BETO 2021 Peer Review

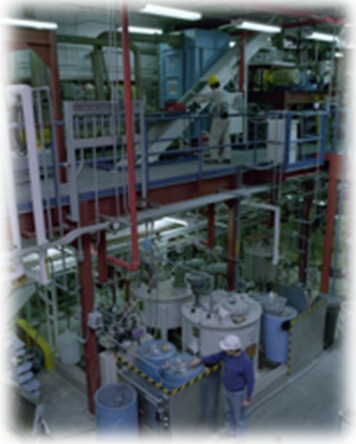
Biochemical Pilot Scale Support and Process Integrations
WBS#: 3.4.2.201

March 24, 2021
Systems Development and Integration

Dan Schell
NREL

Biochemical Pilot Plant at the IBRF

~27,000 ft^2 of open floor and mezzanines

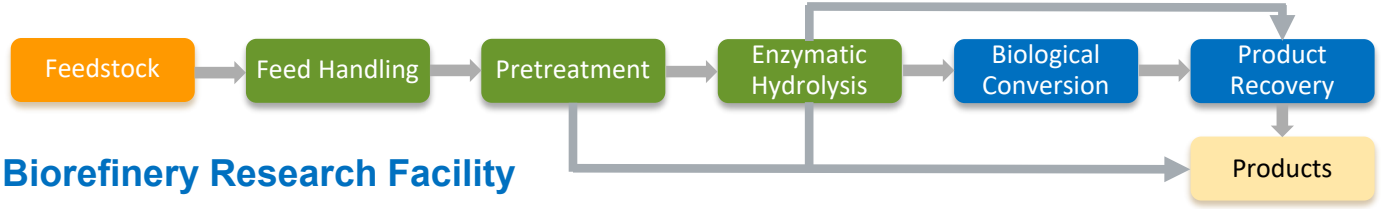


North High Bay (NHB, 1994)

- 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: Integrated Biorefinery Research Facility

Project Overview

Biochemical Pilot Plant (35-year-old facility)

- Biomass conversion to biofuels/biochemicals
- Multiple expansions have occurred

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

Project Overview

Biochemical Pilot Plant (35-year-old facility)

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

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

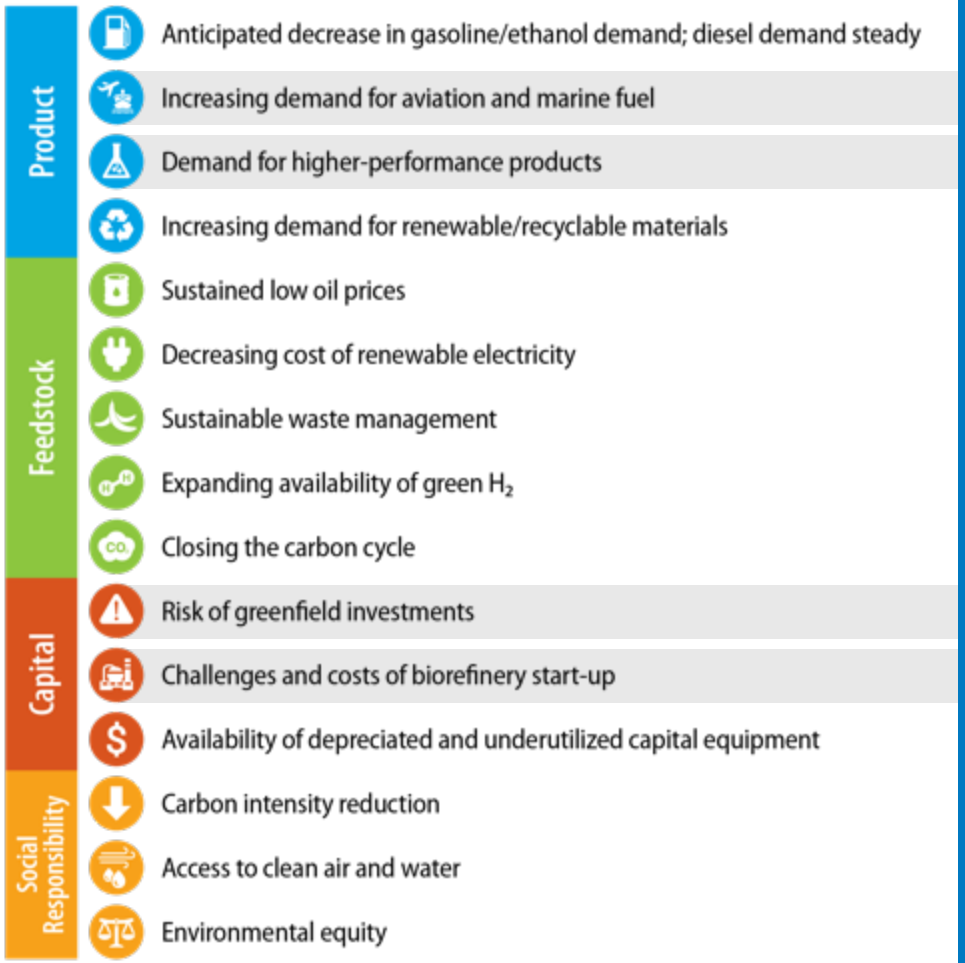
- **What:** Maintain pilot plant meeting data quality needs and generate process-relevant material for bench-scale R&D
- **How:** Effectively use available resources to maintain functionality and safety
- **Why:** Facility for pilot-scale process development and scale up for BETO and industry
- **Risk:** Inopportune failures/low work efficiency due to poor communications and planning

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

Market Trends



NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

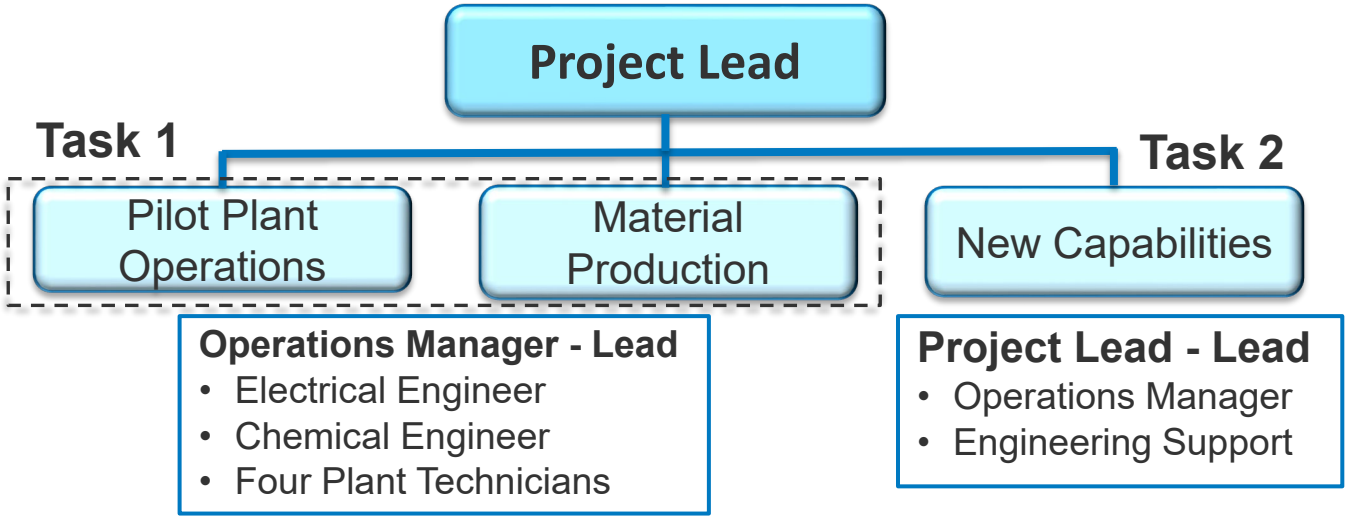
- Readily available pilot plant supported by DOE and made available to all users.

Key Differentiators (U.S.)

- Unique one-of-its-kind U.S based facility for flexible and integrated biomass processing
- Up to 1 ton/d pilot-scale continuous pretreatment reactor systems
- Multiple large bioreactors ranging from 160-L to 9,000-L

1. Management

Current Project Structure (FY19- FY21):



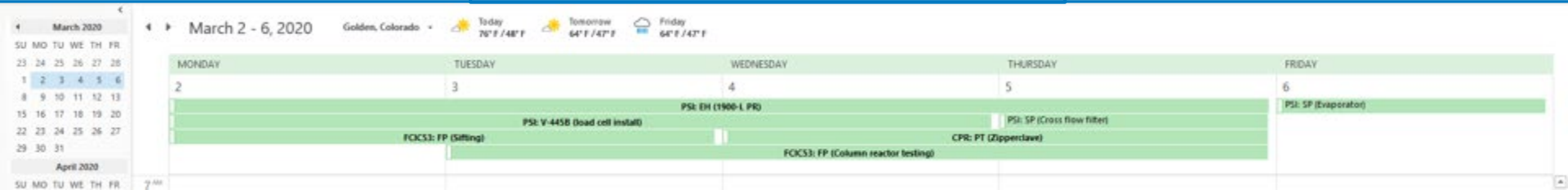
- Pilot Plant Operations Task: Maintain a functional and safe facility (Routine operations: maintenance, repair, upkeep, documentation, safety, etc.)
- New Capabilities: Acquisition managed by milestones and Go/No-Go decisions

1.0 Management

Work Management/Risk Mitigation Elements

- Outlook project scheduling/tracking system (8 years of data)
- Weekly/Bi-weekly operations staff and PI coordination meeting
- Plan-of-the-day meetings
- SharePoint-based system for task assignment/tracking
- SharePoint-based system for routine/non-routine maintenance tracking
- Out of Service program

Outlook Calendar Scheduling/Tracking



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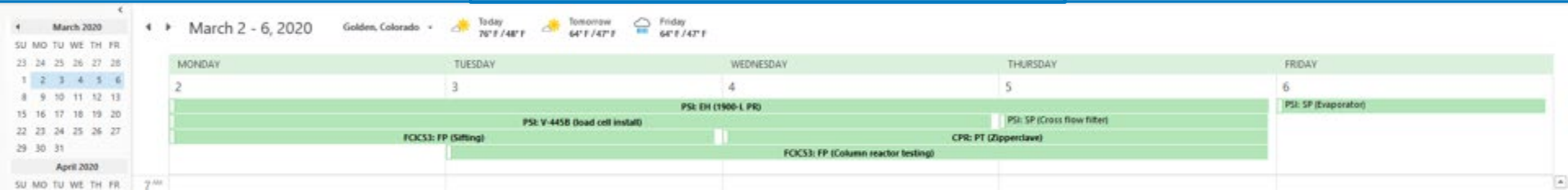
- Out of Service program

What this project doesn't do:

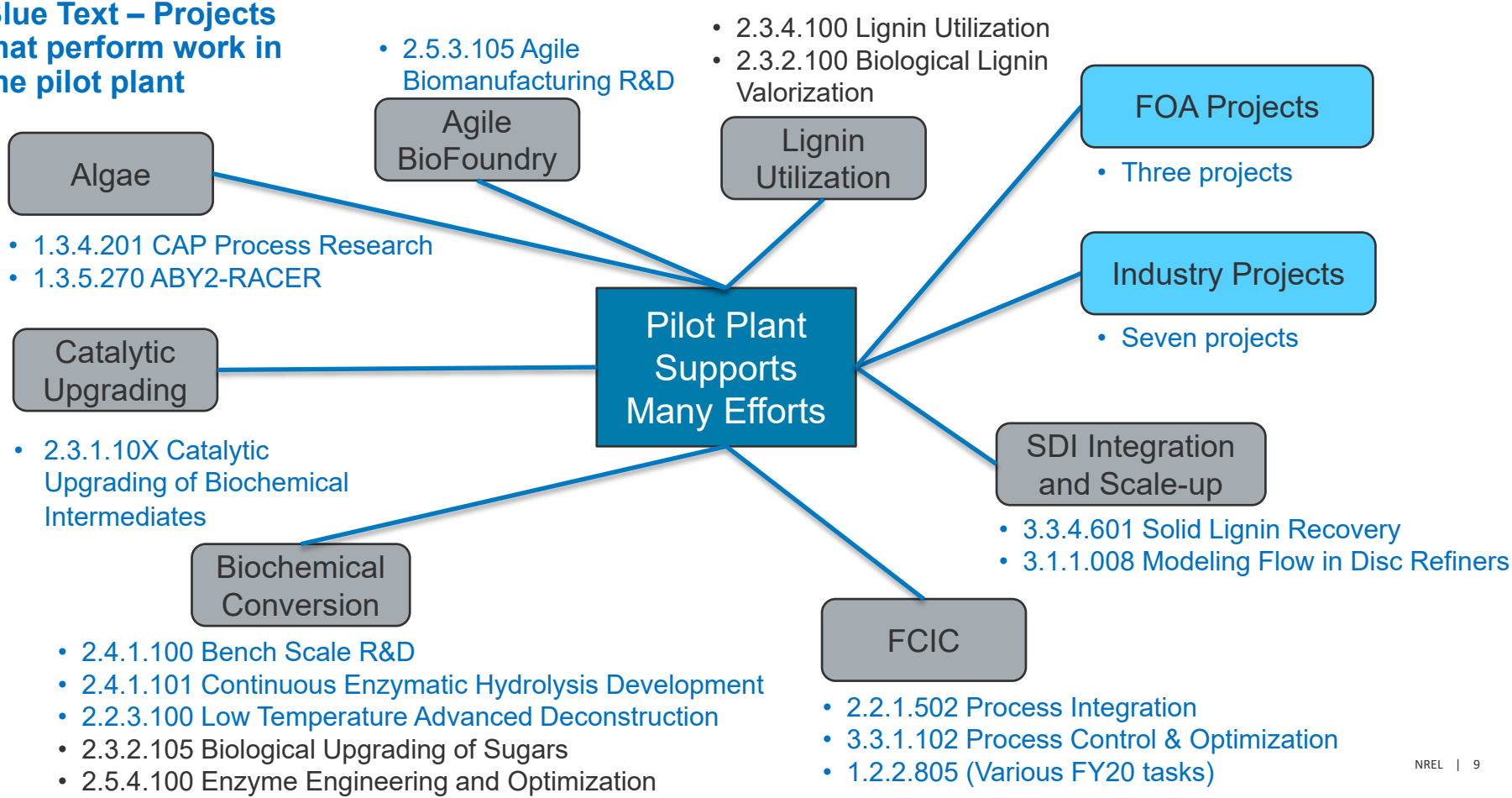
- Research
- Business development
- Direct collaborations

Outlook Calendar Scheduling/Tracking



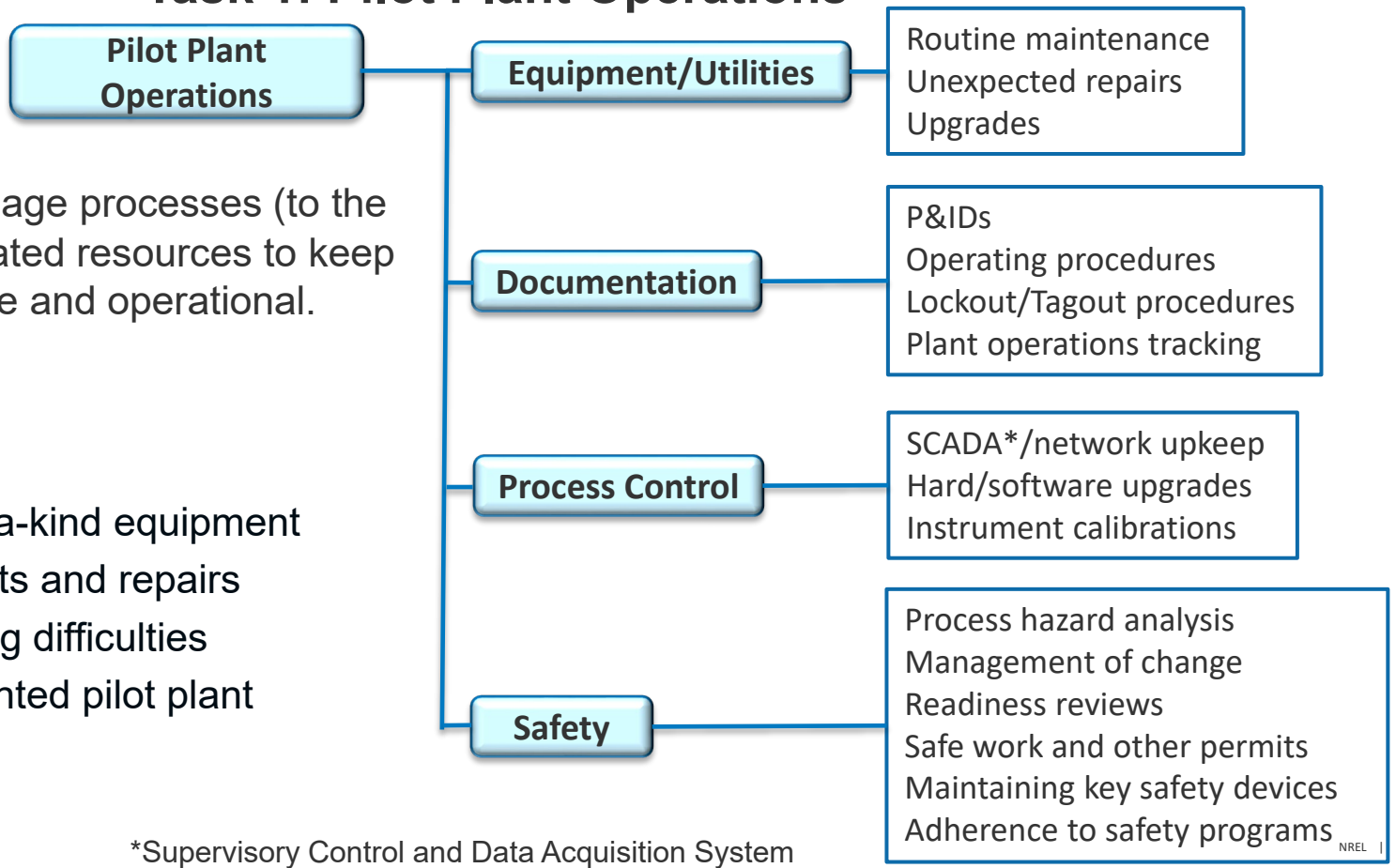
Linkages/Users By Project/Program Areas (FY19/20)

Blue Text – Projects that perform work in the pilot plant



2. Approach

Task 1: Pilot Plant Operations



Objective: Manage processes (to the right) and associated resources to keep the 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

*Supervisory Control and Data Acquisition System

2. Approach

Task 2: New Capabilities

Objective: Acquire new state-of-art capabilities to support BETO's and industry needs.

Approach:

- Identify new needs:
  - Annual consultation with BETO and bioenergy research community
  - Interaction with industry partners
- Define/implement milestones/key decision points (Go/No-Go) based on available resources
- Update plan yearly in response to changing priorities

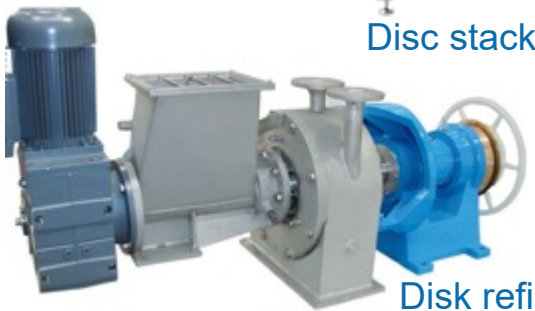
Challenges:

- Enough resources to acquire new equipment
- Long vendor lead times
- Safety upgrades have priority

Recent focus areas:

- Separations
- Alternative pretreatment option (DMR)

Disc stack centrifuge



Disk refiner

3. 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 and FOA)	Partnerships
# of Projects (FY13-FY20)	18	30
Estimate Worth to NREL	~$2 to $3MM annually*	Several $10,000s to several $MM/project

*Excludes this project

New FY21 work:

- Three to four new FOA projects
- Continuing work for two industry clients
- One new SBIR project

Addresses SDI strategic goals (MYP):

- Decrease commercialization risk
- Identity 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

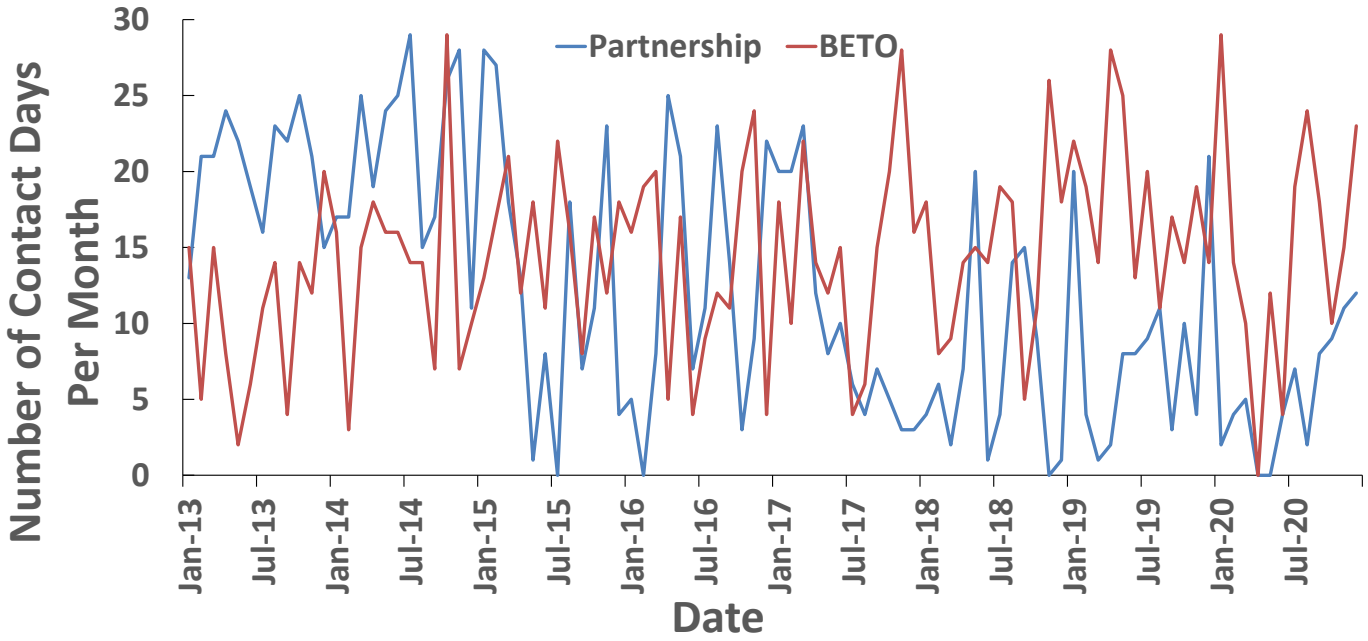
Partner Survey Quotes

"There are no other access to demo-scale bioreactors available with the flexibility that was available at NREL."

"The team at NREL worked with us extensively to modify the process and equipment to make it work."

"We have several projects at NREL. The first was the most important in successfully scaling our process at the IBRF."

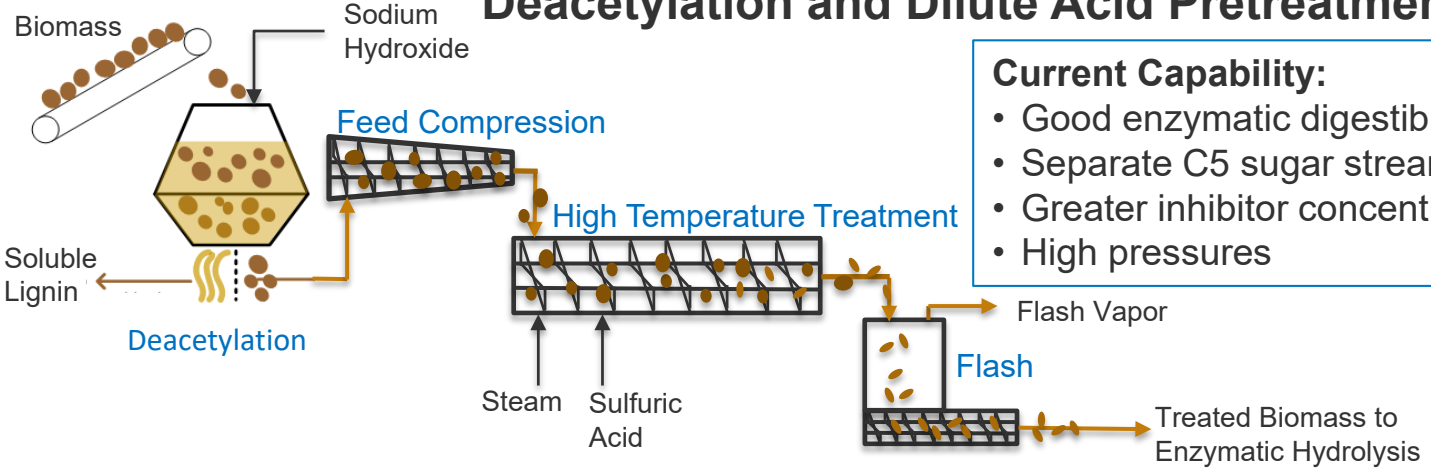
3. Impact - Pilot Plant Use Tracking (2013-2020)



"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.)

4. Progress and Outcomes

Deacetylation and Dilute Acid Pretreatment



Current Capability:

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

4. Progress and Outcomes

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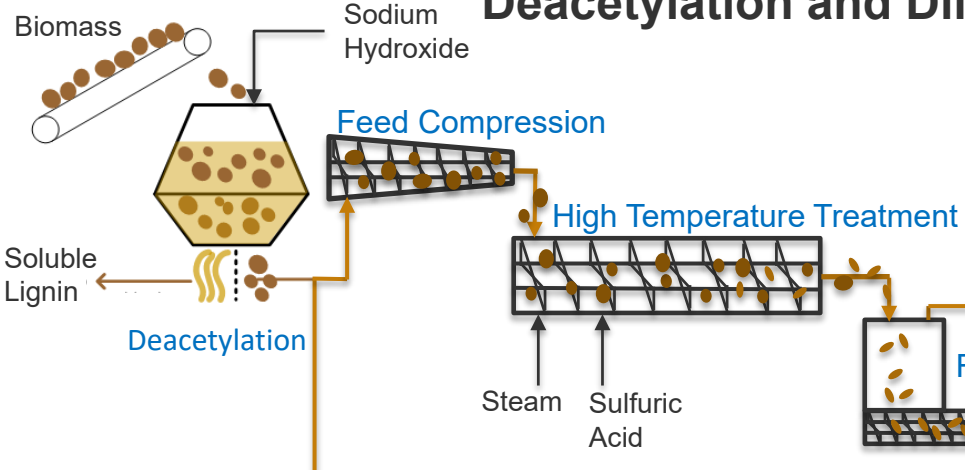

Current Capability:
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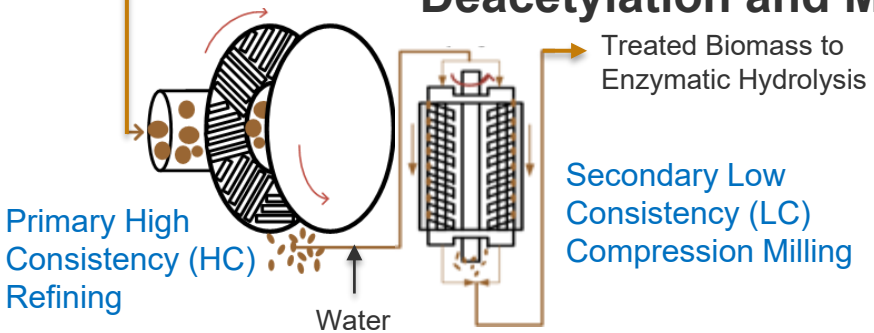
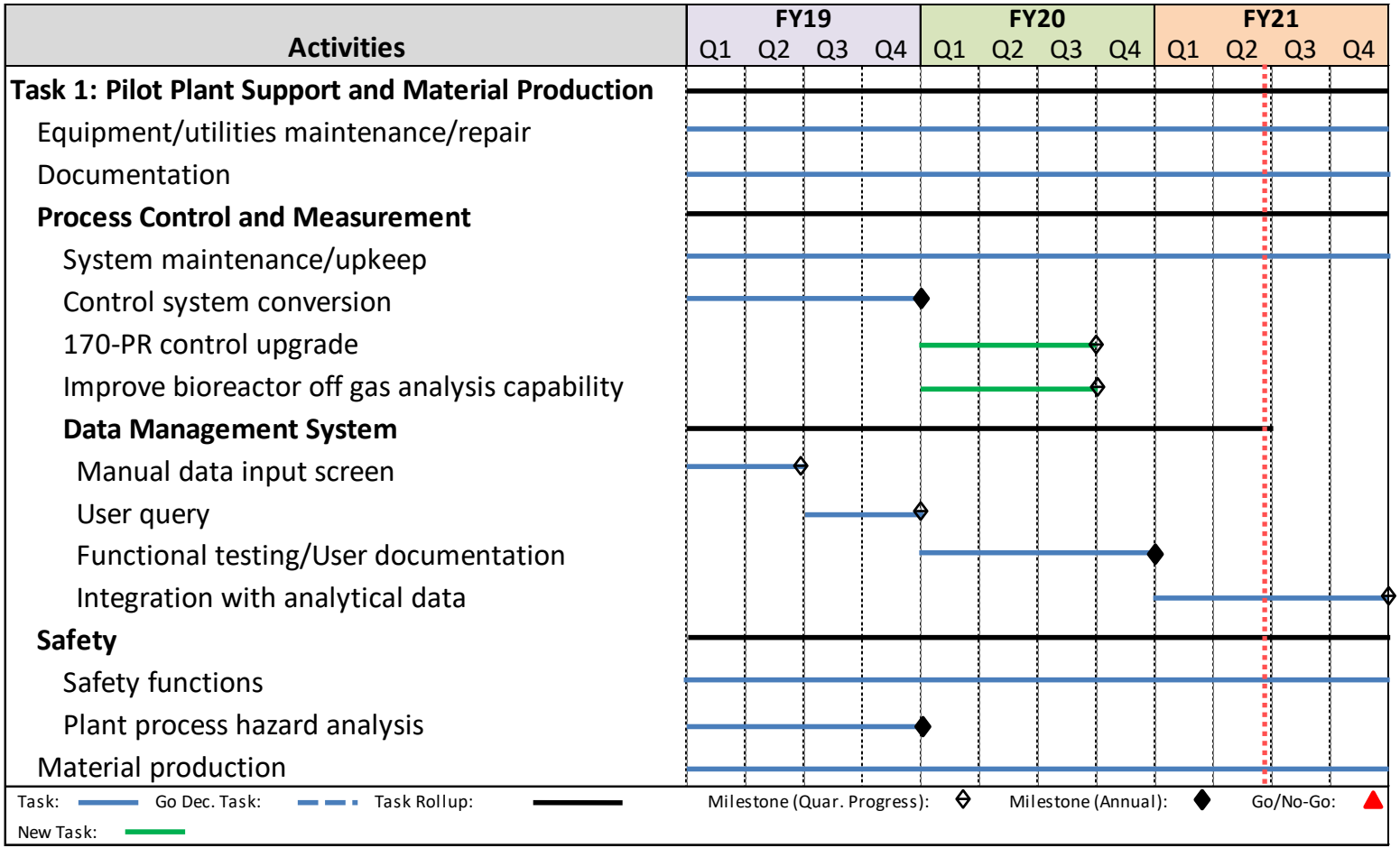
Deacetylation and Mechanical Refining (DMR)



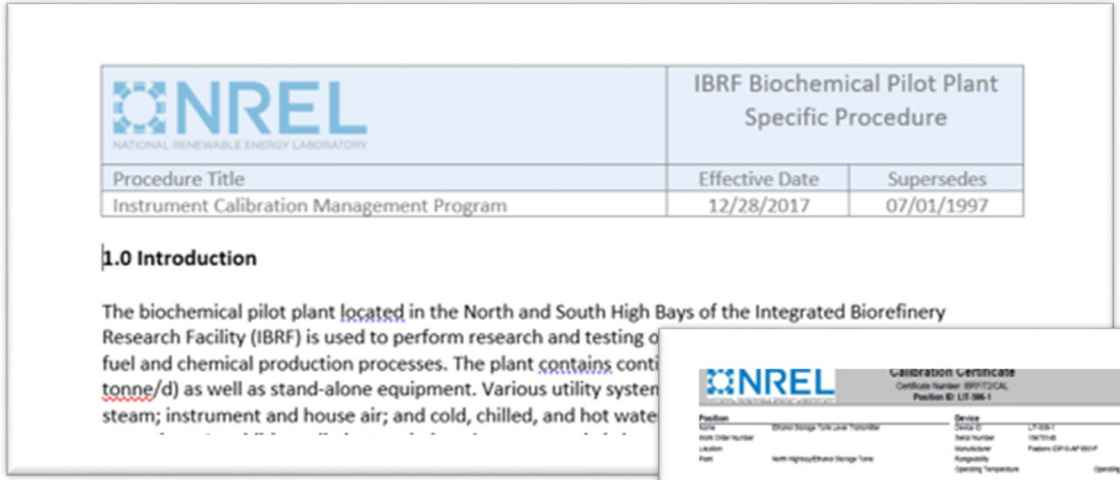
New Capability:
- Good enzymatic digestibility
- Lower inhibitor concentrations
- Atmospheric pressures
- Commercial equipment
- Lower resistance to contamination
- Residual solids harder to separate

Work in the 2.2.3.100 Low Temperature Advanced Deconstruction Project (WBS 2.2.3.100, Biochemical Conversion Platform)

Work Plans – Task 1



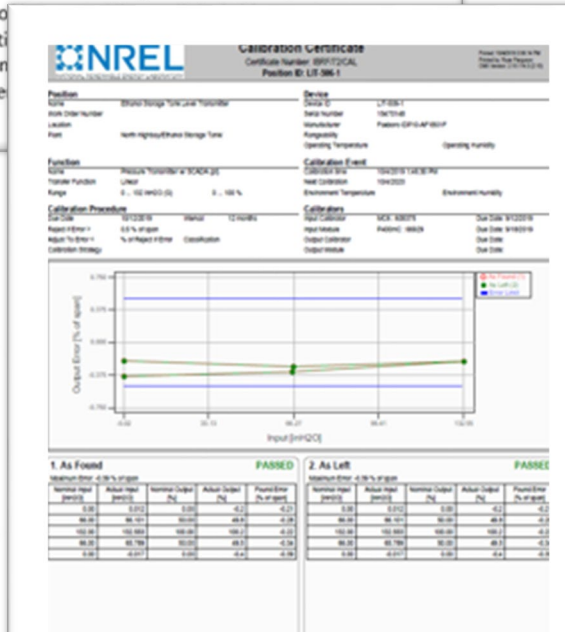
Pilot Plant Support - Calibrations


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

1.0 Introduction

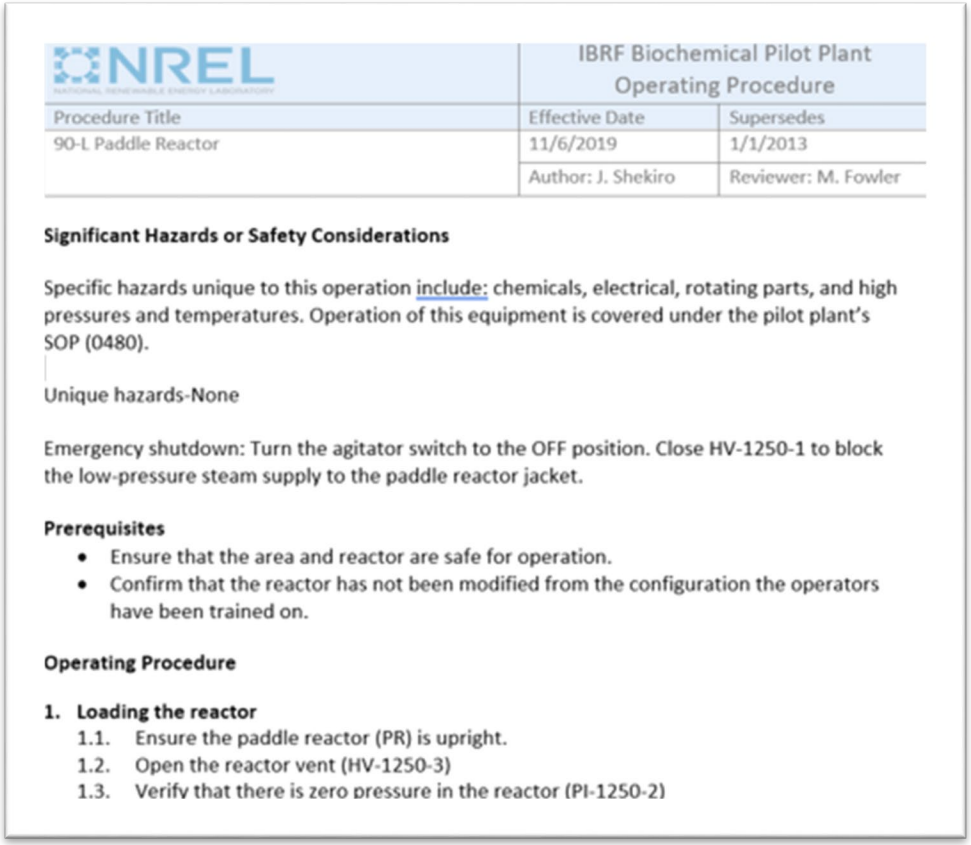
The biochemical pilot plant located in the North and South High Bays of the Integrated Biorefinery Research Facility (IBRF) is used to perform research and testing o
fuel and chemical production processes. The plant contains conti
tonne/d) as well as stand-alone equipment. Various utility systen
steam; instrument and house air; and cold, chilled, and hot wate


NREL
Calibration Certificate

- 96 Process and Instrumentation Diagrams (P&ID)
- ~ 400 electronic instruments
- ~ 1,100 digital control points
- 35 operator control screens

Automated multi-function field calibrator and communicator

Pilot Plant Support - Documentation



NREL

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

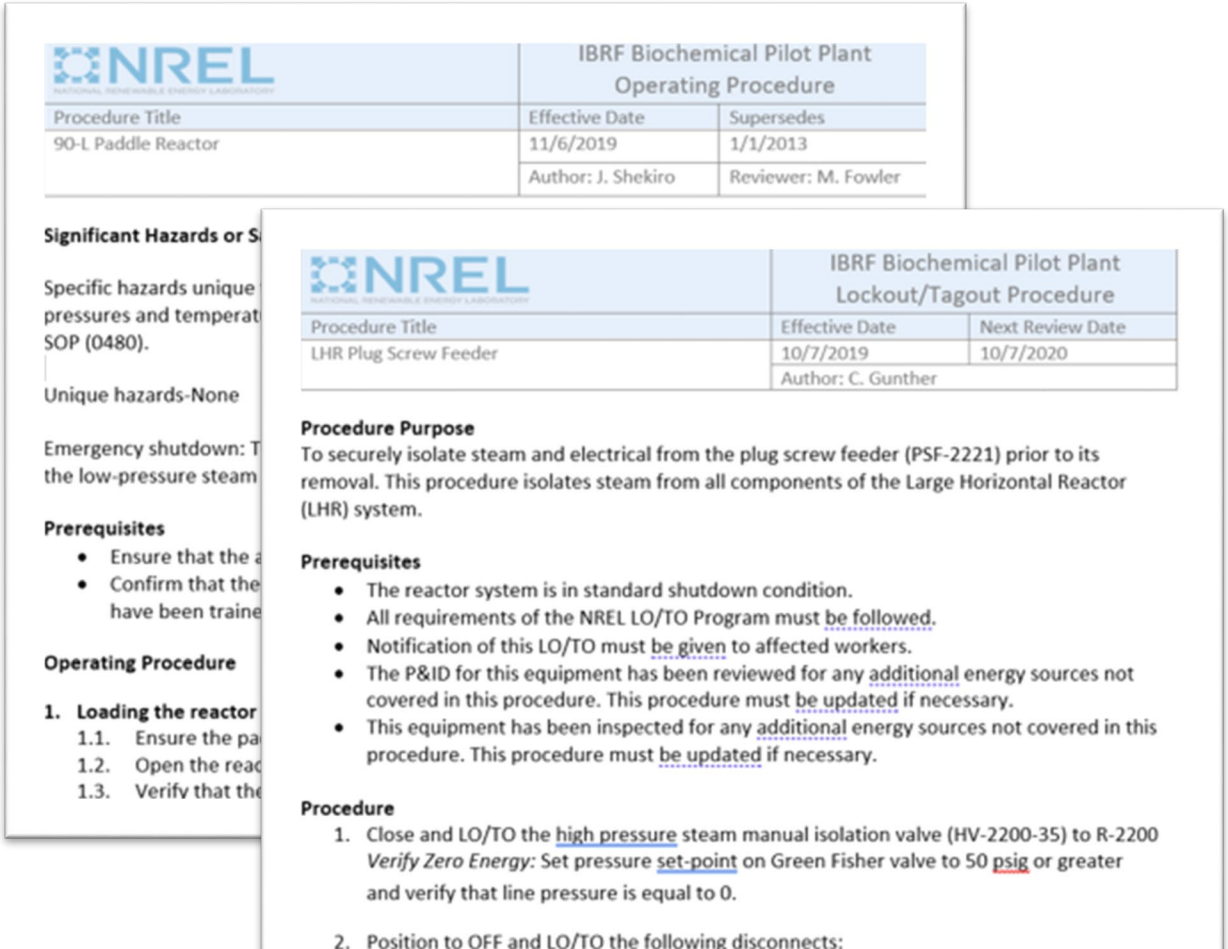
- Ensure that the area and reactor are safe for operation.
- Confirm that the reactor has not been modified from the configuration the operators have been trained on.

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

Pilot Plant Support - Documentation



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Unique hazards-None

Emergency shutdown: T
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Prerequisites

- Ensure that the a
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Operating Procedure

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   1.3. Verify that the

NREL

IBRF Biochemical Pilot Plant Lockout/Tagout Procedure

Procedure Title	Effective Date	Next Review Date
LHR Plug Screw Feeder	10/7/2019	10/7/2020
	Author: C. Gunther	

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

Pilot Plant Support - Documentation

NREL

IBRF Biochemical Pi
Operating Proce

Procedure Title	Effective Date	Supers
90-L Paddle Reactor	11/6/2019	1/1/20
	Author: J. Shekiro	Review

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Unique hazards-None

Emergency shutdown: T
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Prerequisites

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NREL

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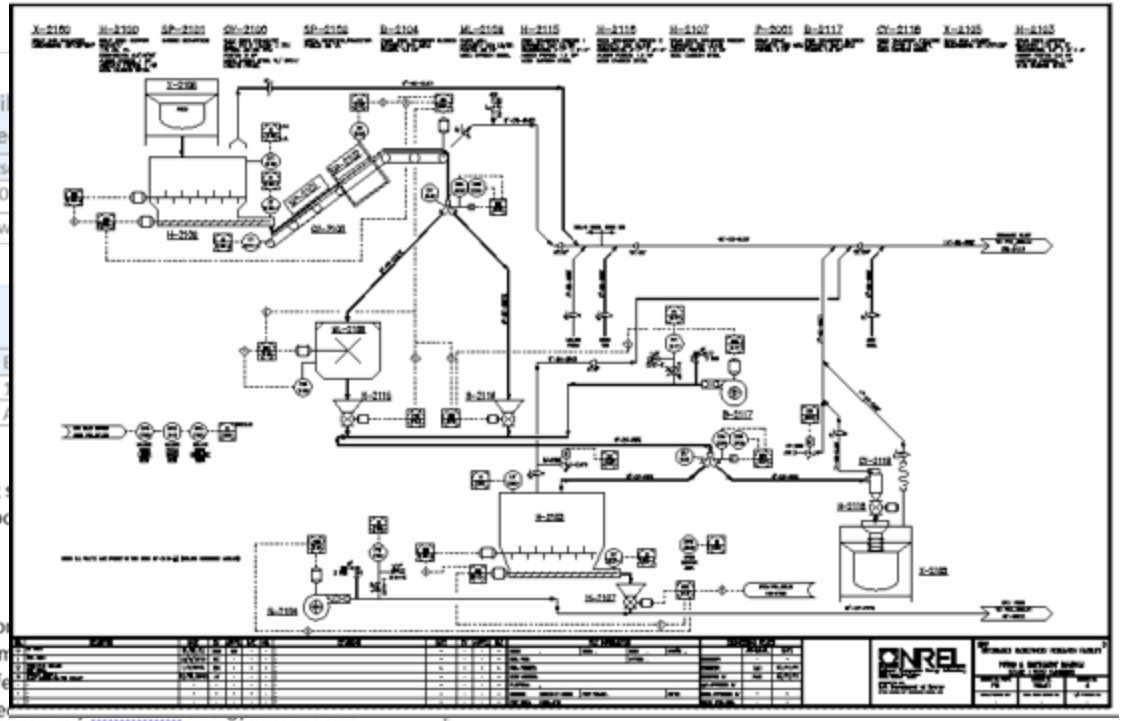
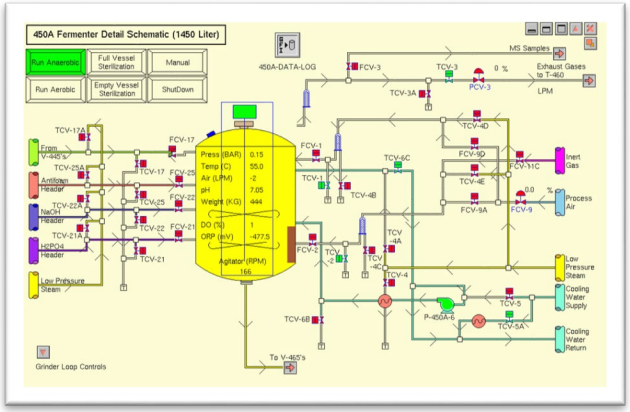


Process and Instrumentation Drawings

Accomplishment - Control System Conversion



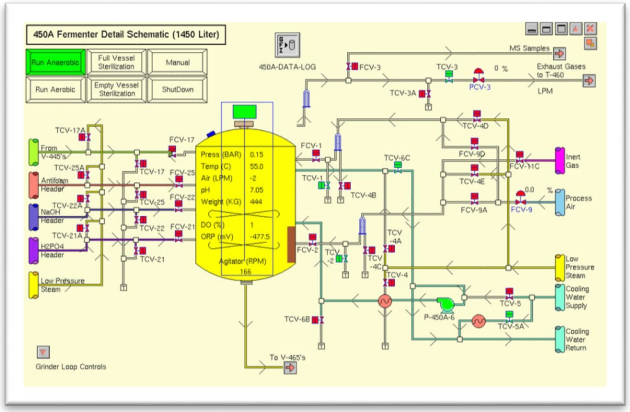
Original HMI System (25-years old)

- 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)

HMI - Human Machine Interface (Control Screens and Logic)

New 1,500-L Bioreactor Control Screen

Accomplishment - Control System Conversion



New HMI System

- Industry standard OPC communications
- License fees are about $4,000/y
- Easier to learn, program, and maintain
- Modernized user interfaces to standard usage recommendations

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- Custom-coded software for data transfer
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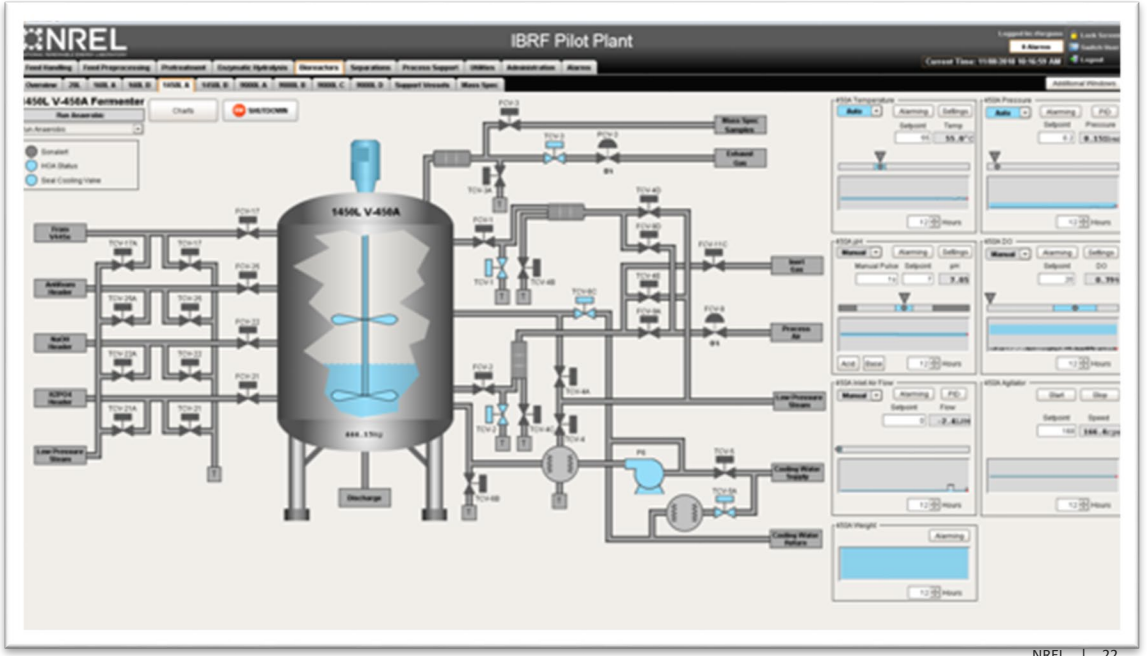
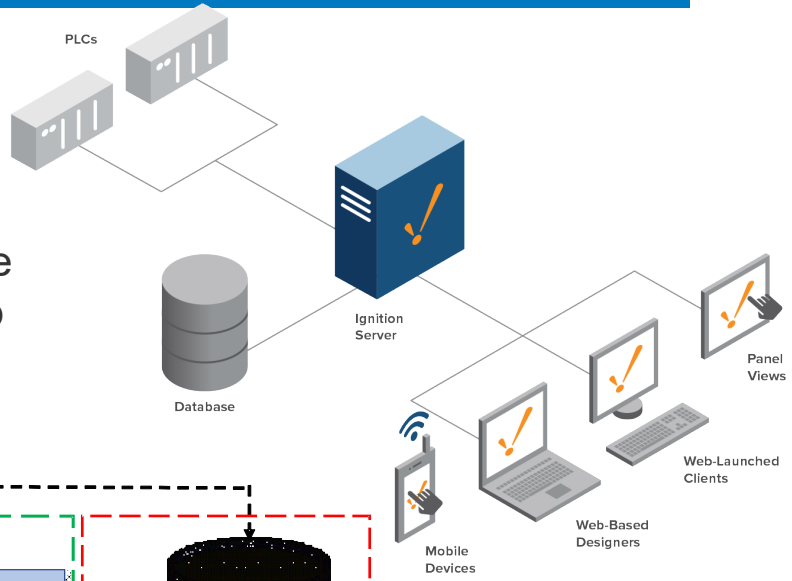
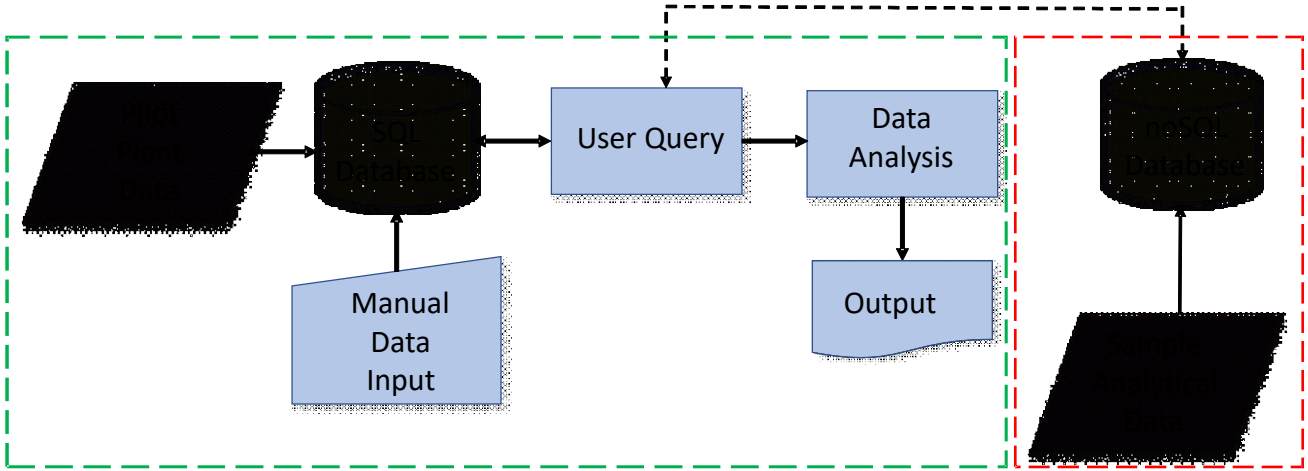


New 1,500-L Bioreactor Control Screen

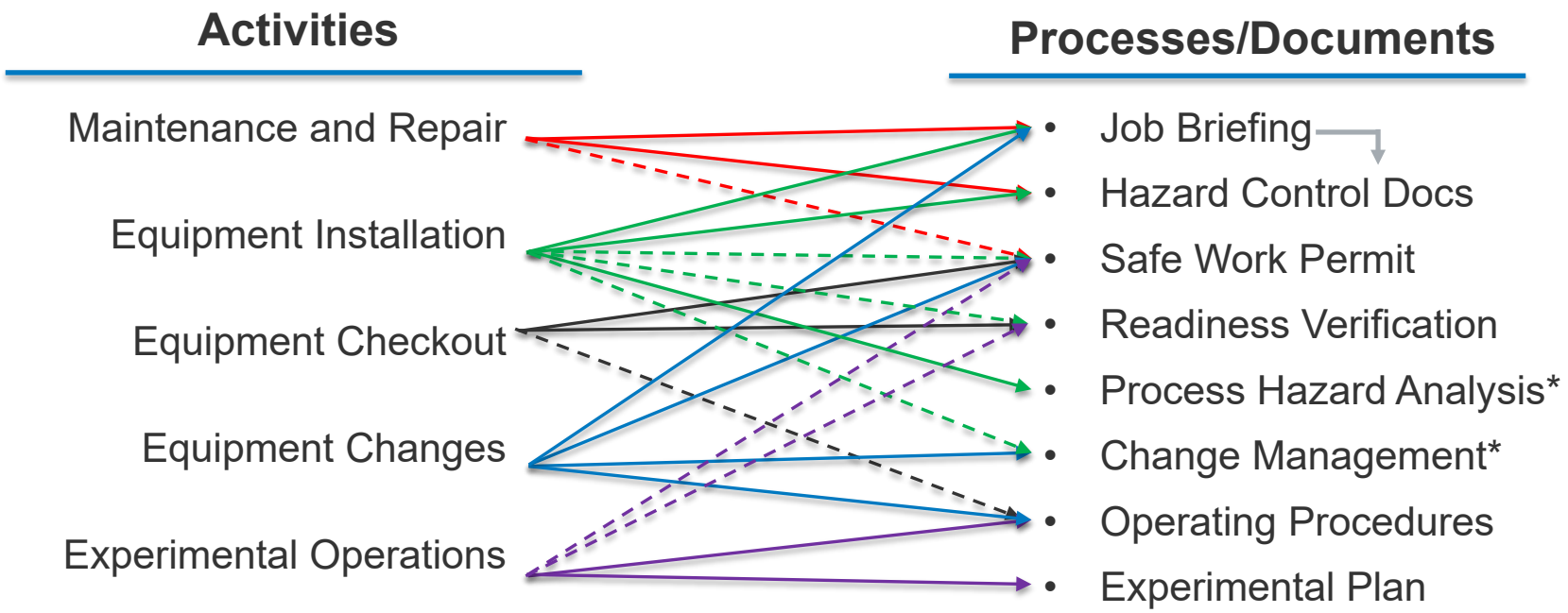
Accomplishment - Data Management System

- Uses built-in capabilities of the HMI software (Ignition, Automation Engineering) for data storage
- Final activity is to link plant runs with associated sample data generated by the NREL analytical chemistry group





Guiding Document – Safe Operating Procedure



*Verification required

Material Production

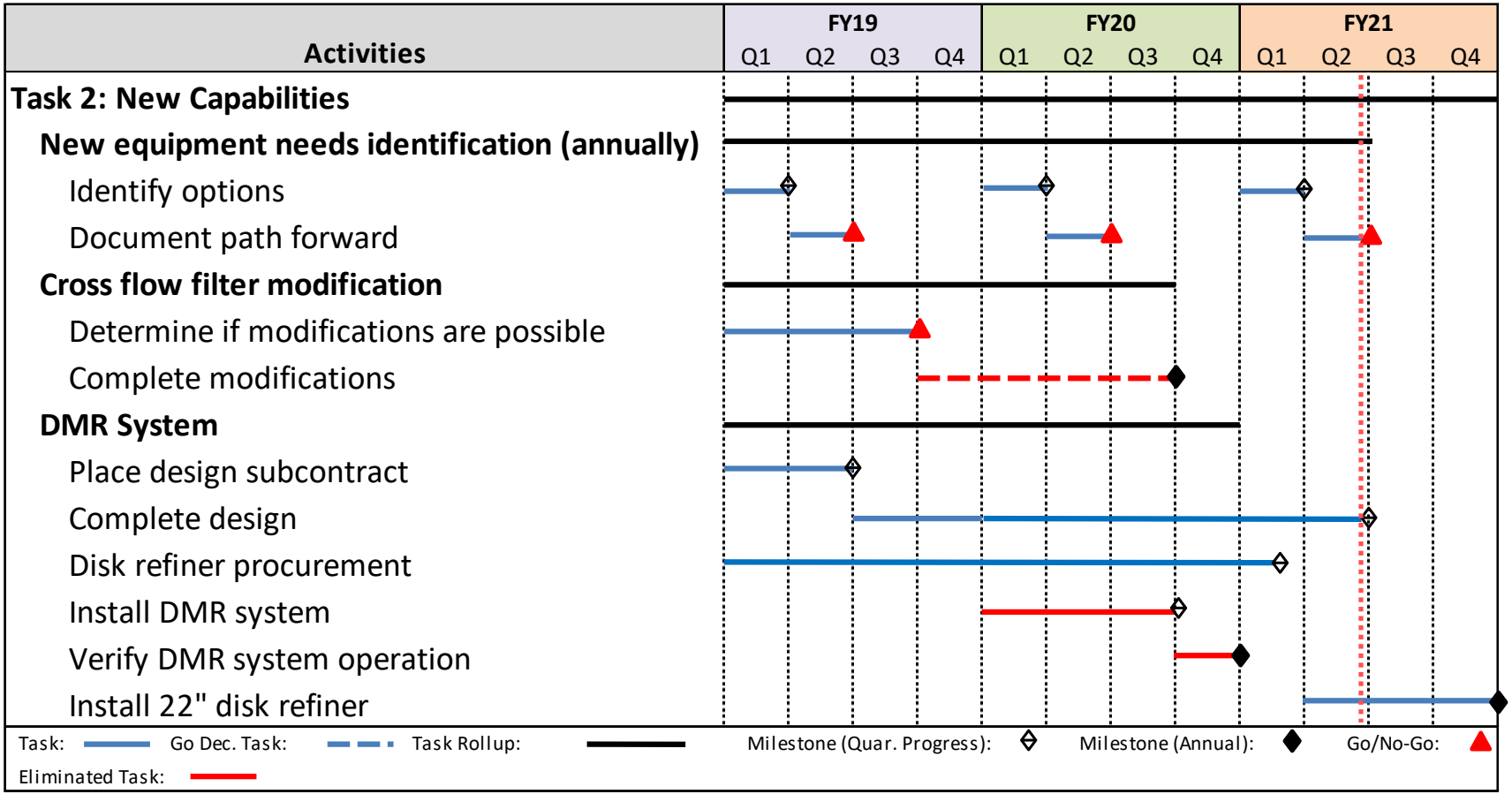
Types of process materials produced on a yearly basis include:

- 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)

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

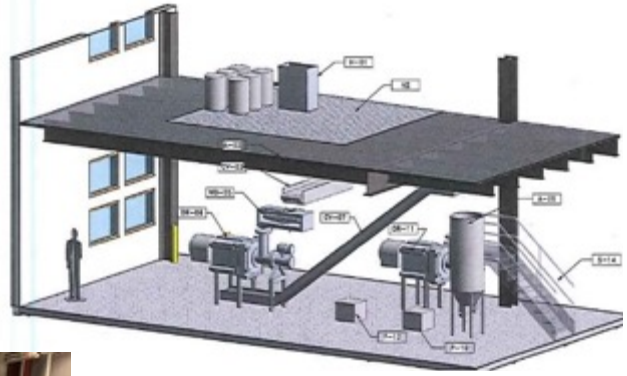
*Deacetylated corn stover shipped to Andritz for off-site disk refining at their Springfield, OH facility.

Work Plans - Task 2



New Capability - Disk Refiner

- Subcontracted design of a DMR system
- 22” disk refiner delivered in Nov. 2020
- Targeting refiner installation by end of FY21
- Needed for new CRADA and FOA projects



3-d rendering of a DMR system located in the SHB.

Feeder Section and Supporting Hydraulic Unit

Andritz 22-in High/Low Consistency Disk Refiner

Summary

Management:

- Strong NREL plant operation crew
- Workflow management process

Approach:

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

Impact:

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

Accomplishments:

- Control system upgrade/new data management system
- Acquiring new DMR capability

Acknowledgments

Team Members

- Ryan Ferguson
- Matt Fowler
- Casey Gunther
- Wes Hjelm
- Ed Jennings
- Luke Klin
- Bob Lyons

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

Quad Chart Overview

Timeline
- Project start date: 10/1/2018
- Project end date: 9/30/2021

	FY20	Active Project
DOE Funding	$1.5 MM	$4.5 MM

Project Partners*
- Partner 1
- Partner 2

Barriers addressed
- **ADO-A: Process Integration**
- **ADO-D: Technology Uncertainty of Integration and Scaling**

Project Goal
Maintain a functional and safe biochemical pilot plant, 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 scales, and link pilot plant data with associated analytical data completing the plant's data management system.

End of Project Milestones
- Complete linking of pilot plant data (sensor readings and operating conditions) with associated analytical sample data stored in a separate database
- Install 22" disk refiner and verify operation under no load conditions

Funding Mechanism
BETO AOP

**Only fill out if applicable.*

Summary

NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- Readily available pilot plant supported by DOE and made available to all users.

Key Accomplishments

- Plant ready to support BETO and industry needs and continually used by a variety of BETO-supported and industry projects
- New modernized control and data management systems

Additional Slides

Responses to Previous Reviewers' Comments

Reviewer's Comments

- 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.
- Suggest forming an industry advisory group to provide feedback on future needs and best use of this facility not only for BETO funded projects, but for all the entire biochemical industry.
- No support for gas fermentation, not designed to handle hazmats, not clear if it can handle flammable or combustible materials.

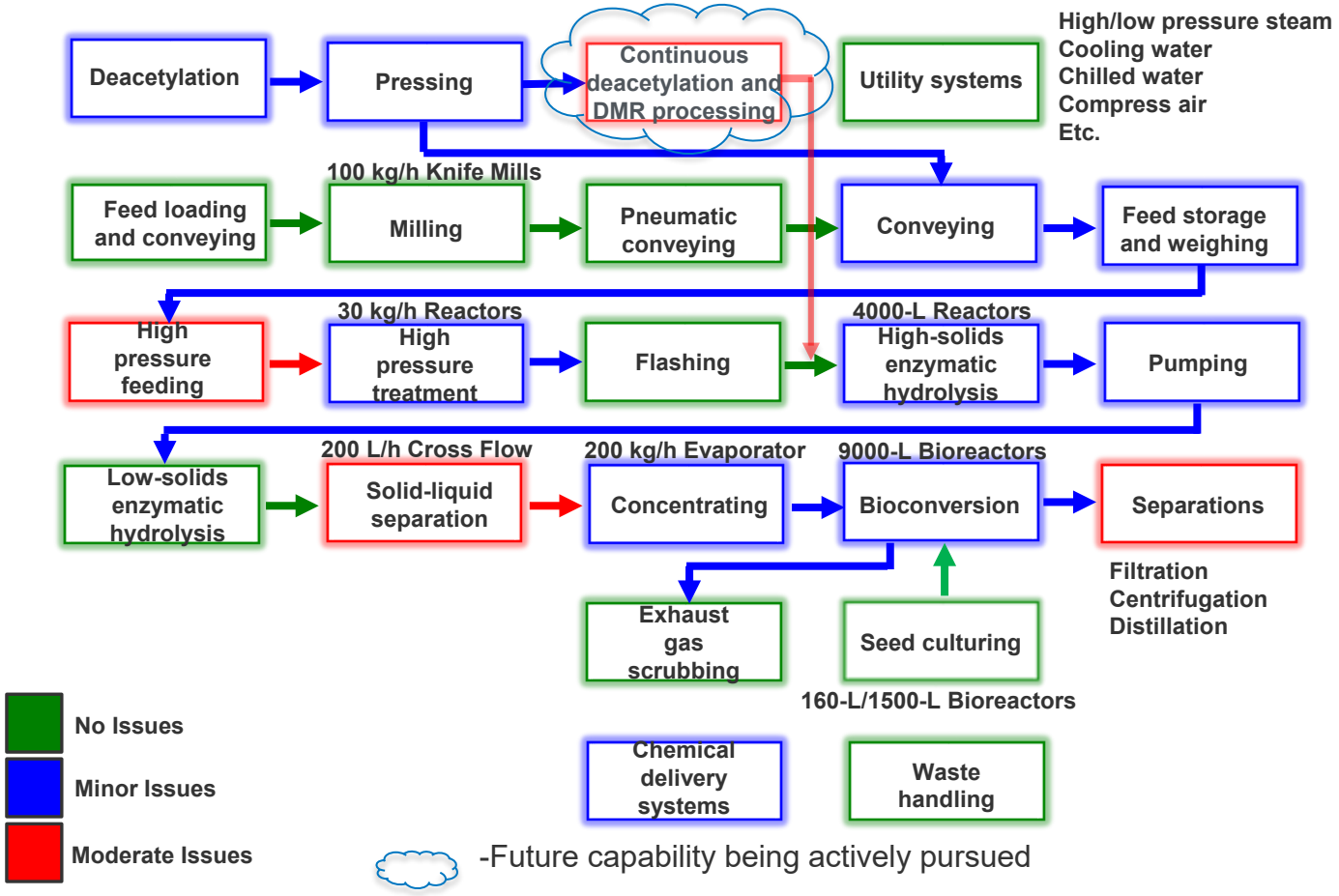
Response

Several reviewers noted the need for more industrial input particularly with respect to new pilot scale capacities. While there is no formal mechanism in this project to address these comments, NREL recently initiated an effort to revitalized the pilot plants starting with gathering input from industry (Fall 2020) on new capacities needed to support low-carbon intensities technologies. We hope to upgrade the facilities soon with these new capabilities.

Publications, Patents, Presentations, Awards, and Commercialization

- None

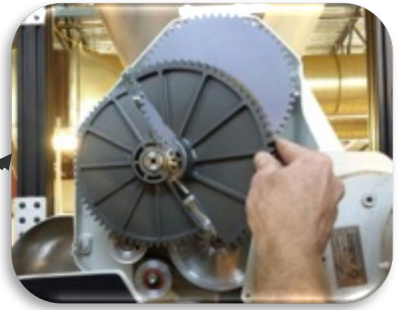
Process Operations Block Diagram

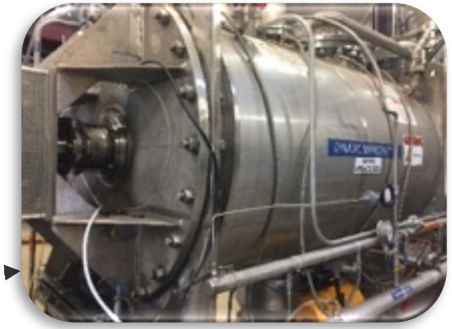


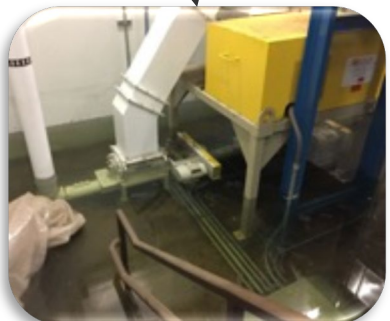
Pilot Plant Support
Representative Work

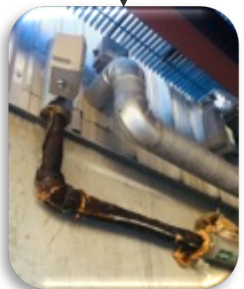
Recent Major Repairs

- Bent shaft and broken drive gear on a feed hopper
- Water leaking into baghouse blower filter housings
- Leaking agitator seals on the 1,900-L Paddle Reactor
- Failed CIP system variable frequency drive and pump motor
- Deteriorating insulation on main boiler access door
- Failed steam shutoff valves on the horizontal pretreatment reactor
- Failed baghouse air control circuit board (in process)
- Failed hot water system pump (in process)
- Multiple equipment failures led to flooded mill room
- Corroded distillation system piping (in process)





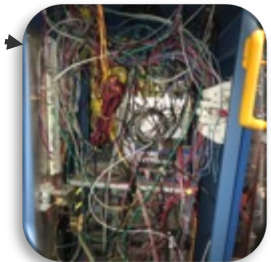




Pilot Plant Support
Representative Work

Recent Major Upgrades

- Enclosures built to contain pretreatment vent gas discharges during biomass collection reducing operator exposure to volatile compounds
- New exhaust gas flowmeters installed on the 1,500-L and 9,000-L bioreactors replacing 25-year-old and outdated meters
- New monitors installed in the SHB control room improve operator monitoring of process operations
- New steam flow meter installed on the evaporator resolves poor piping design and malfunctioning flowmeter (in process)
- New and upgraded variable frequency drives installed on the 160-L and 1,500-L bioreactors
- Load cells installed on the last remaining 160-L bioreactor without them
- Failing electrical system on the 4-L steam gun being replaced and upgraded (in process)



NREL Partnership Survey Comments (Complete List)

NREL has provided value to my organization.: Comments	How has NREL advanced your business objectives?	We selected NREL because its capabilities are distinct/unique in this area.: Comments	The quality of NREL deliverables has been satisfactory.: Comments	The value received has been commensurate with the costs.: Comments	NREL demonstrates flexibility in meeting our requirements.: Comments	The timeliness of NREL deliverables has been satisfactory.: Comments	NREL communications and reporting during the performance of the project have been effective.: Comments	I was satisfied with the timeliness of the agreement negotiation process.: Comments	I would work with NREL again.: Comments	What suggestions can you provide to improve NRELâ€™s effectiveness when working with partners?
	As one vector of a comprehensive research effort to obtain value added components from biomass.									Might want to establish a communication team or process rather than rely on the individual investigators.
	Results from CRADA will be used for further technology selection and the development of strategic alliances in the field of advanced biofuels.	The staff and facilities of NREL are definitely amongst the best available in the US.			There have been unexpected results in the CRADA program that NREL has been able to cope with and solve with trouble.	The program has been completed under schedule		Probably not a technical matter and beyond the reach of NREL, however putting together the agreement with the DOE took more than expected.	Working with NREL has been a great experience of great value to our company. It was the first time that this kind of budget was approved for a biofuel research program and it was definitely worth executing the program with NREL. I would absolutely highlight the work and commitment of Rick Elander in our program.	
	Provide pilot scale demonstration of our process that is not available anywhere else.									
	Assisted in needed advanced processing methodogoies.									
We have several projects at NREL. The first was the most important in successfully scaling our process at the IBRF.	The demo scale run allows us to showcase our technologies to partners leading to commitments for funding and further development. The process is now commercialized.	There are no other access to demo-scale bioreactors available with the flexibility that was able at NREL.	Our first run was very successful. Our most recent was not despite hard work by the team at NREL. The staff reduction in the 2 year in between has in my opinion impacted work at IBRF.	The project was funded by the DOE. If it was out of pocket we could not have afforded it as the national labs have high overhead cost.	The team at NREL worked with us extensively to modify the process and equipment to make it work.		The NREL team work closely with us throughout the process with weekly meetings and on-site visits during the run.			Having more staff would like. A single scientist handling all aspects of scale-up was too much.
	As the result of collaboration with NREL, we could develop our technology and prove the advantages of our technology. It makes our business move forward.									
	Provide validation for our process at relevant scale. Development of new process.									