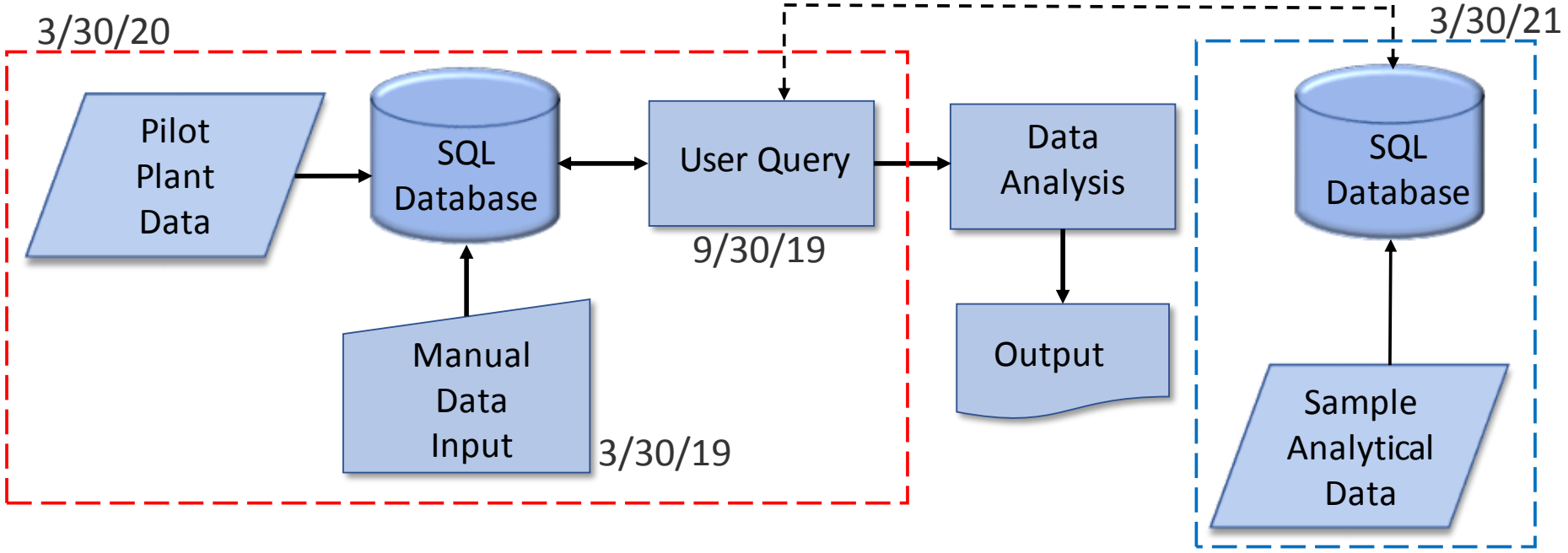
Data Management System Implementation

Original System

- Data collection initiated by operator (on screen toggle)
- CSV formatted files generated for each unit operation

New System

- Uses built-in capabilities of the new control system software
- Data sent to SQL database (collection rate varies with equipment use)
- Manual input tags specific data associated with runs, equipment used, etc.
- Data queried and analyzed using Python (large data sets) or exported as CSV file



Material Production

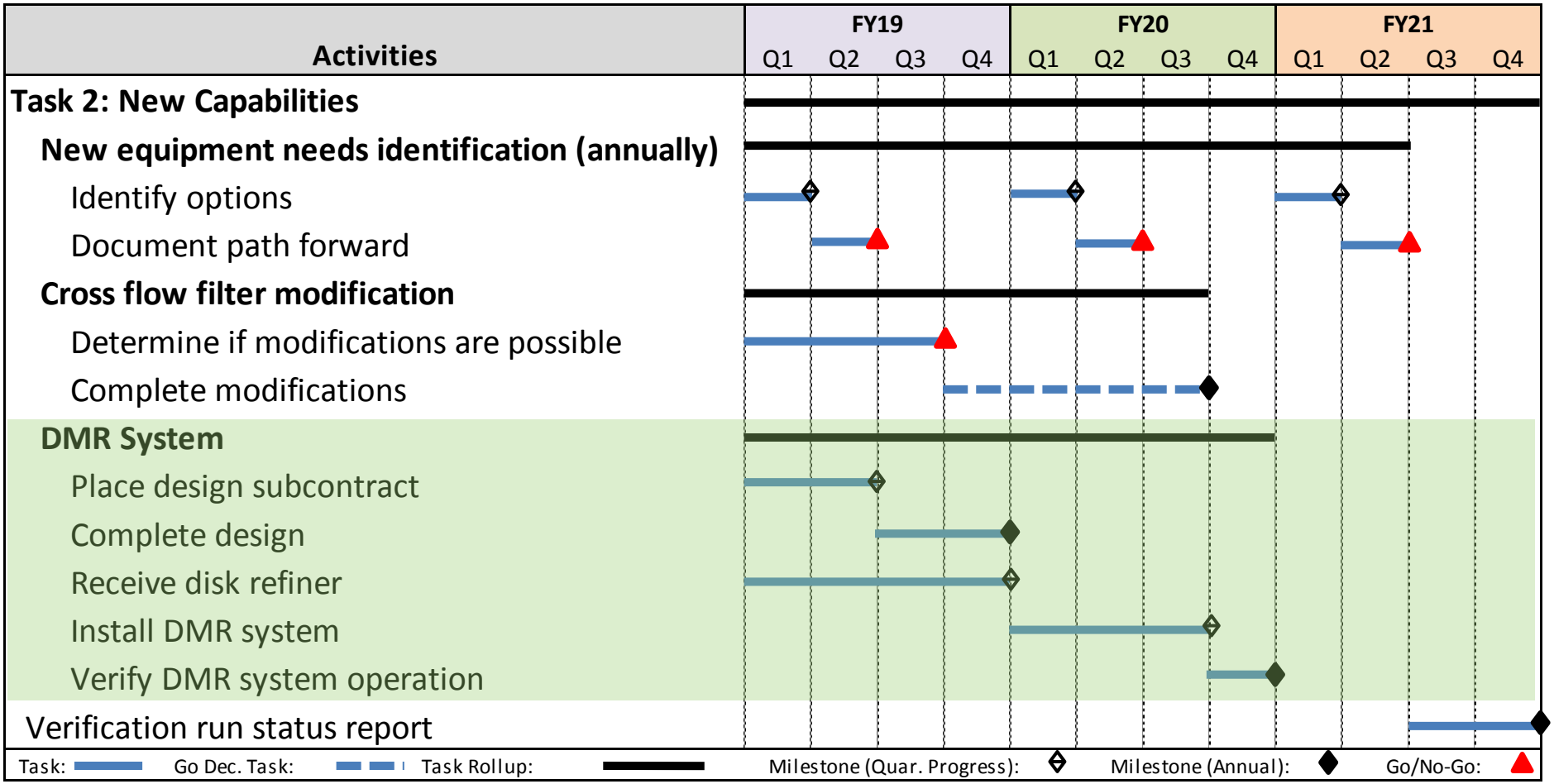
Thirty-six, 55-gal drums of deacetylated corn stover shipped to Andritz for off-site disk refining.

FY19: 18 BETO projects are receiving materials from:

- 1,500 kg (dry basis) of DDR* corn stover producing
  - 400 L of clarified and concentrated sugars from DDR stover
  - DMR solids
  - Black liquor
  - Lignin solids

*DDR: Deacetylated and Disk Refined

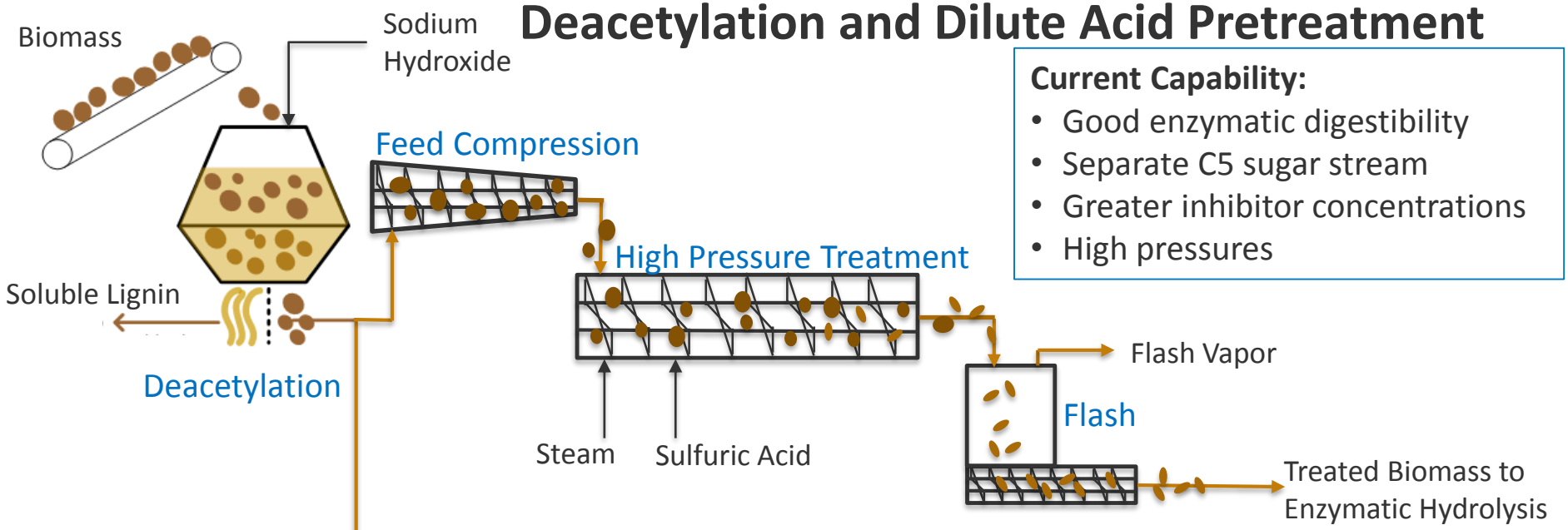
Task 2 Future Work Plans



More details on DMR system (green shaded area) are provided in following slides.

New Capabilities – Advanced Pretreatment System

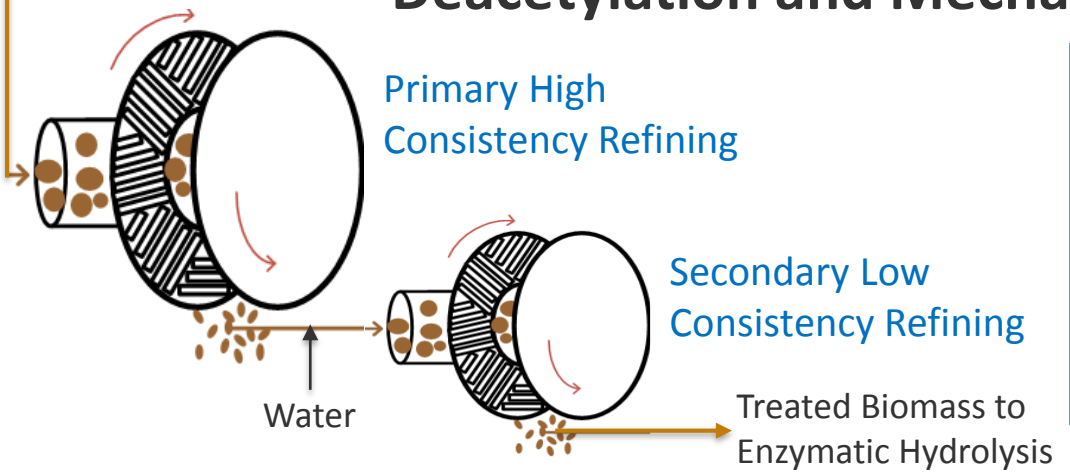
Deacetylation and Dilute Acid Pretreatment



Current Capability:

- Good enzymatic digestibility
- Separate C5 sugar stream
- Greater inhibitor concentrations
- High pressures

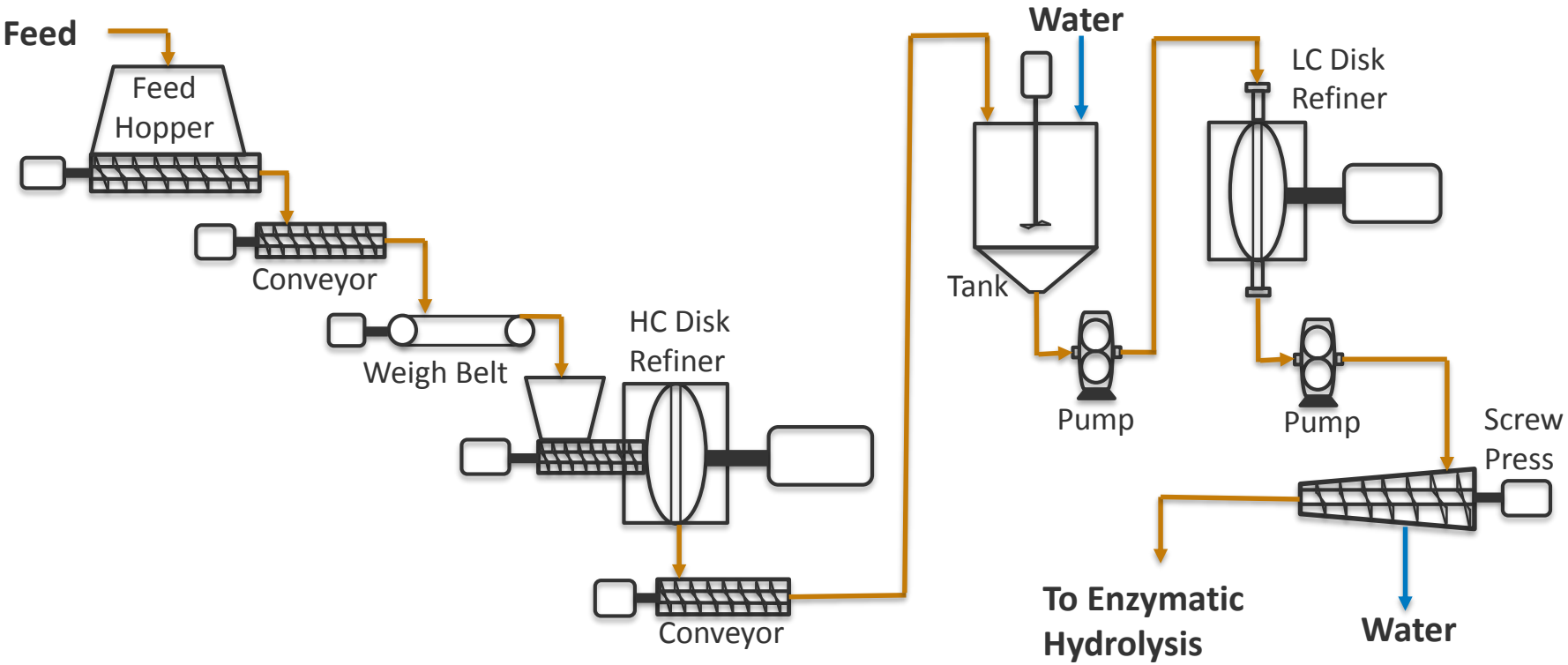
Deacetylation and Mechanical Refining (DMR)



New Capability:

- Good enzymatic digestibility
- Lower inhibitor concentrations
- Atmospheric pressures
- Commercial equipment
- Lower resistance to contamination
- Residual solids harder to separate

DMR System Process Design



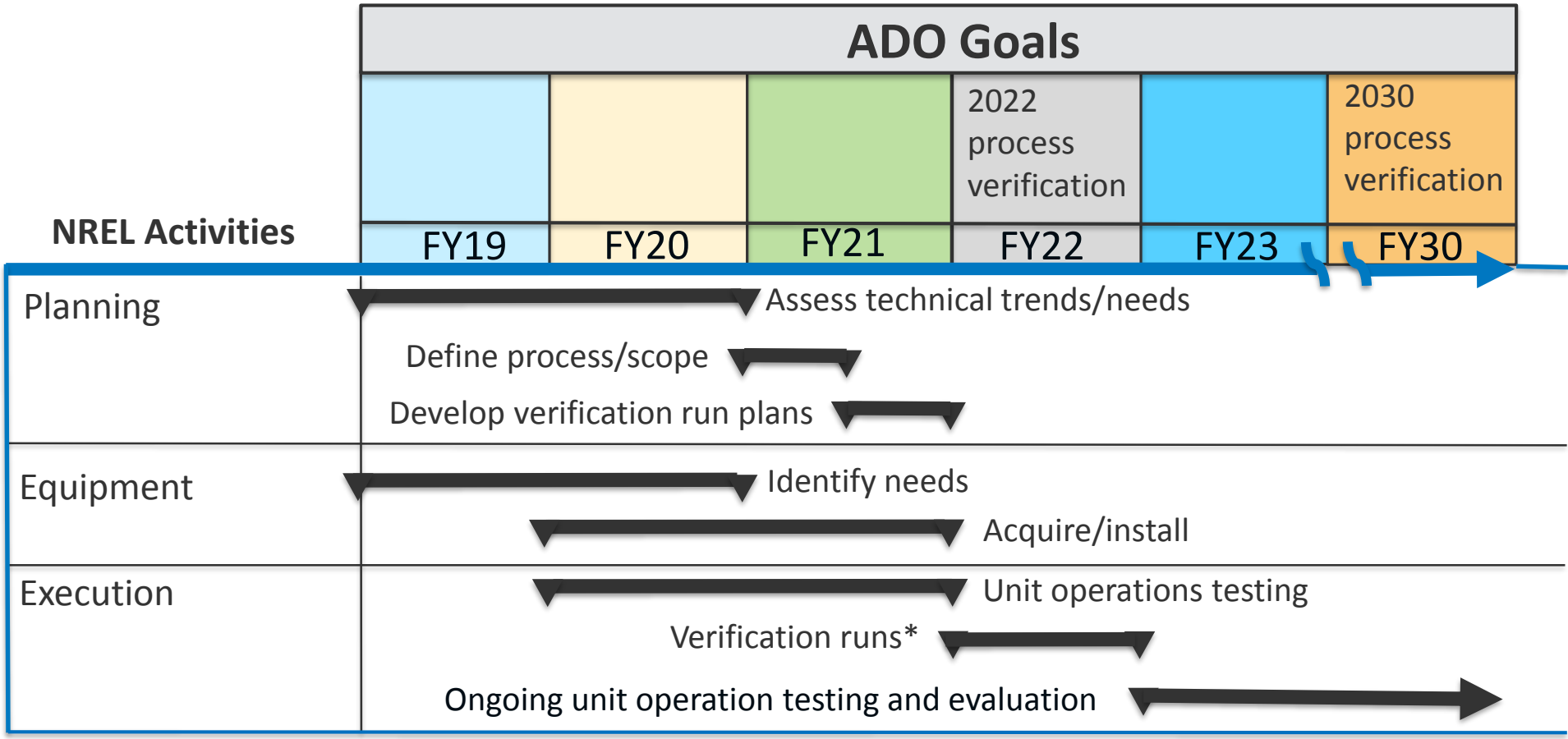
Plans ($300 k currently available)

- HC disk refiner ordered (delivery, summer 2019)
- Place design subcontract (3/30/19)
- Receive HC disk refiner (8/1/19)
- Complete design (9/30/19)
- Install equipment (6/30/20-Funding TBD)
- Complete functional test (9/30/20-Funding TBD)
- Add continuous deacetylation (TBD)

22” HC Disk Refiner

HC – High Consistency LC – Low Consistency

Future Work—Possible Path To Biochemical 2022 Verification and Beyond



*Portions or all of this effort may be in collaboration with other national laboratories or industry partners.

Summary

Objectives:

- Perform plant maintenance, repair, and upgrading
- Acquire new capabilities and unit operations
- Produce process-relevant materials

Approach:

- Structured management of resources and activities
- Collaborative approach to identify new capabilities

Accomplishments:

- Control system upgrade/new data management system
- New separations capabilities
- New DMR capability in progress

Relevance:

- Facility for process development, evaluation, and verification
- De-risk technologies and identify/solve scale-up issues

Future work:

- Finish control system upgrade and data management system
- Acquire capabilities to support technology evaluation/verification

Acknowledgments

Team Members

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- Ed Jennings
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Thank You

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Additional Slides

Responses to Reviewers' Comments

Reviewers' Comments (from 2017 peer review meeting report):

- The pilot scale facility is a must step in any scale-up and as such very important part of BETO's mission to validate near demo scale ready technologies. The team is specialized and know their work and used good practices of mixture designs and scale-up/down models to address scale-up issues. The challenge of lacking publicly available data is understood. The project has good cross talk with the bench-scale integration and analytics team and work closely with the separation consortia. Overall good management and technical approach. It is recommended though that a community of pilot plant facility and know-how (APBDU, NREL, SCADA, bench scale validation and the separation and analytics consortia) will be integrated somehow as they all are continued needed support functions.
- Management structure is rather loose. The team is working on multiple projects as well as doing scale-up work for industry. One clear (and necessary) focus is developing capabilities and equipment to match the needs of BETO efforts. This is another great industry-supporting project.

Response to Reviewer Comments:

We appreciate the reviewers' comments and their efforts reviewing this project. We will continue to evaluate pilot-scale processing needs and acquire capabilities with BETO's support to make the biochemical pilot plant a relevant facility for industry and BETO to develop and test new hydrocarbon biofuel production technologies. As technology development continues and process options for pilot-scale verification are identified we will continue to increase our collaborations with other BETO projects, in particular the Biochemical Bench Scale Integration (BSI) project. An even closer collaboration is planned between BSI and this project beginning in FY20 and indirectly with industrial and academic stakeholders. A capabilities workshop with all BETO facilities performing pilot-scale work that would include industry representation might be useful for soliciting recommendations for new equipment and how best to use these various facilities.

Publications

- Crater, J.; Galleher, C.; Lievense, J. (2017) “Consultancy on Large-Scale Submerged Aerobic Cultivation Process Design - Final Technical Report” SR-5100-67963, NREL, http://www.nrel.gov/docs/fy17osti/67963.pdf.

- Humbird, D.; Davis, R.; McMillan, J. 2017. “Aeration Costs in Stirred-Tank and Bubble Column Bioreactors.” Biochemical Engineering Journal. 127, 161-166.

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Project Scope Change Table

Scope Changes	Date	Logic / Reasoning	Approval / Rejection Date
No scope changes			

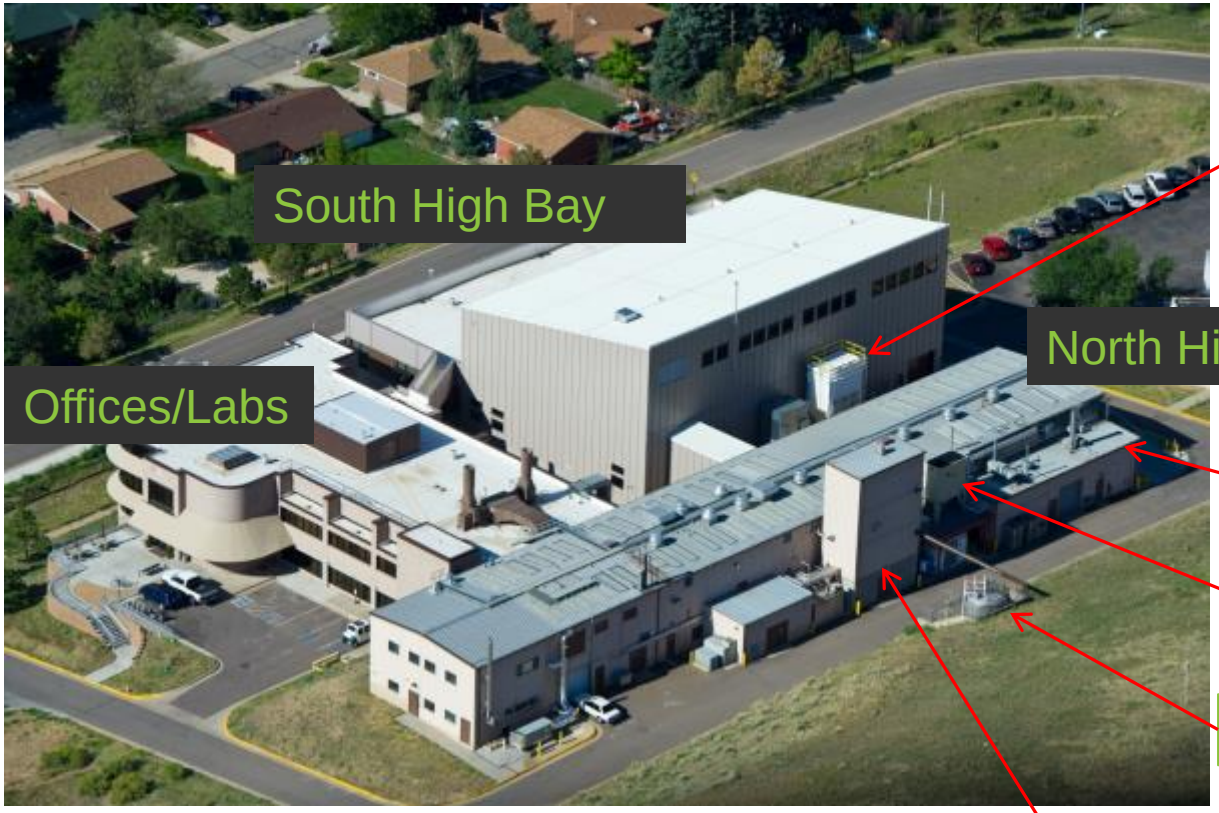
Risk Registry Table

	Risk Identified			Mitigation Strategy		Current Status
Risk ID	Process Step	Risk Description	Severity (High/ Med/Low)	Mitigation Response	Planned Action Date	Active/ Closed
	n/a	Sufficient funds are needed to acquire new pilot-scale equipment and capabilities for process development efforts needed for BETO and industry projects or possible verification runs.	Med	Reduce cost by acquiring used equipment, finding other funds, or reducing scope of research efforts. 2nd strategy is to scale back on possible verification runs or demonstrate some unit operations at a smaller scale.	n/a	n/a
	n/a	Delays in submitting equipment requisitions are possible due to uncertainties in funding, inability to find available equipment within target funding, and lack of response from vendor.	Low	Schedule delays may be accepted and/or mitigation strategies can be developed once the magnitude of delays are known.	n/a	n/a
	n/a	Equipment failures can lead to significant production delays.	Low	Preventive maintenance as needed to maintain key equipment, but random/unexpected failures still occur particularly with equipment handling solids.	n/a	n/a

Risk Registry Table - Continued

	Risk Identified			Mitigation Strategy		Current Status
Risk ID	**Process Step**	**Risk Description**	**Severity (High/ Med/Low)**	**Mitigation Response**	**Planned Action Date**	**Active/ Closed**
Feed Handling						
1	Milling	Fire hazard from sparking	High	Suppression system		
2	Dust collection	Explosion mitigation	High	Suppression or deflection system		
3	Feed delivery	Fall into feed hopper hazard	High	Interlocks and barriers	9/30/19	
4	Feed delivery	Hopper failure	Low	New hopper design		
5	Feed handling	Dust accumulation	Med	Dust control and mitigation strategy	6/30/19	
Pretreatment						
1	Feeding reactor	Bridging above plug screw feeder	Low	Automatic bridge breaking system	9/30/20	
2	Reaction	Reactor fouling	Low	New pretreatment option		
Separations						
1	Lignin recovery	Separation failure	Low	Accept more costly option		

Biochemical Pilot Plant



Pilot Plant

North High Bay (1994)

- Integrated 1 ton/d process train
- Feed handling through product separation
- Houses utilities systems

South High Bay (2010)

- Two integrated 0.5–1.0 ton/d process trains
- Feed handling through high solids enzymatic hydrolysis
- Space for expansion

North High Bay Equipment

Pretreatment

- 1.0 ton/d vertical reactor
- 0.2 ton/d horizontal screw reactor
- 160-L batch reactor
- 1-L and 4-L batch reactors

Fermentation

- 30-L seed vessel
- Two 160-L vessels
- Two 1500-L vessels
- Four 9000-L vessels

Separations

- Distillation column (19-sieve trays)
- Perforated 100-L basket centrifuge
- Forced recirculation evaporator

South High Bay Equipment

Feed Handling
- Two knife mills
- Continuous conveyance systems
- Multiple hoppers and weigh belts

Pretreatment
- 1.0 ton/d vertical reactor
- 0.5 ton/d horizontal screw reactor

Enzymatic Hydrolysis
- 1900-L paddle reactor
- Four 4000-L paddle reactors

Separations
- Screw presses
- Perforated 450-L basket centrifuge
- Rotary vacuum drum filter
- Cross flow filter

Pilot Plant Utilities Systems

- Steam
  - 500 psi, 3400 lb/h boiler
  - 300 psi, 1200 lb/h backup boiler
  - Distributed in high (up to boiler pressure) and low pressure (35 psi) headers
- Cooling water
- Process water
- Chilled water
- Deionized water
- Hot process water
- Plant compressed air


Boiler (500 psi)


Cooling Tower


Boiler (300 psi)

DMR System P&ID