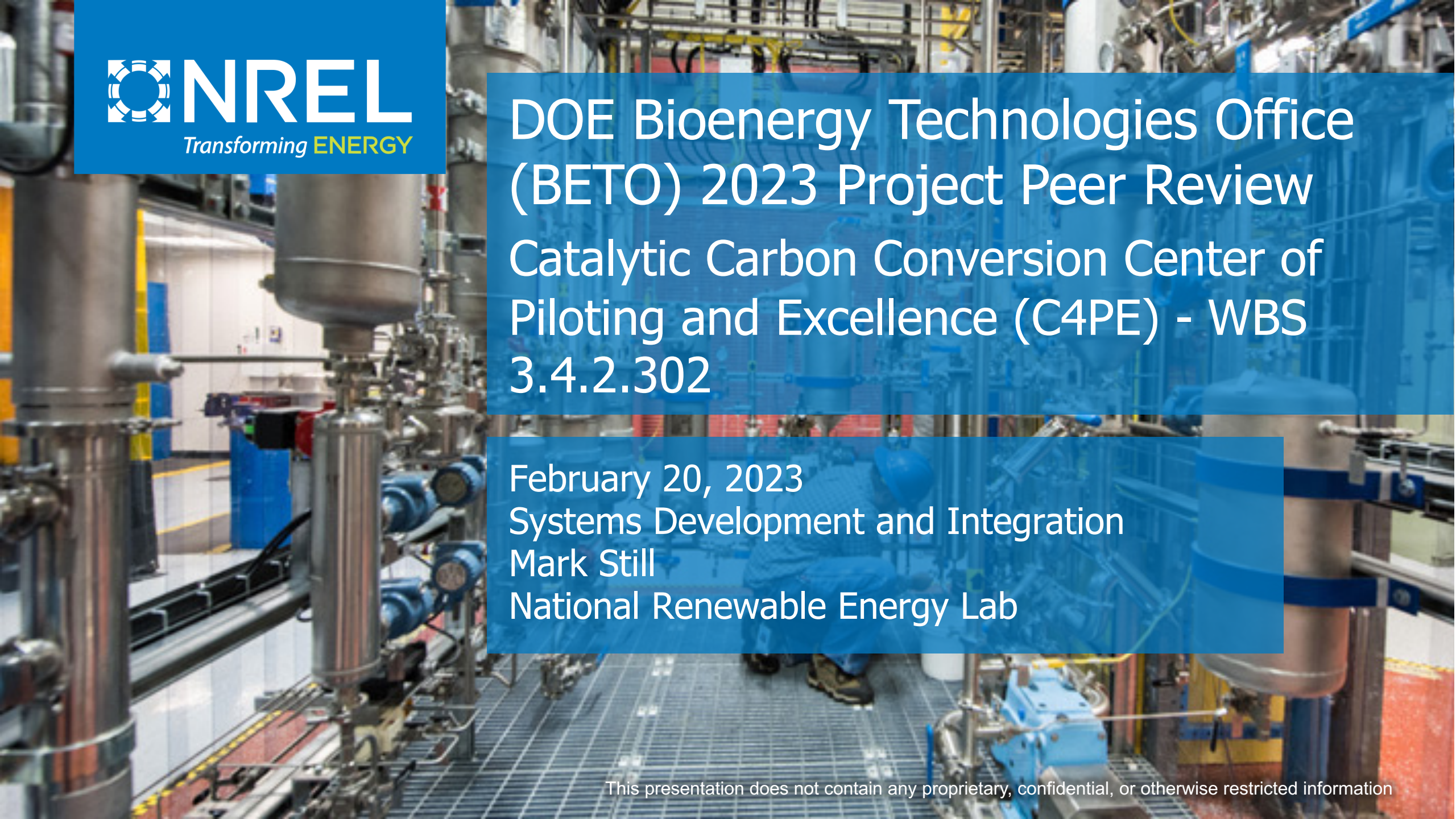


DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

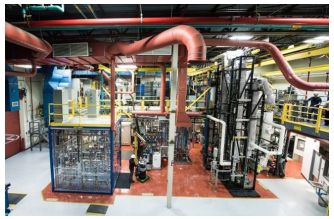
Catalytic Carbon Conversion Center of Piloting and Excellence (C4PE) - WBS 3.4.2.302

February 20, 2023
Systems Development and Integration
Mark Still
National Renewable Energy Lab

Project Overview

- Not a traditional BETO R&D Project
  - Doesn't directly fund R&D activities, it enables them
- Maintenance & upkeep of existing pilot facilities
  - 4 Pilot units – biomass to fuels and chemicals
  - 2 Support labs
    - Catalyst production
    - Physical & chemical characterization
- Facilities support funded R&D projects
  - Industrial partnerships
  - Government projects

Pilot Units



Thermocatalytic Process Development Unit (TCPDU)

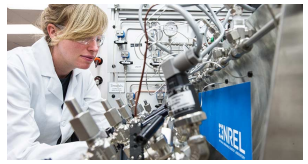
Davison Circulating Riser (DCR)

2" Fluidized Bed Reactor (2FBR)

Continuous Hydrotreater (CHT)

Support Labs

Catalyst Scale-up Lab (CSUL)



Biomass Catalyst Characterization Lab (BCCL)

Project Overview

BETO – Form public-private partnerships to support R&D to produce industrially viable biofuels and bioproducts using renewable biomass and waste

Sustainable Aviation Fuel Grand Challenge
- 3B gal/y by 2030
- 35B gal/y by 2050

Requires broad industrial adoption – Critical risks need to be addressed

Technical and Economic Risks

- Large capital investment
- Financing & ROI
- Time to market
- Technical viability
- Process performance
- Design scale-up

Mitigation Strategies

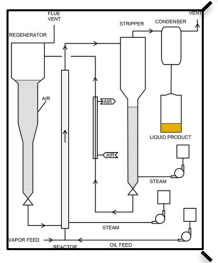
- Partnership between government and industry
- Leveraging existing refinery infrastructure
- Piloting of industrially relevant systems
- Techno-economic assessment
- Process modeling

This project enables R&D of biofuels and bioproducts technologies including SAF
1. **Industrial engagement**
2. **Maintenance and upkeep of industrially relevant pilot systems**

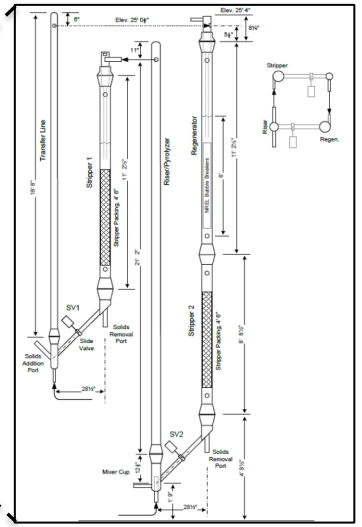
Project Overview

Importance of Piloting

- Can't afford to get the commercial design wrong
  - Cost of changes increases dramatically with scale
- Gap between R&D and industry is large
  - Information is needed that can't be supplied by bench units
    - Mass, heat, and momentum transfer are scale dependent
    - Solids handling and other complex processes are difficult to scale-up
    - Unlike bench units, pilot units have the same reactors and unit operations as commercial plants
- Need to justify commercial investment
  - Pilot data supports design scale-up and commercial projections
    - Process modeling
    - Techno-economic assessment
    - Generates representative products and byproducts for testing



Davison Circulating Riser (DCR)



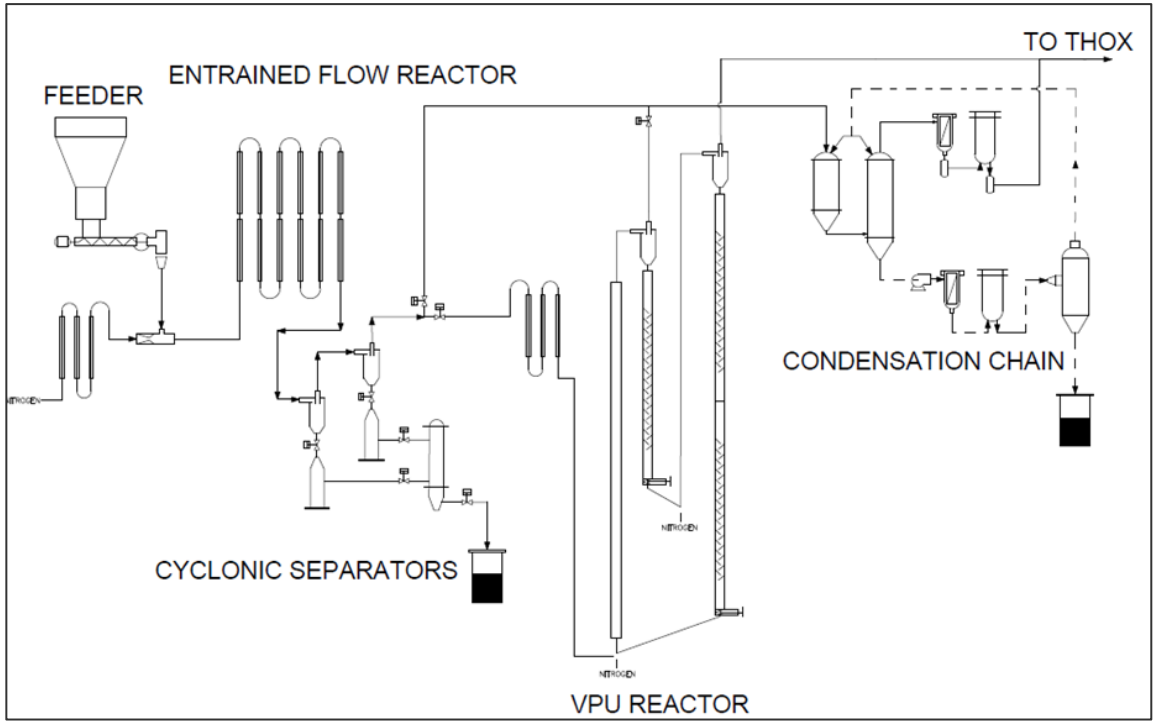
Thermocatalytic Process Development Unit (TCPDU)

Piloting plays a critical role in de-risking biofuels deployment

Project Overview

Goals

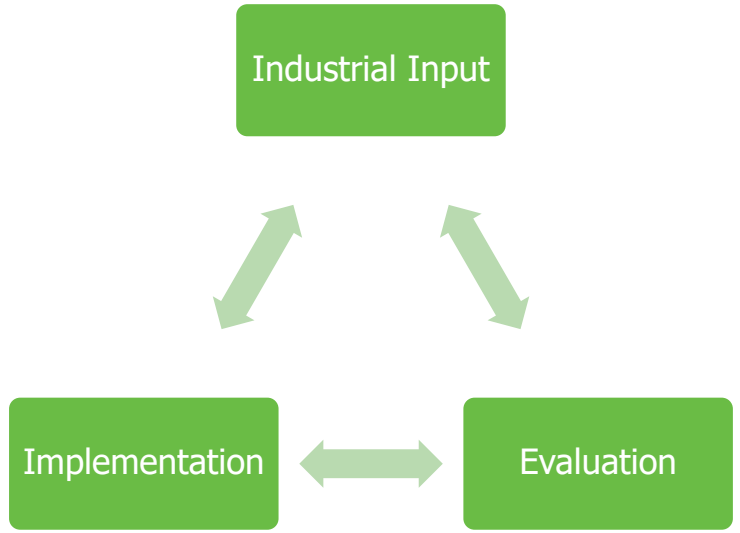
1. Maintain piloting capabilities in a readiness state
   - Support current biofuel production pathways and future BETO priorities
2. Ensure industrial relevance and attract support
   - Actively seek industrial input and partnership
   - Identify system modifications needed to align capabilities with industry
   - Continuously improve operations and support systems



Thermocatalytic Process Development Unit (TCPDU)

1. Approach

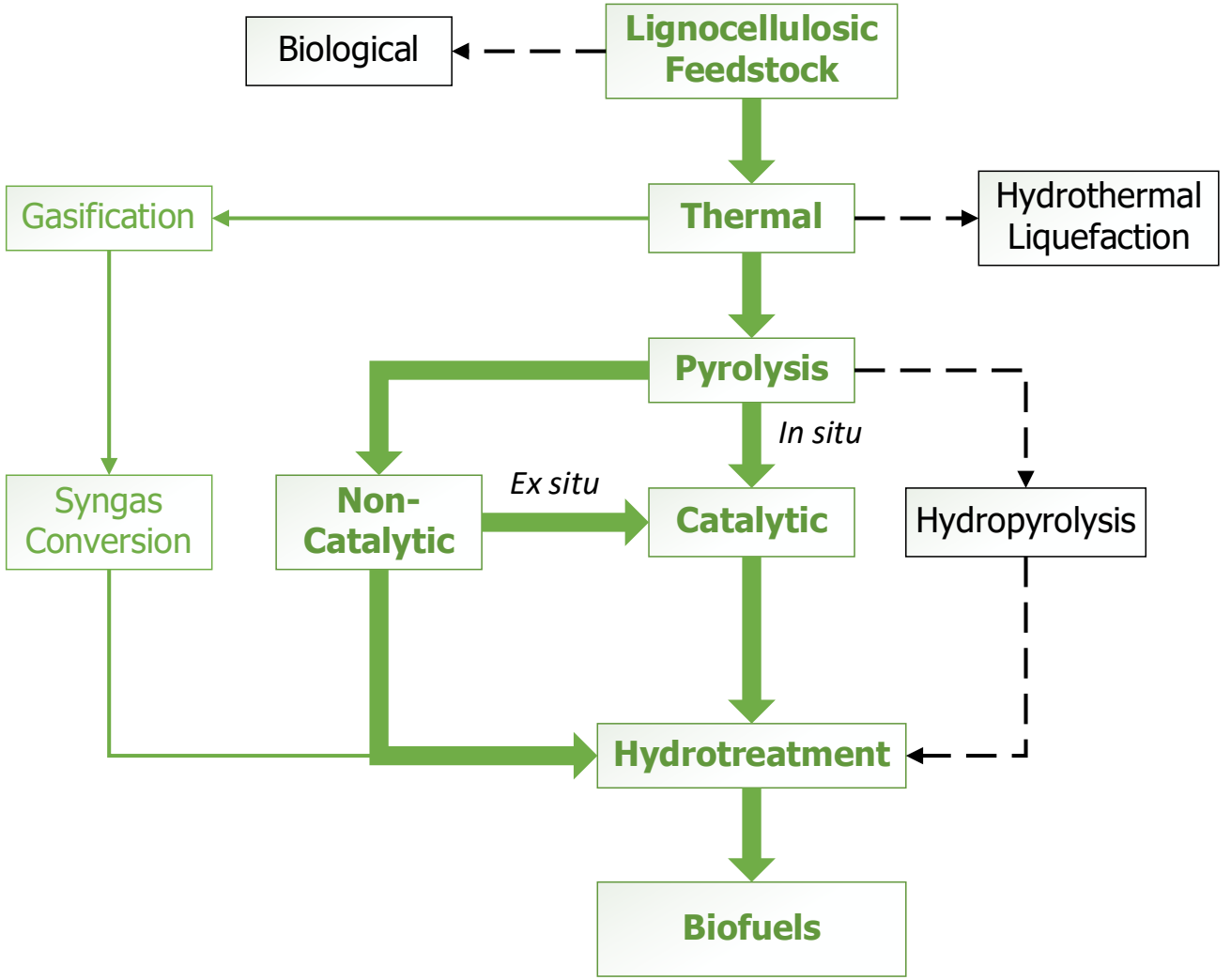
- Seek industrial input
  - Perform industrial outreach
    - Expert interviews and listening sessions
      - Review of current NREL pilot facilities
      - Identify bioeconomy piloting and scale-up needs
      - Form vision of state-of-the-art pilot facility
  - Form industrial R&D partnerships
- Evaluate
  - Review industry input for alignment with BETO goals and current capabilities
  - Identify gaps and prioritize action items
- Implement
  - Make modifications to equipment and systems to align with industry needs
  - Maintain systems and personnel in a readiness state



1. Approach: Supported Renewable Pathways

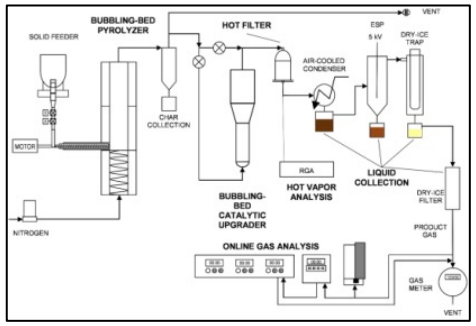
Currently supported biofuel pathways

- Thermal deconstruction and fractionation
  - Pyrolysis
    - Non-catalytic
    - Catalytic pyrolysis (*in situ*)
    - Vapor phase upgrading (*ex situ*)
  - Gasification
- Synthesis and upgrading
  - Syngas conversion
  - Hydrotreating
- Enabling capabilities
  - Catalyst scale-up
  - Catalyst and product characterization

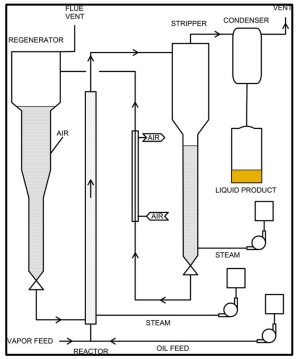


C4PE pilot facilities support the development of multiple biofuels pathways

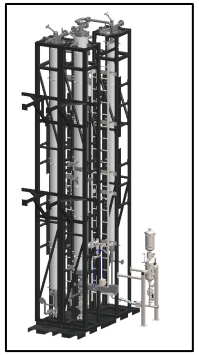
1. Approach: Integrated Pilot and Support Facilities



2” Fluidized Bed Reactor (2FBR)
0.5 kg/h Feed
Semi-continuous bench process
Pyrolysis and catalytic pyrolysis (*in/ex situ*)
Catalyst screening, feed testing, and parametric testing

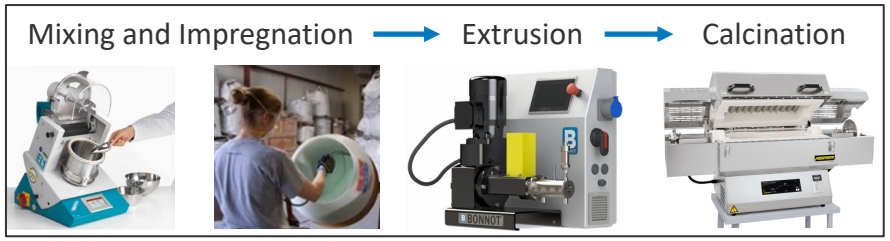


Davison Circulating Riser (DCR)
3 kg/h Feed
Industrially relevant small pilot - FCC process
Integrated with fluidized bed pyrolysis reactor
Performs *ex situ* catalytic pyrolysis and co-feeding

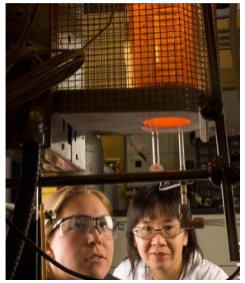


Thermocatalytic Process Development Unit (TCPDU)
30 kg/h Feed
Industrially relevant integrated pilot - FCC Process
Integrated with entrained flow pyrolysis reactor
Scale-up of *in/ex situ* catalytic pyrolysis

Continuous Hydrotreater (CHT)
10 mL/h Feed
Industrially relevant small pilot
Upgrading of bio-oils to finished products



Catalyst Scale-up Lab
(CSUL)
Production of kg quantities of formed catalysts



Biomass Catalyst Characterization Lab (BCCL)
Physical and chemical characterization of catalysts and products
Catalyst performance testing

The C4PE maintains a unique combination of integrated pilot facilities and support labs in one facility

1. Approach: Attracting Industrial Partners

- Website development
  - Effective marketing tool
  - Significant inquiries based on website engagement
- Technical presentations and networking at conferences and meetings
  - Advanced Bioeconomy Leadership Conference
  - Industry trade shows
  - Organization meetings (AIChE, ACS, etc.)
- Publications
  - Biofuels Digest
  - Scientific journal articles
- NREL Innovation & Entrepreneurship Center
  - Networks, programs, and events to bring cleantech innovations to market
- Industry facing R&D programs
  - Technology Commercialization Fund, Small Business Voucher, etc.
  - FOAs – collaboration with NREL pilot plants specifically called out

2. Progress and Outcomes: Industrial Partnerships

C4PE Industrial Partnerships
Cooperative R&D Agreements

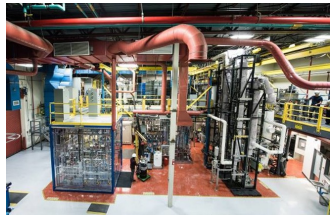
ExxonMobil - Fuels and chemicals via catalytic pyrolysis

Alder Fuels - Scale-up of pyrolysis to SAF technology

West Biofuels - Co-processing of F-T wax to SAF

The C4PE has attracted multiple industrial partners
1. **Unique facilities**
2. **Industrial outreach**
3. **Continuous improvement**
4. **Maintenance and readiness**

Pilot Units



Thermocatalytic Process Development Unit (TCPDU)

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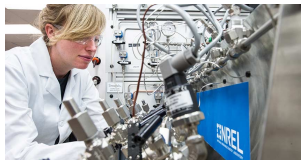
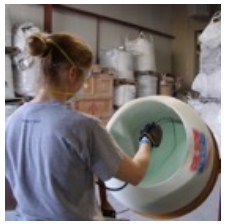
Support Labs



Biomass Catalyst Characterization Lab (BCCL)



Catalyst Scale-up Lab (CSUL)

2. Progress and Outcomes: Industrial Feedback

- Conducted industry expert interviews and compiled summary report
  - 12 experts from industry, universities, government agencies, other national labs, and finance and business
  - Evaluation of current TCPDU facility
  - Direction for future pilot plant improvements
- Held bioeconomy listening sessions and compiled feedback
  - Interview process with 130 experts
  - Piloting and scale-up needs
  - Vision for state-of-the-art pilot plant facilities

2. Progress and Outcomes: Evaluation and Implementation

Industry Feedback Summary

- Need to invest in analytics, instrumentation, and data management
  - Achieve high material and carbon balances
  - Support computational modeling
- Strong QA/QC practices are a must
  - Safety, good housekeeping, sample management and calibration, rigorous data management and sample tracking (LIMS)
- Need to consider end-to-end process
  - Real feedstocks
  - Continuous operations of all process steps with commercially planned units
  - Produce finished products of commercial quality

Improvements to C4PE

- Analytics, instrumentation, and data management
  - Installed new control system architecture on DCR
  - Added a new micro-GC on CHT to improve light gas analysis
  - Redesigned 2FBR condensation train to increase product collection efficiency and mass closure
  - Added *operando* capabilities to Raman, infrared, and UV-visible spectrometers to observe catalysts at operating conditions
- QA/QC
  - Performed annual mass balance closure verification on CHT
  - Installed new gas manifolds in BCCL to improve safety
  - Evaluated new system (SLIMS) for sample and workflow tracking on all systems
  - Established preventative maintenance plans
- End-to-end process
  - Completed TCPDU engineering study to identify modifications needed for industrially preferred operating conditions and commercial feedstocks

2. Progress and Outcomes: Evaluation and Implementation

Industry Feedback	Milestone Description	Criteria	End Date
Need to invest in analytics, instrumentation, and data management to achieve high material and carbon balances and support computational modeling	Revitalize Davison circulating riser control system, including updating of computers and control system architecture for reliable automation of safety-critical interlocks	New computers and control system architecture were installed to ensure system reliability for years to come. The new computers have better processing capability to run multiple processes simultaneously	6/30/2021

2. Progress and Outcomes: Evaluation and Implementation

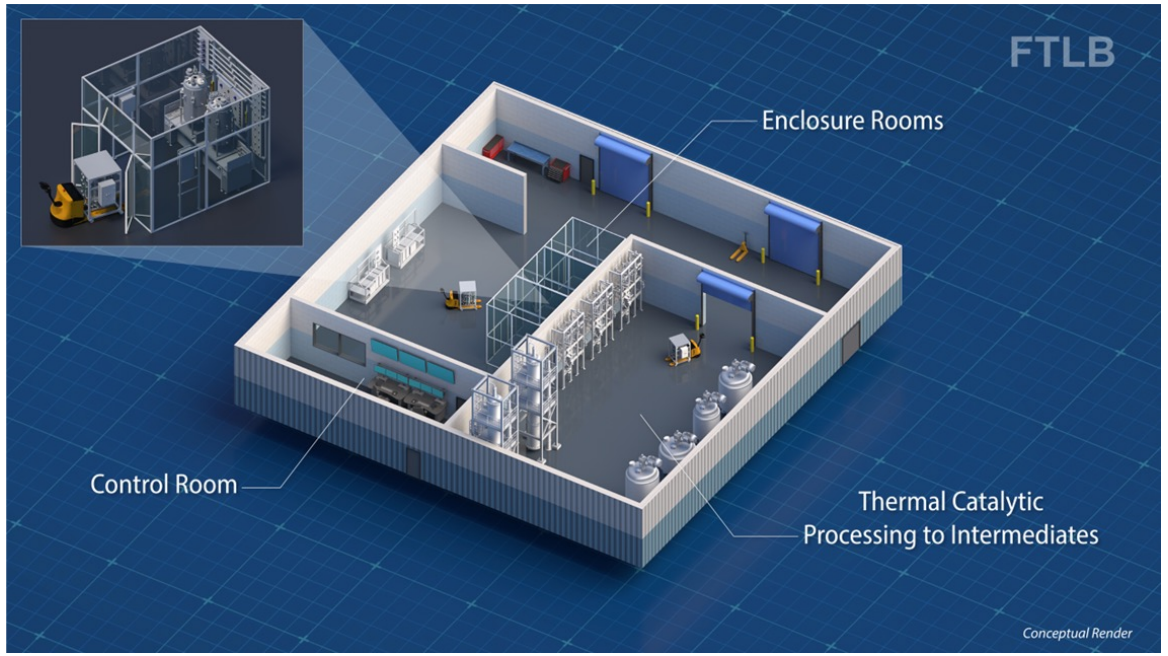
Industry Feedback	Milestone Description	Criteria	End Date
Strong QA/QC practices are a must including safety, good housekeeping, sample management and calibration, rigorous data management, and sample tracking (LIMS)	Preliminary evaluation of SLIMS trial for sample management	Generated a report on the suitability of SLIMS (Software Laboratory Information Management System) for managing samples from DCR, TCPDU, 2FBR, hydrotreater, and analysis lab (BCCL). SLIMS was evaluated based on ease-of-use by operators, ability to handle, share, and track samples and associated metadata across systems, firewalling, and integration with existing NREL capabilities.	3/31/2022

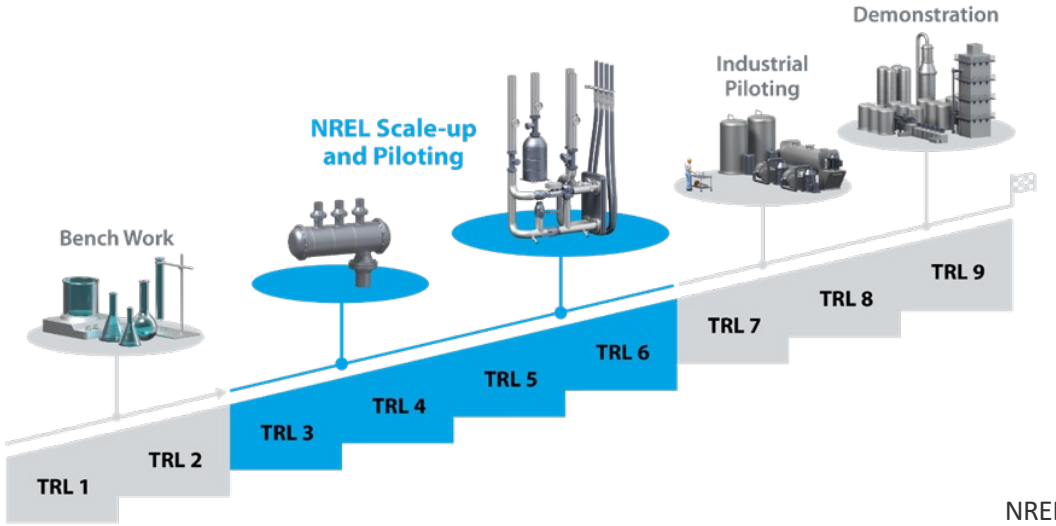
2. Progress and Outcomes: Evaluation and Implementation

Industry Feedback	Milestone Description	Criteria	End Date
Need to consider end-to-end process with real feedstocks, continuous operation of all commercial process steps, and production of finished products of commercial quality	Complete engineering review of TCPDU R-cubed system	An engineering review, supported by industrial feedback, was performed to ensure industrial relevance and enable current and future partnership activities within the TCDPU. A summary report was generated including an assessment of typical user requirements, preferred operating conditions, and required system modifications.	12/31/2022

2. Progress and Outcomes: TCPDU Pilot Plant Revitalization

- Planning and conceptual design initiated
  - State-of-the-art facility based on industrial feedback
  - Fully integrated TRL 5-6
    - Thermal deconstruction and downstream fuel and chemical finishing capabilities
  - Risk-based and flexible
    - Address scale-up and design needs
    - Modular skid designs
    - Expand safety envelope (P, H_2)
- Funding not finalized





3. Impact

- C4PE helping generate industrial buy-in to renewables production
  - Signed CRADAs with 4 industrial partners
  - Performed technical services for 5 industrial partners
- Advancing BETO and DOE goals
  - C4PE facilities awarded 6 government funded projects
- Improving industrial relevance with facility improvements based on industry input
- Building the vision for a state-of-the-art pilot facility

NREL Transforming ENERGY

Summary

- The C4PE M&U project supports facilities that address key technical and economic risks of biofuel production
- Industrial relevance is maintained through industry engagement, internal evaluation, and implementation
- Maintenance and upkeep of C4PE facilities helps generate industrial partnerships and accelerate progress toward BETO's renewables production goals
- Planning for a pilot plant revitalization is underway

Quad Chart Overview

Timeline

- *10/1/2021*
- *9/30/2024*

	FY22 Costed	Total Award
DOE Funding	*$1,682,130*	*$1,796,000*
Project Cost Share		

Project Goal

Maintain thermochemical piloting capabilities in a readiness state to support current SAF production pathways and future BETO priorities. Conduct industrial outreach to ensure relevance and attract support. Identify system modifications needed to align capabilities with industry.

End of Project Milestone

Retire risks associated with integrated operation of CFP technology
Deliver a capstone report for the Pt/TiO2 + standalone hydrotreating pathway
Revitalize DCR control system, including updating of computers and control system architecture for reliable automation of safety-critical interlocks
Preliminary evaluation of SLIMS trial for sample management
Evaluate breakdown of M&U costs across six systems
Produce CFP Bio-oil using similar feedstocks and catalysts
Establish robust preventative maintenance procedures
Complete Engineering Review of TCPDU R-cubed system
Design and modification of TCPDU system to revitalize operation

Funding Mechanism

AOP Project (Direct-Funded Lab Project)

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

Project Partners

Thank You

Q&A

www.nrel.gov

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