

# BETO 2023 Peer Review

## Biochemical Pilot Scale Support and Process Integrations

**WBS#: 3.4.2.201**

April 5, 2023

Systems Development and Integration

Dan Schell  
NREL

# Project Overview

## Biochemical Pilot Plant (38-year-old facility)

- Biomass conversion to biofuels/biochemicals
- Multiple expansions have occurred over the years

**High Level Project Goal:** Provide a **well-maintained and process-relevant, engineering-scale pilot plant** for process development and technology verification.

- **What:** Maintain pilot plant meeting data/quality needs and generate process-relevant material for bench-scale R&D
- **How:** Effectively use available resources to maintain functionality and safety
- **Why:** Provide a facility for pilot-scale process development and scale up for BETO and industry
- **Risk:** Inopportune equipment failures; maintaining effective resource use when executing multiple projects

**This is not a research project, nor do we perform business development activities with project funds.**



1985: First pilot plant, cellulose hydrolysis



1994: First integrated pretreatment/SSF fermentation process and added labs



2010: Multiple integrated process trains, high-solids enzymatic hydrolysis

# Biochemical Pilot Plant

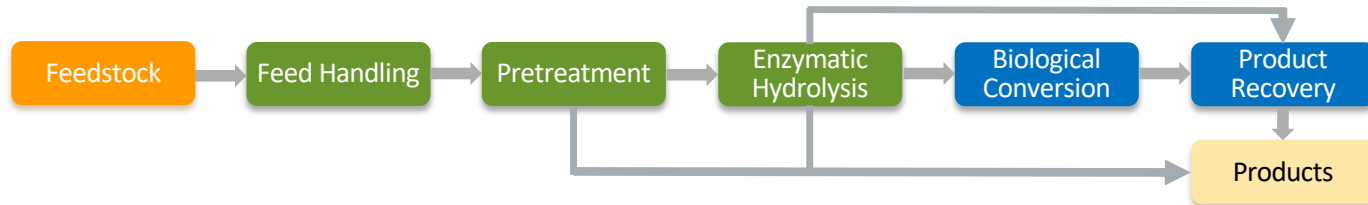


## North High Bay (NHB, 1994)

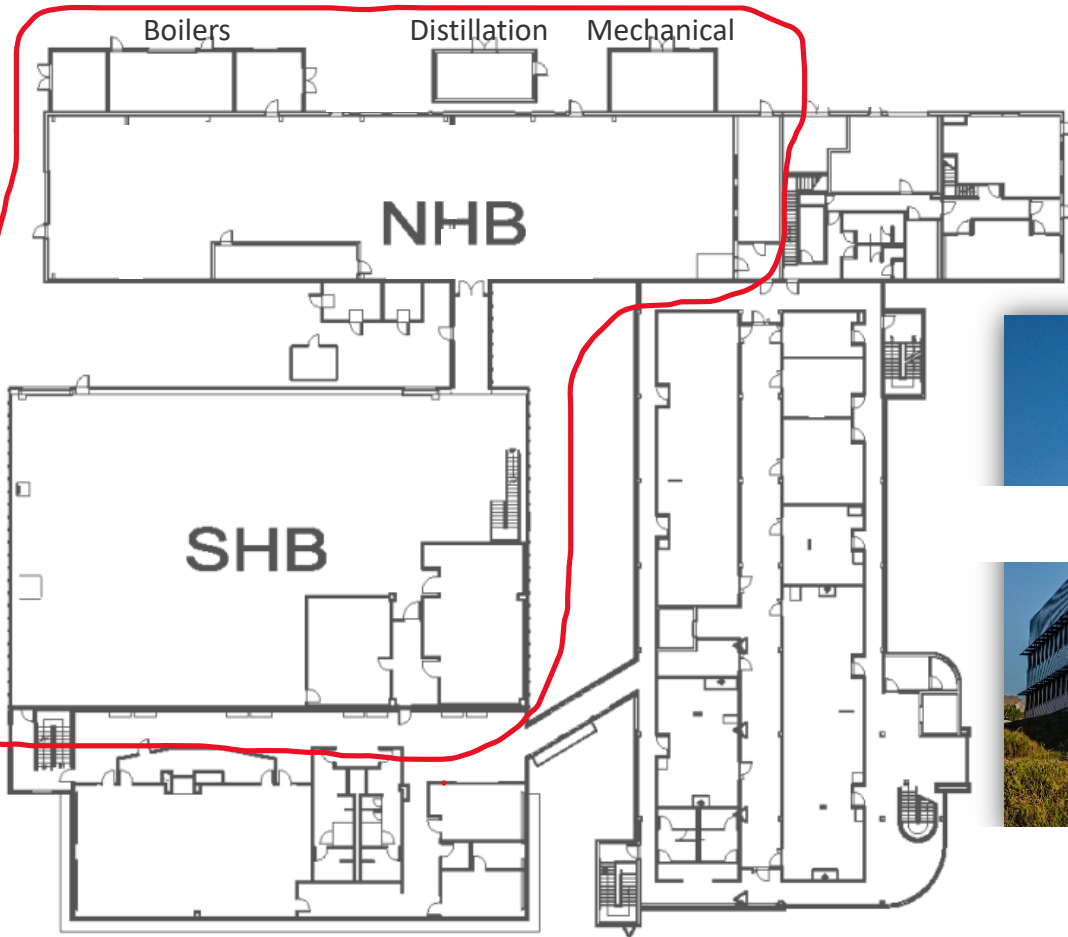
- Integrated 1 t/d process train
- Feed handling through product separation
- Utilities and emission control systems

## South High Bay (SHB, 2010)

- Integrated 0.5–1.0 t/d process trains
- Feed handling through high-solids enzymatic hydrolysis
- Some separations equipment
- Room for expansion



# IBRF Facility



- Two high bays: North (NHB, oldest) and South (SHB, newest)
- Total of ~27,000 ft<sup>2</sup> of open floor and mezzanines



# Approach-Plant Maintenance and Upkeep (M&U)

## Pilot Plant M&U

**Objective:** Manage processes (to the right) and associated resources to keep the plant safe and operational.

These processes keep the plant able to advance BETO's goals by supporting new and innovative BETO- and industry-supported work.

## Challenges:

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

### Equipment/Utilities

Routine maintenance  
Unexpected repairs

### Documentation

P&IDs  
Operating procedures  
Lockout/Tagout procedures  
Plant operations tracking

### Process Control

SCADA\*/network upkeep  
Hard/software upgrades  
Instrument calibrations

### Safety

Process hazard analysis  
Management of change  
Readiness reviews  
Safe work and other permits  
Maintaining key safety devices  
Adherence to safety programs

### Upgrades/Improvements<sup>†</sup>

<sup>†</sup>Generally, this work are project milestones defined yearly

# Documentation Examples



## IBRF Biochemical Pilot Plant Operating Procedure

Procedure Title	Effective Date	Supersedes
90-L Paddle Reactor	11/6/2019	1/1/2013
	Author: J. Shekiro	Reviewer: M. Fowler

### Significant Hazards or Safety Considerations

Specific hazards unique to this operation include: chemicals, electrical, rotating parts, and high pressures and temperatures. Operation of this equipment is covered under the pilot plant's SOP (0480).

Unique hazards-None

Emergency shutdown: Turn the agitator switch to the OFF position. Close HV-1250-1 to block the low-pressure steam supply to the paddle reactor jacket.

### Prerequisites

- Ensure that the area and reactor are safe for operation.
- Confirm that the reactor has not been modified from the configuration the operators have been trained on.

### Operating Procedure

#### 1. Loading the reactor

- 1.1. Ensure the paddle reactor (PR) is upright.
- 1.2. Open the reactor vent (HV-1250-3)
- 1.3. Verify that there is zero pressure in the reactor (PI-1250-2)

## Equipment Specific Operating Procedures

# Documentation Examples

 NATIONAL RENEWABLE ENERGY LABORATORY	IBRF Biochemical Pilot Plant Operating Procedure	
	Procedure Title	Effective Date
	90-L Paddle Reactor	11/6/2019
	Supersedes	Author: J. Shekiro
		Reviewer: M. Fowler

## Significant Hazards or Safety

Specific hazards unique to this equipment, including high pressures and temperatures (SOP 0480).

Unique hazards-None


Emergency shutdown: This procedure isolates the low-pressure steam from the reactor.

## Prerequisites

- Ensure that the area is clear.
- Confirm that the operators have been trained.

## Operating Procedure

1. Loading the reactor
  - 1.1. Ensure the paddle is in the down position.
  - 1.2. Open the reactor.
  - 1.3. Verify that the reactor is open.

 NATIONAL RENEWABLE ENERGY LABORATORY	IBRF Biochemical Pilot Plant Lockout/Tagout Procedure	
	Procedure Title	Effective Date
	LHR Plug Screw Feeder	10/7/2019
	Next Review Date	Author: C. Gunther
		10/7/2020

## Procedure Purpose

To securely isolate steam and electrical from the plug screw feeder (PSF-2221) prior to its removal. This procedure isolates steam from all components of the Large Horizontal Reactor (LHR) system.

## Prerequisites

- The reactor system is in standard shutdown condition.
- All requirements of the NREL LO/TO Program must be followed.
- Notification of this LO/TO must be given to affected workers.
- The P&ID for this equipment has been reviewed for any additional energy sources not covered in this procedure. This procedure must be updated if necessary.
- This equipment has been inspected for any additional energy sources not covered in this procedure. This procedure must be updated if necessary.

## Procedure

1. Close and LO/TO the high pressure steam manual isolation valve (HV-2200-35) to R-2200. Verify Zero Energy: Set pressure set-point on Green Fisher valve to 50 psig or greater and verify that line pressure is equal to 0.
2. Position to OFF and LO/TO the following disconnects:

## Equipment Specific Lockout/Tagout Procedures

# Documentation Examples



IBRF Biochemical Plant  
Operating Procedure

Procedure Title	Effective Date	Superseded
90-L Paddle Reactor	11/6/2019	1/1/2019
	Author: J. Shekiro	Reviewed

## Significant Hazards or Safety Concerns

Specific hazards unique to this procedure include high pressures and temperatures (SOP 0480).

Unique hazards-None

Emergency shutdown: The procedure isolates the low-pressure steam from the reactor system.

## Prerequisites

- Ensure that the reactor system is in standard shutdown condition.
- Confirm that the reactor system has been trained.

## Operating Procedure

1. Loading the reactor
  - 1.1. Ensure the paddle reactor is in standard shutdown condition.
  - 1.2. Open the reactor system.
  - 1.3. Verify that the reactor system is in standard shutdown condition.



Procedure Title  
LHR Plug Screw Feeder

## Procedure Purpose

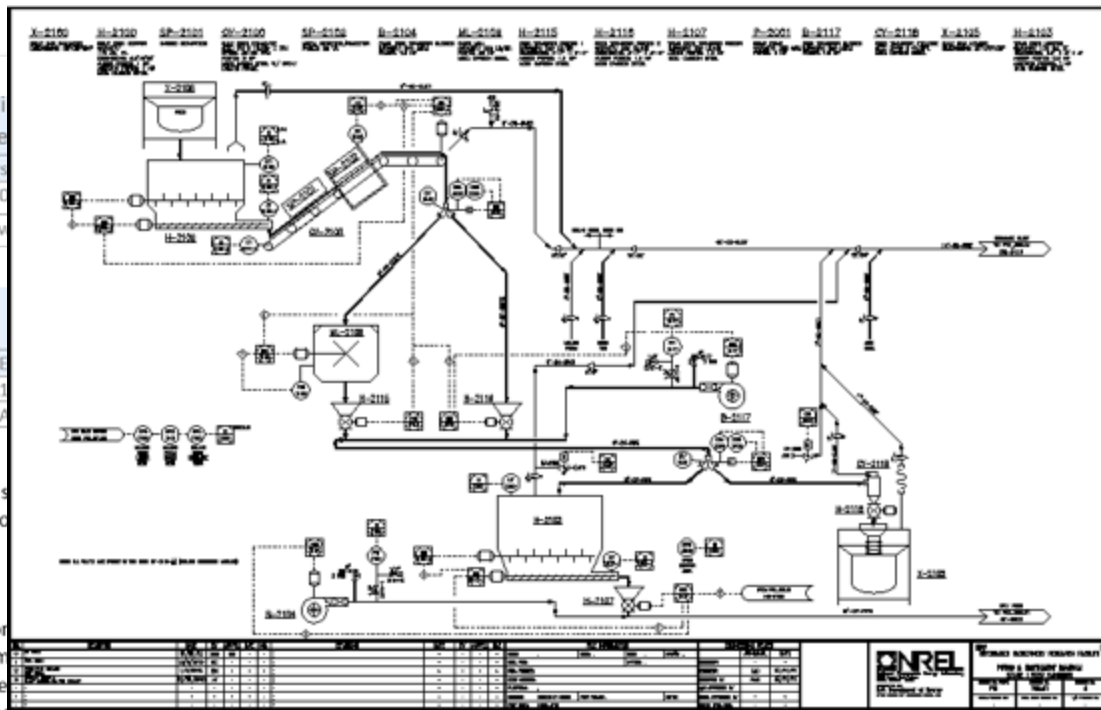
To securely isolate steam and electrical from the plug screw feeder removal. This procedure isolates steam from all components (LHR) system.

## Prerequisites

- The reactor system is in standard shutdown condition.
- All requirements of the NREL LO/TO Program must be met.
- Notification of this LO/TO must be given to affected personnel.
- The P&ID for this equipment has been reviewed and approved. This procedure must be updated if necessary.
- This equipment has been inspected for any additional energy sources not covered in this procedure. This procedure must be updated if necessary.

## Procedure

1. Close and LO/TO the high pressure steam manual isolation valve (HV-2200-35) to R-2200. Verify Zero Energy: Set pressure set-point on Green Fisher valve to 50 psig or greater and verify that line pressure is equal to 0.



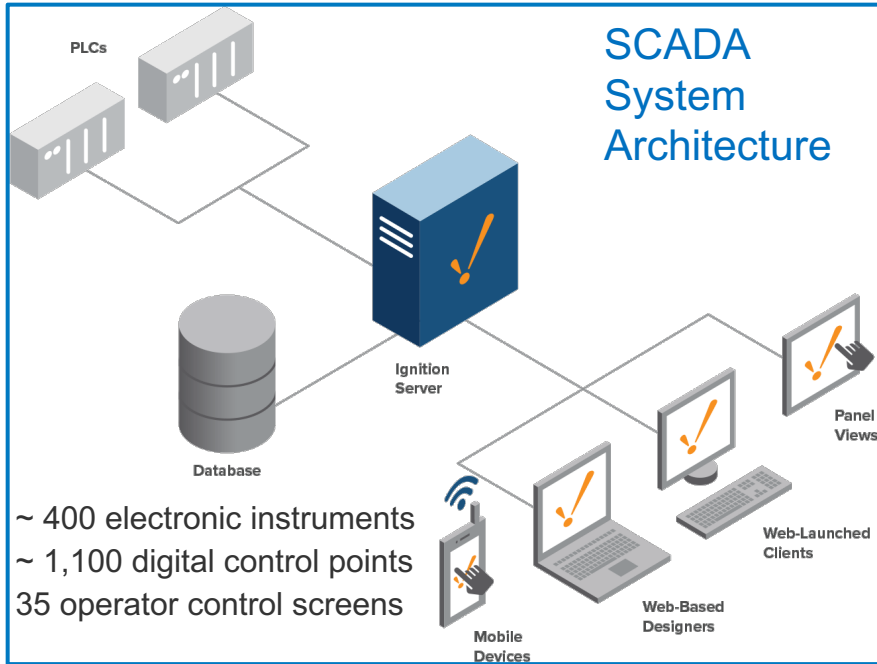
## Process and Instrumentation Drawings (96 drawings)



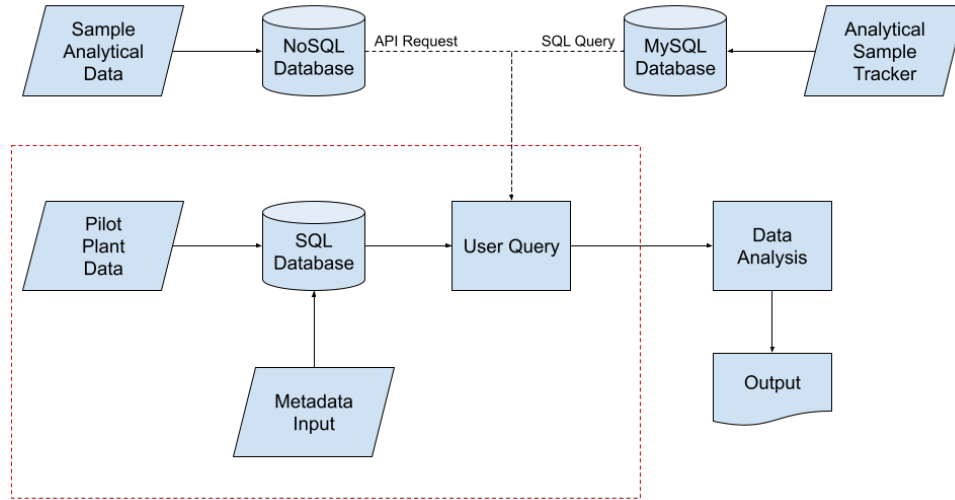
# Pilot Plant Process Control and Sample Tracking

## Supervisory Control and Data Acquisition (SCADA) System

- Opto® 22 Programmable Logic Controllers and Input/Output modules
- Ignition® SCADA software from Automation Engineering

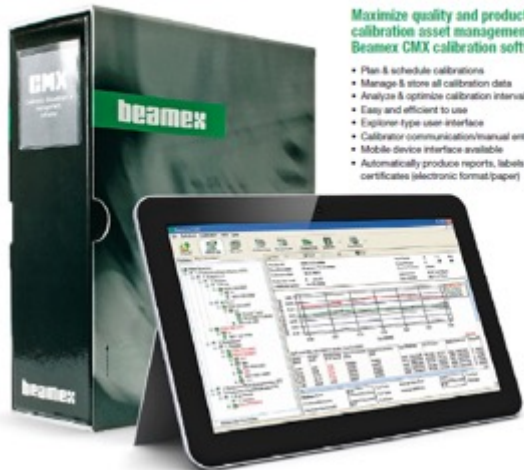


## Data Storage and Analytical Sample Tracking



# Instrument Calibration Management

BEAMEX CMX  
CALIBRATION MANAGEMENT SOFTWARE



Maximize quality and productivity of calibration asset management with Beamex CMX calibration software

- Plan & schedule calibrations
- Manage & store all calibration data
- Analyze & optimize calibration interval
- Easy and efficient to use
- Ergonomic type user interface
- Calibrator communication manual entry
- Mobile device interface available
- Automatically produce reports, labels & certificates (electronic format/paper)

Automated multi-function field calibrator and communicator

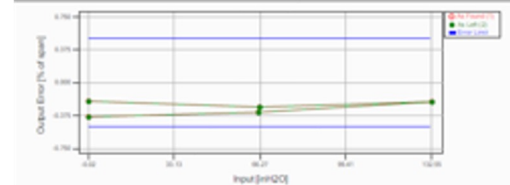


 NATIONAL RENEWABLE ENERGY LABORATORY	IBRF Biochemical Pilot Plant Specific Procedure	
	Procedure Title	Effective Date
Instrument Calibration Management Program	12/28/2017	07/01/1997

## 1.0 Introduction

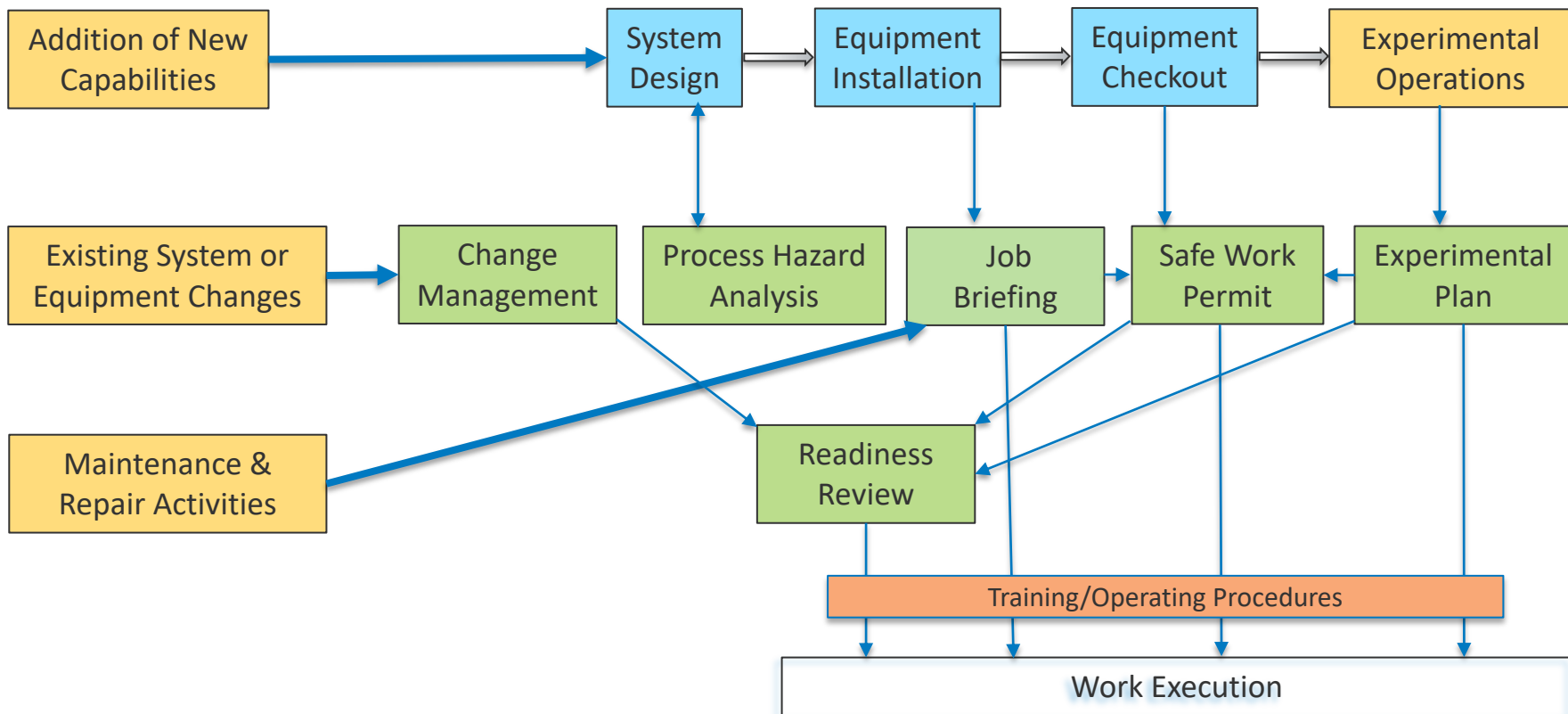
The biochemical pilot plant located in the North and South High Bays of the Integrated Biorefinery Research Facility (IBRF) is used to perform research and testing of integrated lignocellulosic biomass to fuel and chemical production processes. The plant (1000 tonne/d) as well as stand-alone equipment. Various streams include: steam; instrument and house air; and cold, chill

NREL		Version: 1.0.0 (2017-12-28)		Position ID: IIR-001-1	
<b>Location:</b>	IBRF Biochemical Pilot Plant	<b>Device:</b>	LT-001-1	<b>Calibration Event:</b>	1000 TONNE/D
<b>Device:</b>	LT-001-1	<b>Serial Number:</b>	1000 TONNE/D	<b>Next Calibration:</b>	1000 TONNE/D
<b>Unit:</b>	1000 TONNE/D	<b>Operating Temperature:</b>	1000 TONNE/D	<b>Environment Humidity:</b>	1000 TONNE/D
<b>Calibration Procedure:</b>	1000 TONNE/D	<b>Calibrator:</b>	1000 TONNE/D	<b>Due Date:</b>	1000 TONNE/D



1. As Found			PASSED			2. As Left			PASSED		
Minimum Error (% of span)	Maximum Error (% of span)	Span Error (% of span)	Minimum Error (% of span)	Maximum Error (% of span)	Span Error (% of span)	Minimum Error (% of span)	Maximum Error (% of span)	Span Error (% of span)	Minimum Error (% of span)	Maximum Error (% of span)	Span Error (% of span)
0.00	0.00	0.00	-0.02	-0.02	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00
0.00	0.00	0.00	-0.02	-0.02	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00
0.00	0.00	0.00	-0.02	-0.02	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00
0.00	0.00	0.00	-0.02	-0.02	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00

# Workflow and Safety Processes\*



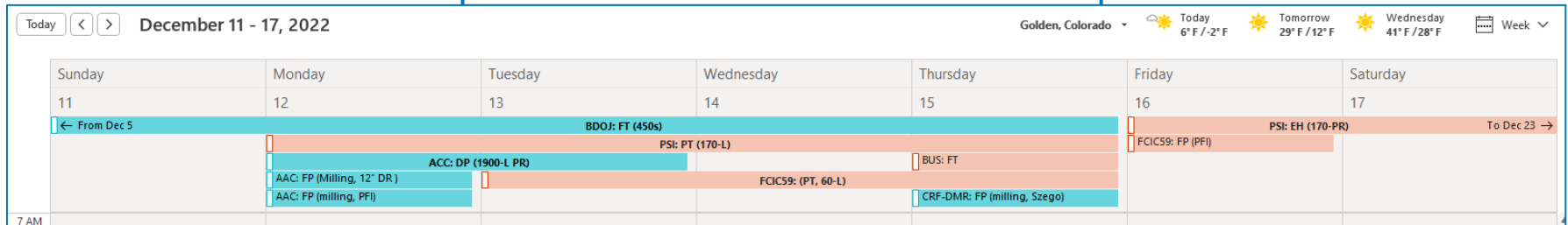
\*May not capture all possible processes or flow paths.

# Approach-Managing Plant Scheduling and Use

## Work Management Process/Risk Mitigation Elements

- Outlook scheduling/tracking system (9 years of data)
- Operations staff plan-of-the-day meeting
- Weekly operations staff and PI coordination meeting
- SharePoint-based system for task assignment/tracking for operations staff
- SharePoint-based system for routine/non-routine maintenance tracking
- Out of Service program

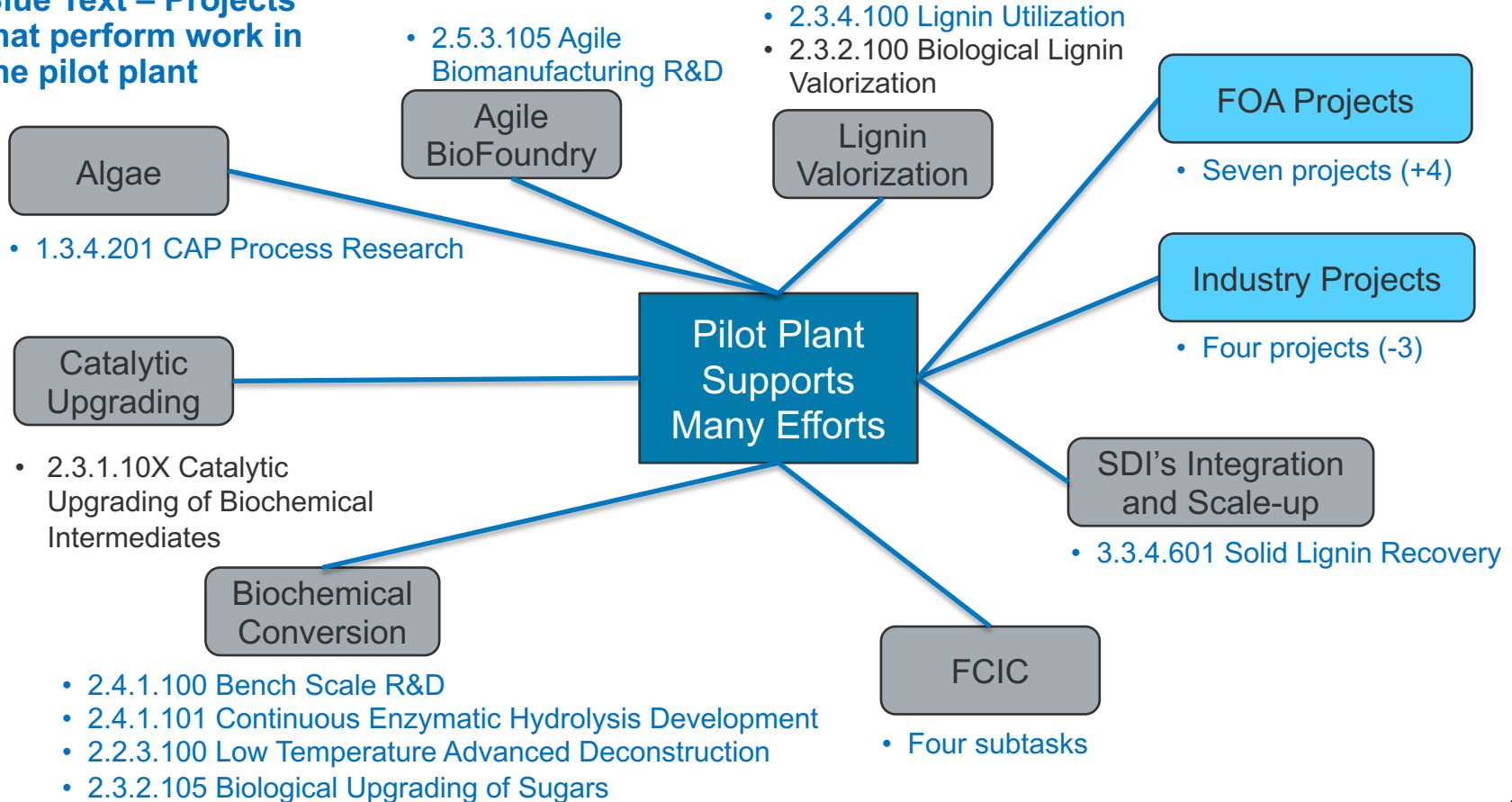
### Outlook Calendar Scheduling/Tracking



Nomenclature: Project code: Unit operation identifier (equipment or other information)

# Linkages/Users By Project/Program Areas (FY21/22)

**Blue Text – Projects that perform work in the pilot plant**



# Progress and Outcomes


## Recently Completed Activities/Milestones



Knockback condensers installed on the two 160-L bioreactors



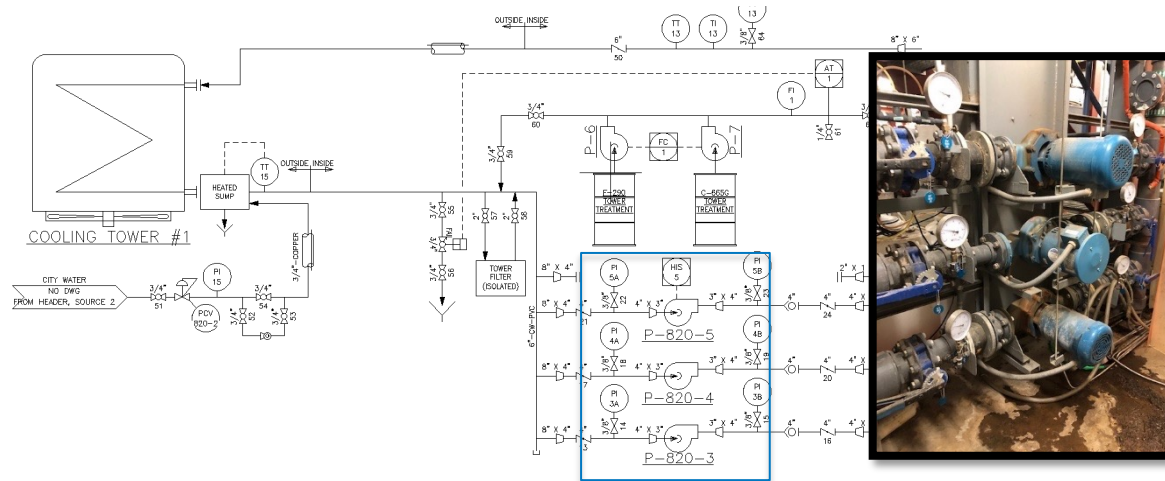
Decanter centrifuge returned to service

		IBRF Biochemical Pilot Plant Return to Service (RTS) Form	
Effective Date:		1/11/2021	Supersedes Date: n/a
<b>Equipment/System Information</b>			
Equipment/System: Decanter Centrifuge			
Location: IBRF 278 NHB			
<b>RTS Checklist (number items in this list and refer to them in the commissioning list)</b>			
	Checked By	Date Reviewed	Actions or Comments
Check system against current P&ID(s)	Ryan Spiller	6/14/2022	<ul style="list-style-type: none"> <li>8"-CPVC solids outlet and flex hose from FF-610 not attached.</li> <li>From P-601 the SS was modified to flex hose for a recirculation pump to V-455B.</li> <li>SS pipe added after PI 601-2 with two valves and one pipe going to neutralization tank. Another SS pipe added before FIT 601-2 with a valve to decanter exit.</li> <li>Remove valves: 601-2, 601-3, 601-19</li> </ul> 1. Missing tags need replaced.
	Ryan Spiller	6/29/2022	Outlets from FF-610 not attached. Connector between V-601 and FF-610. ? Unit needs greasing

# Progress and Outcomes

## Water System Improvements

- Process water
  - Variable frequency drive installed on pump motor
- Cooling Water Systems
  - Cooling tower fan motors replaced
  - External cooling loop pumps replaced
  - Improved system automation in progress



**All Plant Utility Systems:** Improve remote sensing and monitoring of the plant's various utility systems by end of FY23.

# Progress and Outcomes

## Large Facility Improvement Projects

### Boiler Replacement



Replacing existing old 100 hp high-pressure boiler with two 60 hp units.



### Air Compressor Replacement



Replacing old, large volume air compressor.

> \$3 MM of upgrades funded out of NREL general purpose funds.

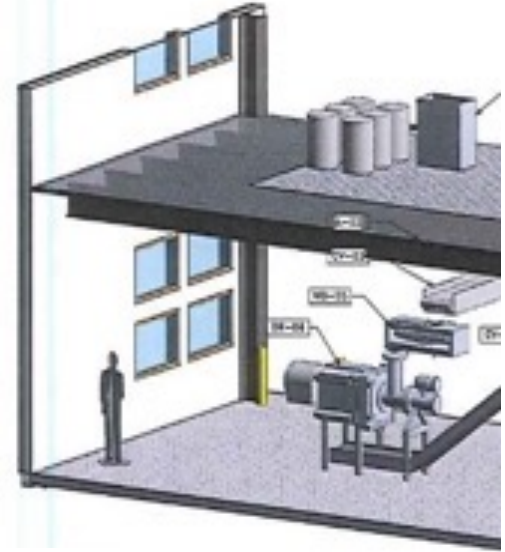


# Progress and Outcomes

## 22" Refiner Installation Project

The new 22" disk refiner allows on-demand production of Deacetylated and Mechanically Refined (DMR, see slide in additional materials) biomass.

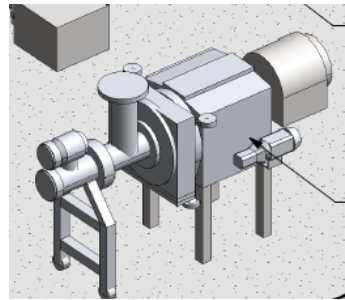
- Most system components delivered
- Andritz completing control system
- Installation subcontract placed February 9



**Feeder**



**22" Disk Refiner**



Multiple SAF development pathways are being explored at NREL and several industry partnerships are using DMR-treated biomass as the preferred starting material.

# Progress and Outcomes

## Material Production

Types of process materials produced as needed include:

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

\*Deacetylated corn stover shipped to Andritz for off-site disk refining at their Springfield, OH facility.



Twine used to bale stover pugged the membrane separation modules during clarification of an enzymatic hydrolysate.



# Impact

**The pilot plant supports DOE/BETO's mission to scale up and commercialize biofuel/bioproduct production technology.**

- Test technical feasibility of single or multiple unit operations
- Produce integrated, engineering-scale data
- Generate process relevant materials and bioproducts

## Pilot Plant Used by Many Projects

	BETO (AOP)	Partnerships
# of Projects (FY13-FY22)	19	37
Estimate Worth to NREL	~\$2 to \$3 MM annually*	Several \$10,000s to several \$MM/project

\*Excludes funding for this project

## New Pilot Plant Projects in FY23:

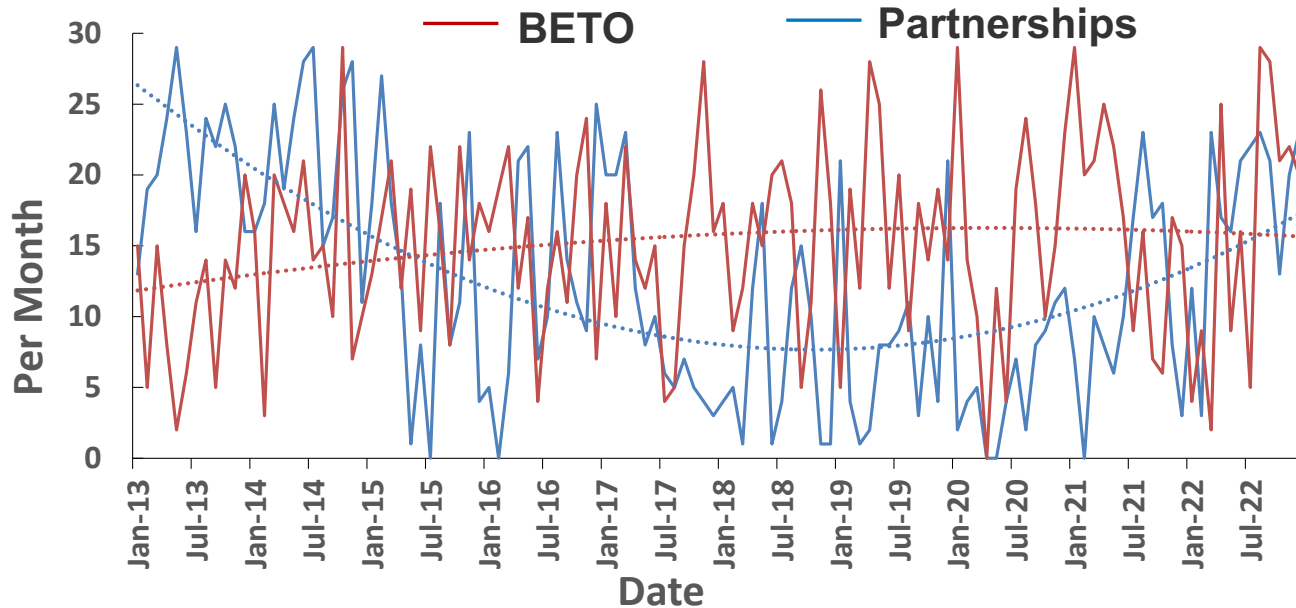
- Three new FOA projects
- Work for one industry client currently
- One new SBIR project

## Addressing SDI strategic goals (old MYP):

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

# Impact - Pilot Plant Use Tracking (2013-2022)

Number of Contact Days  
Per Month



**LYGOS**



**TOYOTA**

**HONDA**

Honda R&D Americas, Inc.

**ExxonMobil**

Energy lives here™



**DSM**  
BRIGHT SCIENCE. BRIGHTER LIVING.



**General Mills**  
Making Food People Love



**ecopETROL** ENERGÍA PARA EL FUTURO



Helping the world thrive

**ABENGOA**

**novozymes™**

Rethink Tomorrow



**VISOLIS**  
CARBON NEUTRAL MATERIALS

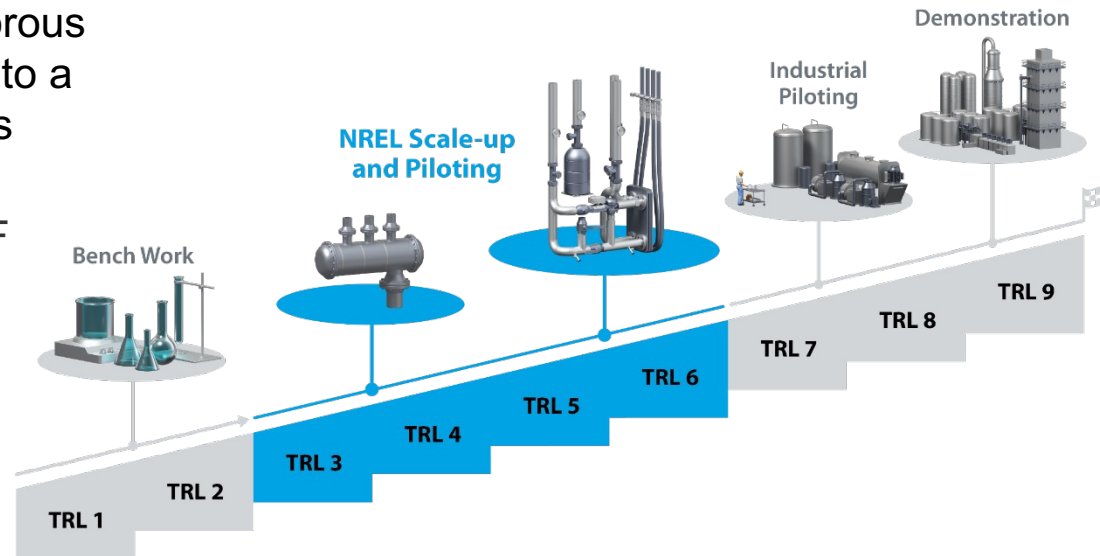
“Contact Day” – On a given day, a BETO (AOP or Lab Call) or industry (any industry partner work including FOAs) project used at least one piece of equipment or unit operation in the pilot plant. (Does not include routine repair and maintenance activities performed by this project. The scale and cost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

# IBRF Pilot Plant Revitalization

NREL's IBRF pilot plant is not currently equipped to meet all future piloting demands.

We are investing in revitalization of the IBRF pilot plant (NHB) to allow NREL to:

- Play a critical role in deploying bioeconomy, electrons-to-molecules (E2M), and circular economy (CEM) technologies and processes
- Address a critical shortcoming of the bioeconomy – inadequate piloting
- Meet industry requirements for rigorous scale-up and piloting by upgrading to a plug-and-play technology readiness level (TRL) 5/6 facility
- Increase the success of taking SAF and bioeconomy technologies to commercialization



## Funding:

- \$19 MM Inflation Reduction Act
- \$10 MM BETO (equipment)
- \$6 MM NREL General Purpose

# IBRF Pilot Plant Revitalization

**Create a new highly flexible facility for scale up and integration of biomass to finished fuels and other new technologies supporting BETO and industry needs.**





- Convert existing NHB into areas rated for highly hazardous (e.g., flammable gases and solvents) and biosafety level 2 pilot scale operations
- Preserve ability to generate biologically-derived intermediate molecules from biomass sugars using equipment in the SHB (biomass deconstruction and microbial conversion)
- Utilize play and play to extent possible and target for ability to rapidly reconfigure unit operations to minimize turnaround and downtime
- Include sufficient instrumentation to accurately close mass balances and support computational modeling








**Existing NHB**

# Market Trends




## Product

-  Anticipated decrease in gasoline/ethanol demand; diesel demand steady
-  Increasing demand for aviation and marine fuel
-  Demand for higher-performance products
-  Increasing demand for renewable/recyclable materials




## Feedstock

-  Sustained low oil prices
-  Decreasing cost of renewable electricity
-  Sustainable waste management
-  Expanding availability of green H<sub>2</sub>
-  Closing the carbon cycle

## Capital

-  Risk of greenfield investments
-  Challenges and costs of biorefinery start-up
-  Availability of depreciated and underutilized capital equipment

## Social Responsibility

-  Carbon intensity reduction
-  Access to clean air and water
-  Environmental equity

# DOE's/NREL's Biochemical Pilot Plant Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

## Value Proposition

- This readily available pilot plant supported by BETO is made available to all users (BETO projects and industry) helping BETO to achieve its biofuel goals.

## Key Differentiators (U.S.)

- Unique one-of-its-kind U.S based facility for flexible and integrated biomass processing
- 1 ton/d continuous pretreatment and multiple large bioreactors ranging from 160-L to 9,000-L
- Soon will be equipped with raw biomass to finished fuel processing capability

# Summary

## Approach:

- Use plant personnel effectively for maintenance and upkeep activities
- Follow structured management process for plant scheduling and use

## Impact:

- Support BETO/industry scale up/commercialization efforts
- Use plant for process development, evaluation, and verification
- De-risk technologies and identify/solve scale-up issues

## Accomplishments:

- Completed control system upgrades and finished a new data management system
- Completed utility water system repairs
- Received funding for major utility (steam, air) systems upgrades and work is in progress
- Installing new DMR material production capability
- Design of new NHB capabilities for finished fuels is in progress





# Acknowledgments

## FY21/22 Team Members

- Mike Baker
- John Bombard
- Matt Fowler
- Ryan Ferguson
- Casey Gunther
- Wes Hjelm
- Luke Klin
- Frank LaForge
- Bob Lyons
- Ryan Spiller



## Funding

- US Department of Energy Office of Energy Efficiency and Renewable Energy Bioenergy Technologies Office
- Josh Messner – BETO Technology Manager
- Jim Spaeth – SDI Program Manager

# Questions

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[www.nrel.gov](http://www.nrel.gov)

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# Quad Chart Overview

## Timeline

- Project start date: 10/1/2022
- Project end date: 9/30/2024

	FY22	Total Award
DOE Funding	\$1,631,000	\$5,200,000
Project Cost Share		

TRL at Project Start: 4-6  
TRL at Project End: 4-6

## Project Goal

Maintain a functional and safe biochemical pilot plant, upgrade or add new capabilities to support BETO funded R&D or support industry projects as needed, produce process materials to enable R&D at bench/pilot scale.

## End of Project Milestones

- None

**Funding Mechanism:** BETO Direct

## Project Partners

- None

**Additional Slides**

# Responses to Previous Reviewers' Comments

Reviewer Comment: Process improvements appear to be based upon internal discussion and do not include much (if any) industry guidance; the move to the DMR process, while it has potential, looks to be driven from internal research and not an external industry need. More clear industrial guidance and input should be collected.

- A nearly identical comment was also provided to the project that helped develop DMR technology; the project resides under the Conversion Platform. However, in the two years since these comments, two collaborative NREL/industry projects have been awarded that continue to develop this technology demonstrating industries interest in the DMR process.

Reviewer Comment: No support for gas fermentation, not designed to handle hazmats, not clear if it can handle flammable or combustible materials.

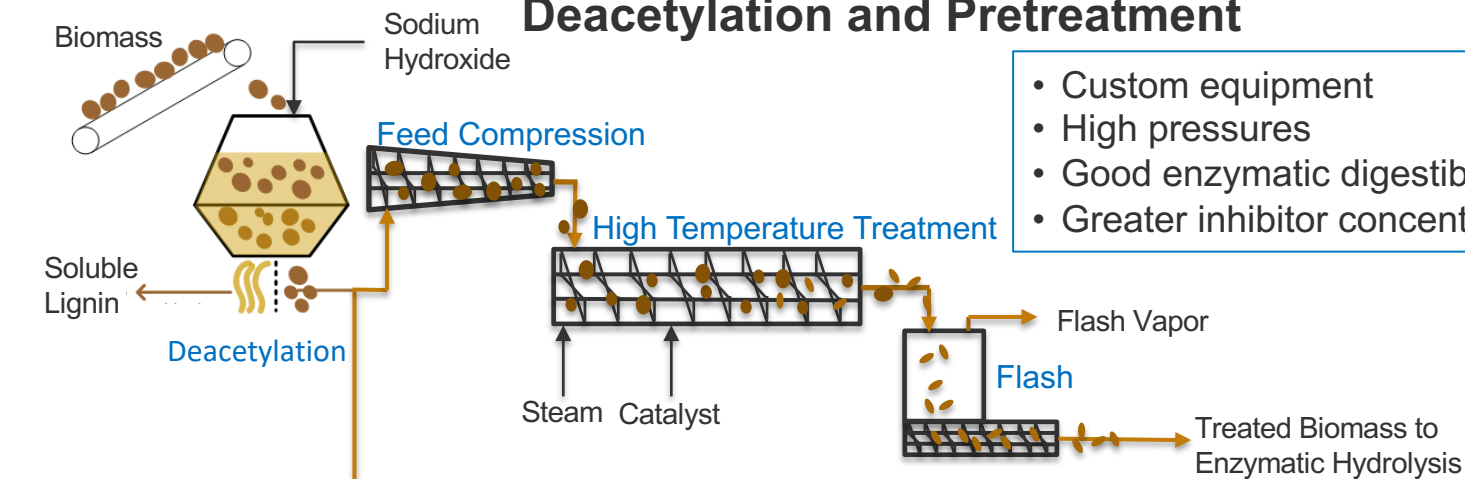
- NREL began work in FY20 to upgrade our biochemical pilot plant to be able handle the type of technologies (more specific upgrading of biologically-produced intermediate molecules to fuels. The NHB is currently in the process of being re-configured and upgraded to handle flammable gases and hazardous liquid to support these current technologies and new concepts in the future.

## Publications, Patents, Presentations, Awards, and Commercialization

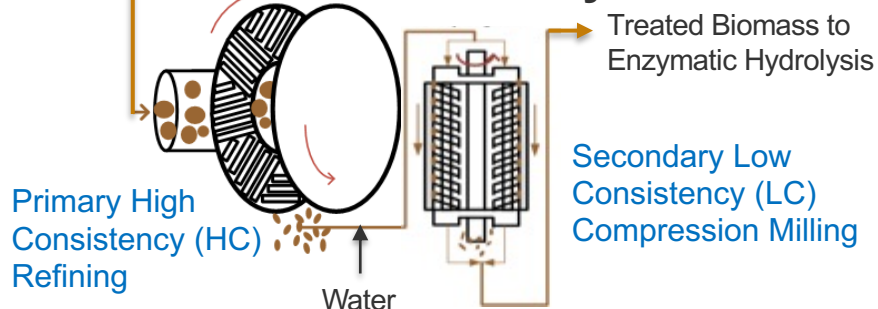
- This project doesn't produce these types of products.

# Pretreatment

## Deacetylation and Pretreatment



## Deacetylation and Mechanical Refining (DMR)

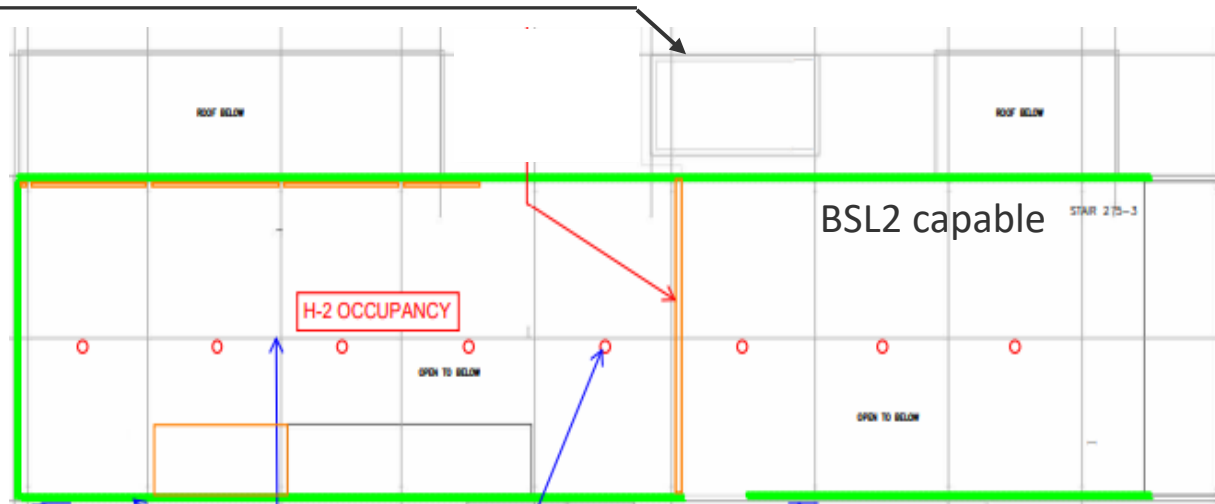


- Commercial equipment
- Atmospheric pressures
- Lower inhibitor concentrations
- Good enzymatic digestibility
- Lower resistance to contamination
- Residual solids harder to separate

# IBRF Pilot Plant Revitalization Floor Plan

Refurbished Class I, Div 2 area (~270 ft<sup>2</sup> with ~40 ft high ceiling)

**Reconfigured  
NHB**



- Building interior/exterior improvements
- Open design with new ventilation capabilities and supporting utilities/gases/electricity