DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Integration & Scale-Up (WBS 2.4.1.301)

March, 2019

Technology Session Area Review

David Robichaud

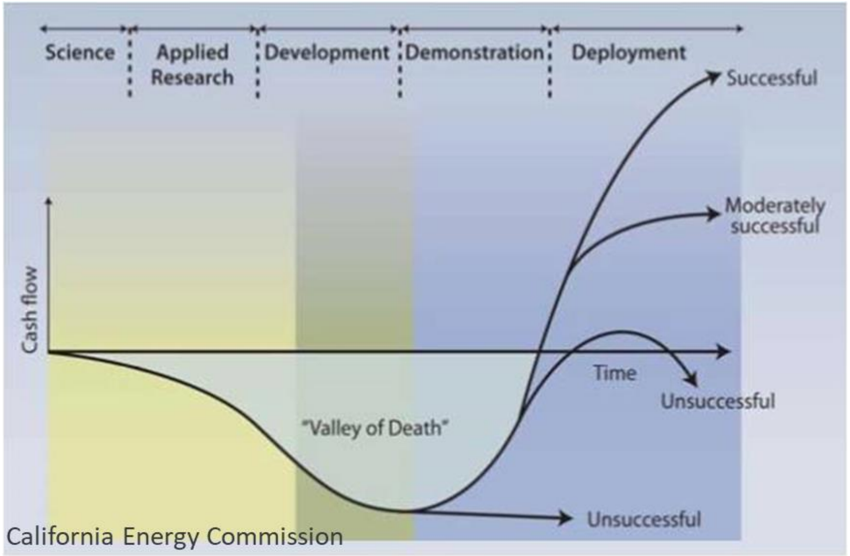
National Renewable Energy Laboratory

Goal Statement and Outcomes

Goal: **Verify thermal and catalytic conversion technologies** and operations in an integrated, pilot-scale facility.

Outcomes:

- **Scaling relationships** that enable predictions of product yields and composition based on fundamental process conditions.
- **Engineering solutions** for scale-up challenges of biomass technologies.
- **Pilot scale verification data** for technoeconomic analysis (TEA) and applied research projects.

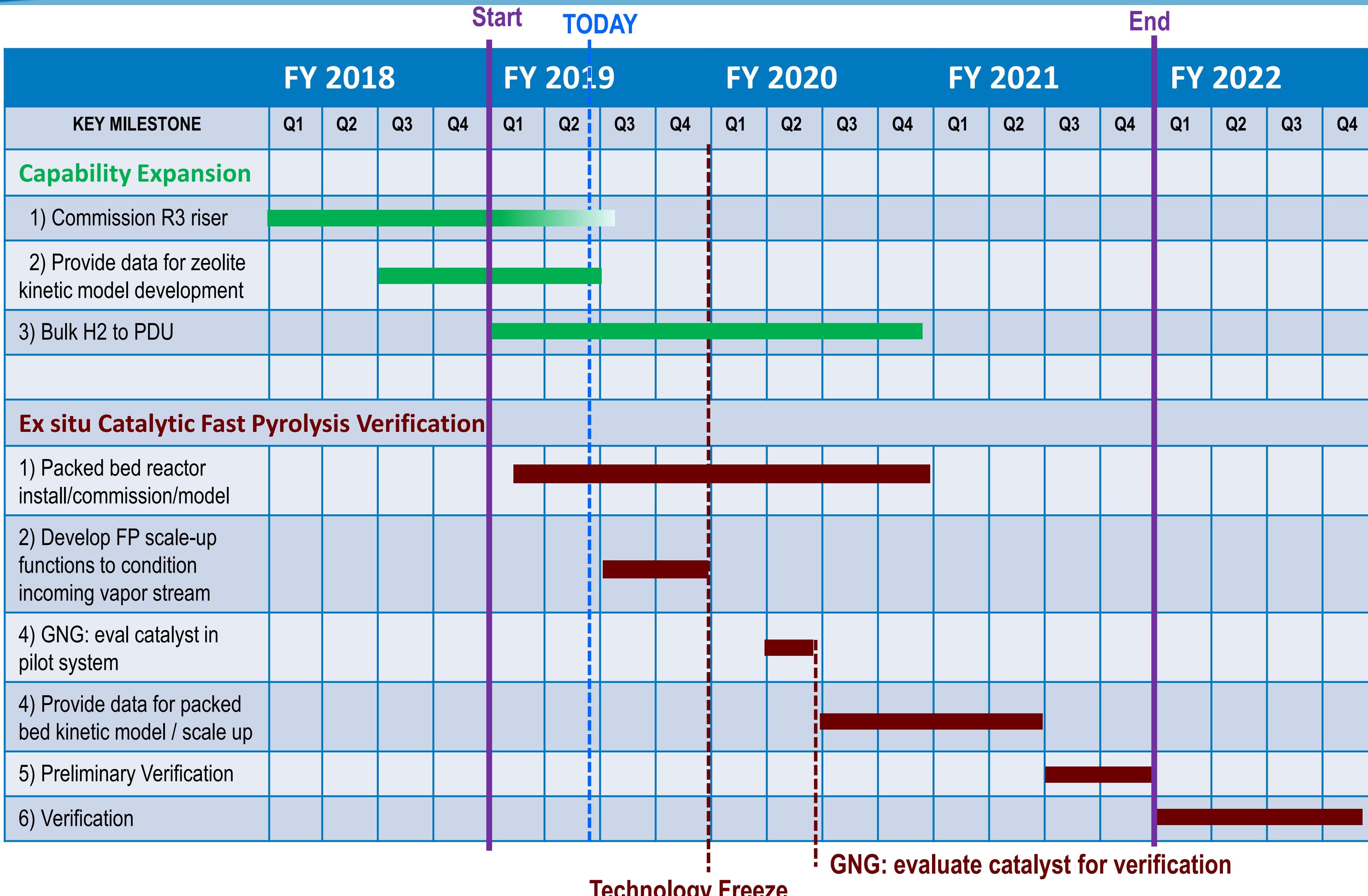


Relevance: Reducing cost and risk for industry by bridging the technology valley of death.

Tangible outcome for the United States:

Enables the successful industrial adoption of biomass technologies; supporting the continued growth of the U.S. bio-economy.

Key Milestones



Project Budget Table

	Original Project Cost (Estimated)		Project Spending and Balance		Final Project Costs
Budget Periods	**DOE Funding**	**Contingency**	**Spending to Date**	**Remaining Balance**	**What funding is needed to complete the project.**
FY19	$1.90M	$640k	$470k	$2.07M	
- Maintenance, Upgrades, Repair	$650k		$320k		
- Experiments	$1.15M		$150k		
- Installations (H_2)	$200k				
FY20	$1.90M				
- Maintenance, Upgrades, Repair	$650k				
- Experiments	$1.15M				
- Installations (H_2)	$200k				
FY21	$1.90M				$2M in FY22 for verification
- Maintenance, Upgrades, Repair	$805k				
- Experiments	$1.15M				

Upkeep: 30%
Installation: 10%
Experiments: 60%

Quad Chart Overview

Timeline

- Project start date: 2019
- Project end date: 2021
- Percent complete: 17%

	Total Costs FY15 - FY17	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$6.08M	$1.62M	$5.7M ($1.9M/year)
Project Cost Share*			

Barriers addressed

ADO-A. Process Integration

– Integration of feedstock, conversion, and bio-oil upgrading technologies.

ADO-D. Technical Risk of Scaling

– Develop scaling factors based on pilot-and bench-scale systems.

Objective

Develop critical resources required to reduce risk and encourage commercialization of thermal and catalytic technologies.

Partners:

ChemCatBio, FCIC,
Engineering of Catalyst Scale-Up (3.2.1.1),
Thermochemical Platform Analysis (2.1.0.301-302),
CCPC (2.5.1.301-307)
Materials & Degradation in Biomass-Derived Oils (2.4.2.301)

1- Project Overview: Project History

The TCPDU serves as a production-relevant environment to assess processing operability while generating foundational longer-term catalyst and reactor performance data

Over 20 years of pilot operations

- Recent upgrades improved mass balances, reduction in operational downtime/maintenance, enhanced safety
- New capability: R-cubed riser system
- Designed to be functionally flexible

Multiple industry partnerships

- Petrobras, DOW

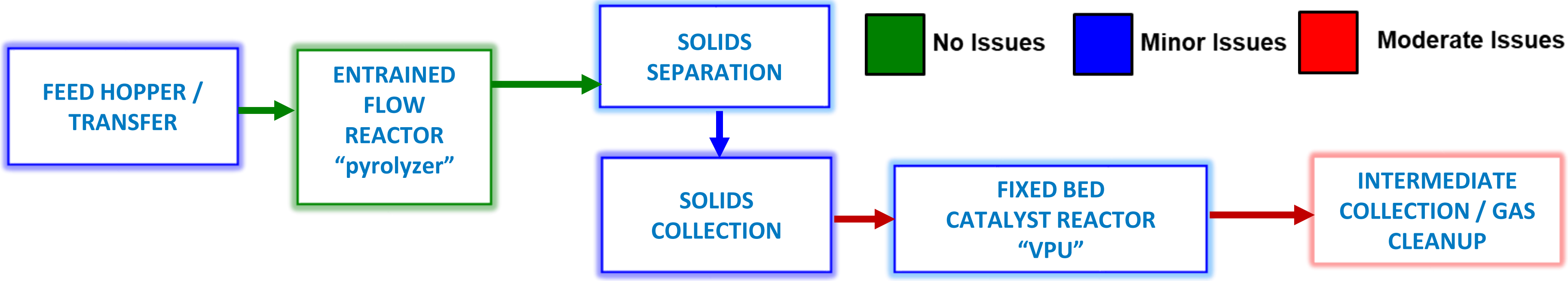
Various thermochemical technologies

- Pyrolysis
- Catalytic fast pyrolysis
- Gasification

Utilized to meet BETO verification targets

- Mixed alcohols (2012)
- Fast pyrolysis + hydrotreating (2017)
- Catalytic fast pyrolysis (2022)

2 – Technical Approach: Ex-Situ Catalytic Fast Pyrolysis



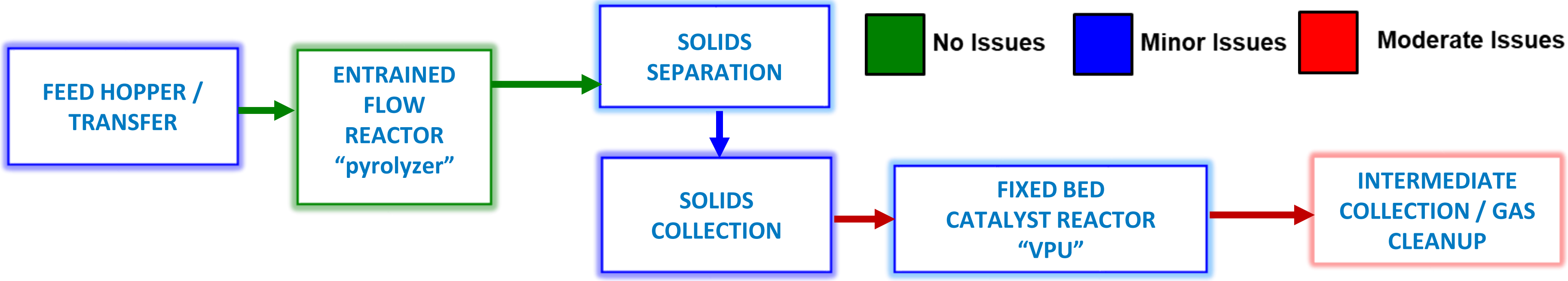
Critical Success Factor	Challenge	Strategy
Meets design specifications and requirements for biomass conversion and upgrading	Large-scale PDU operation are slow to adapt to rapid changes implemented at bench scale.	Technology to be ‘frozen’ by ChemCatBio and FCIC in FY20-Q1. Allowing us two years to install equipment, commission, and conduct preliminary experiments.

days

vs

months

2 – Technical Approach: Ex-Situ Catalytic Fast Pyrolysis



Critical Success Factor	Challenge	Strategy
Meets design specifications and requirements for biomass conversion and upgrading	Large-scale PDU operation are slow to adapt to rapid changes implemented at bench scale.	Technology to be 'frozen' by ChemCatBio and FCIC in FY20-Q1. Allowing us two years to install equipment, commission, and conduct preliminary experiments.
Maintaining consistency with bench-scale state-of-technology	Scaling of technology usually leads to loss in performance	• Working closely with ChemCatBio/FCIC to ensure consistency in materials sourcing and operational conditions • Developing scaling relations (CCPC) for both pyrolysis and VPU steps to understand loss expectations and mitigation strategies.

2 – Approach (Management)

PI:
Robichaud

PM:
Smith

Dedicated operators

Safety

Qualified/certified

- Electrical/chemical
- Rigging and hoisting
- First aid

Hazardous response team

Management of change

- Every change = hazard analysis
- Periodic systems PHA/RV
- Regular review of procedures and P&IDs

Dedicated POC for safety

Operations

- Analytical
- Feedstock/catalyst logistics
- Equipment calibration/recertification
- Product storage

Engineers:

- Control
- Mechanical
- Chemical

POCs building engineer/facilities

2 – Approach (Management)

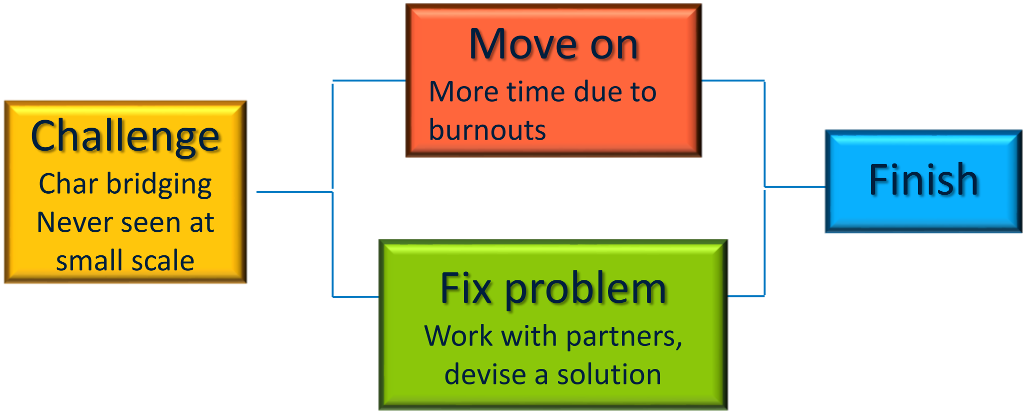
Active project management:

- Interaction and coordination across multiple R&D projects (e.g. consortia), other national labs, building coordinators, safety
- Constant communication
- Logistics of material and technology transfers defined in advance and checked often.

Example: FY2017 verification

Role: provide 100 gallons bio-oil

Pre-verification run



This management approach allowed us to successfully deliver ahead of schedule

SCRUM – Agile method

- Allows team to focus on the task at hand while leaving longer-term concerns to leadership

Task structure:

1. General maintenance
2. Installation and commissioning
3. Generating experimental data

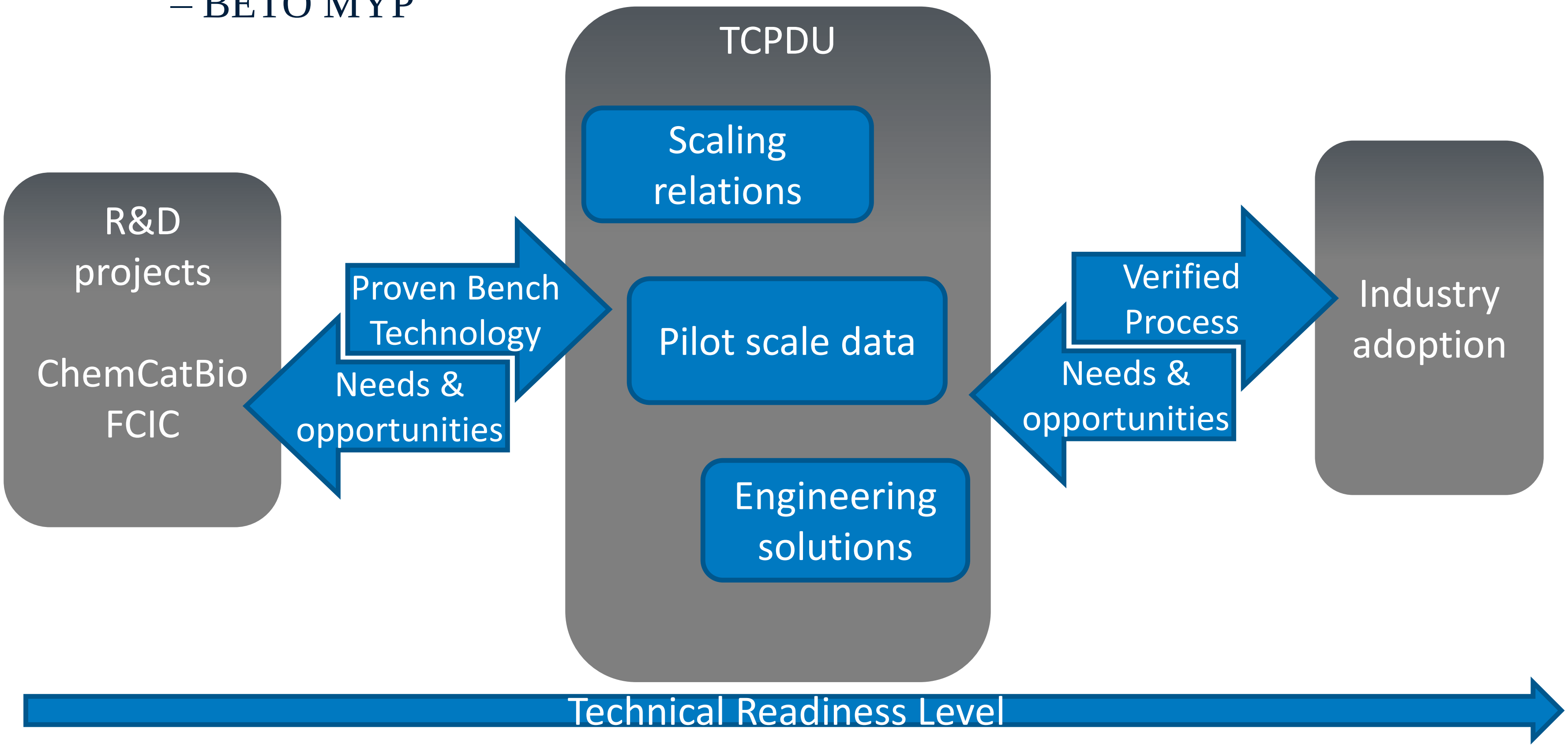
Milestones are used to:

1. Monitor progress in installation/commissioning of unit operations
2. Denote progress toward interproject objectives (modeling, catalyst, feedstock).

4 – Relevance (BETO)

The strategic goal of Advanced Development and Optimization (ADO) program area is to *develop and de-risk bioenergy production technologies through* ***verified proof of performance in engineering-scale systems*** *and relevant environments and identify innovative end uses.*

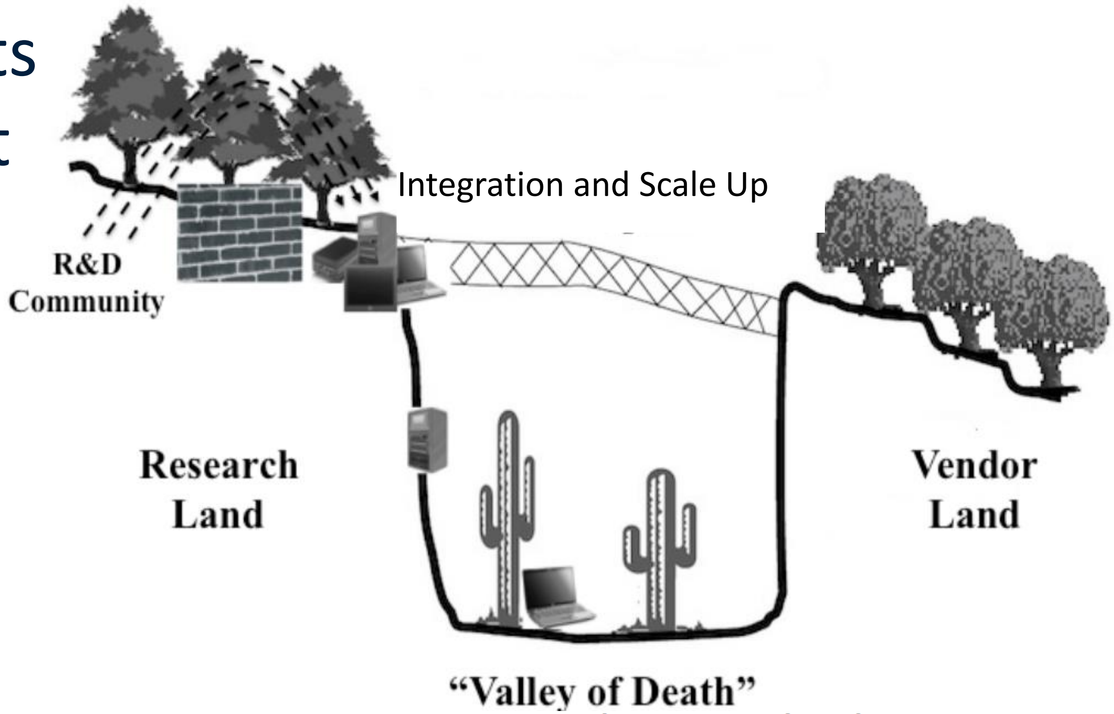
– BETO MYP



The Integration and Scale-Up Project, via the TCPDU, is a key vehicle for this proof of performance.

4 – Relevance (BETO) – Bridging the "Valley of Death"

- Connects R&D projects with industry-relevant scales
  - Integration of technologies
  - Verifications



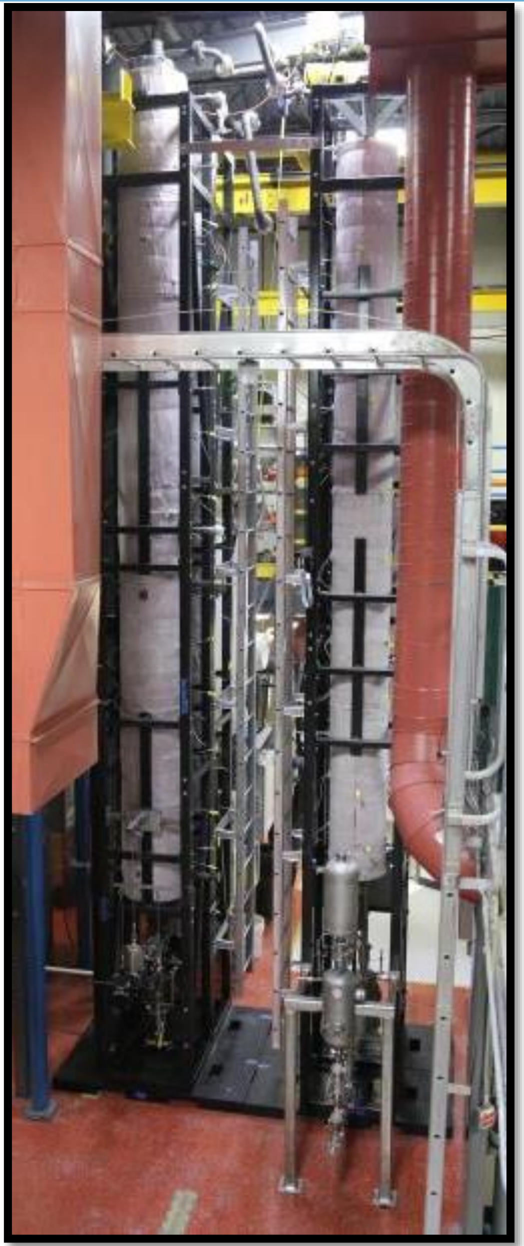
IEEE Security & Privacy Magazine, Vol. 11, No. 2, March-April 2013, pp. 14-23

- Scaling relationships
  - Critical attributes
    - Provided back to FCIC/ChemCatBio
  - Connection with modeling (CCPC)
    - Intersection of empirical relation and modeling
    - First principles foundation scaling relationship that are applicable beyond the systems at NREL

4 – Relevance (industry)

- Pilot plants are expensive to build, maintain, and operate
- Provides industry with access to a variety well-instrumented research reactors
- Industrial partners can connect equipment to test proprietary technologies.
  - Insert skid-mounted operations
- Leverage our knowledge of biomass technologies (critical materials attributes)

- Examples:
  - Coprocessing petroleum/CFP oils in R-cubed riser system
  - Evaluation of waste-to-energy feedstocks (i.e. plastics, nut shells/hulls waste, or poultry litter)

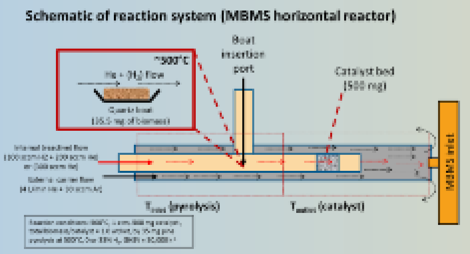


5 – Future Work: FY2022 Verification

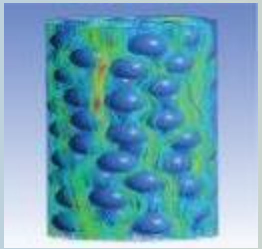
Using inputs from ChemCatBio, Feedstock Conversion and Interface Consortium, Consortium for Computational Physics & Chemistry modify the TCPDU to collect pilot-scale verification data on catalytic fast pyrolysis

FY2019

Bench-scale selection of catalysts and feedstocks for verification (technology frozen)

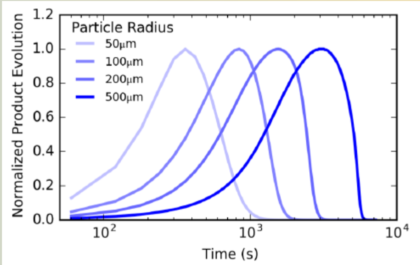


CFD model development of TCPDU packed bed reactor and catalyst kinetics



FY2020

Begin parameter sweeps using catalyst kinetic model to inform TCPDU runs



Commissioning of TCPDU packed bed reactor and bulk H_2 to meet catalyst requirements

FY2021

Produce sufficient quantity of catalyst

Engineering of Catalyst Scale Up

Preliminary verification run using feedstock (FCIC), catalyst (ChemCatBio), and operating conditions (CCPC)

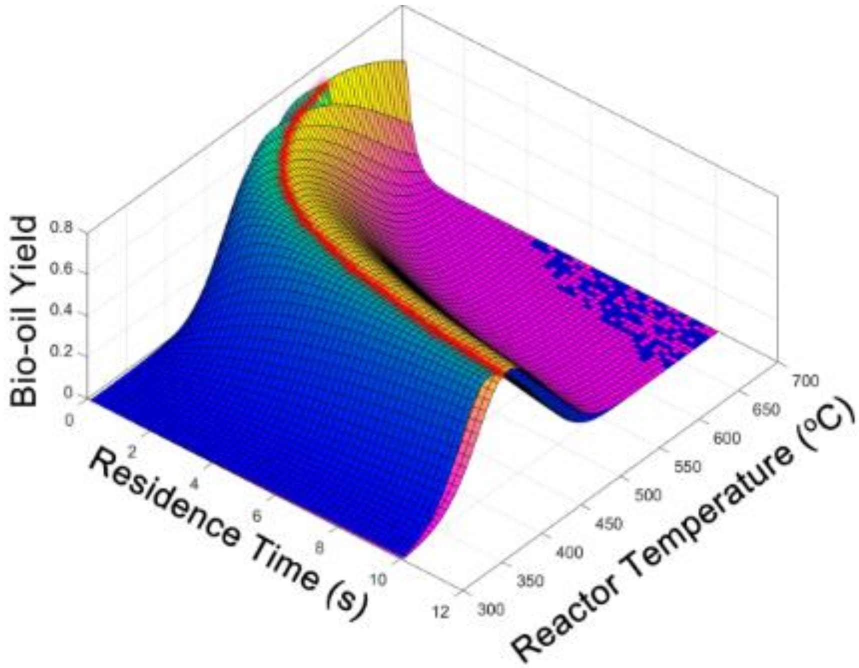
FY2022

Verification!

5 – Future Work: Pyrolysis Vapor Consistency Across Scales

Matching pyrolysis vapor quality across scales is critical for downstream catalyst performance

- Same feedstock
  - Sourced from INL, delivered in FY20
- large differences in operations
  - reactor type, flow conditions, preparation (particle sizes)
- Past efforts focused on empirical-based relations
- Incorporating a first-principles foundation (CCPC)
- Integration and Scale Up role:
  - ID Critical material attributes (FCIC)
  - Validation of models at pilot scale



Semi-empirical scaling relation between TCPDU pyrolyzer and bench-scale 2FBR pyrolyzer on clean pine in 2017.

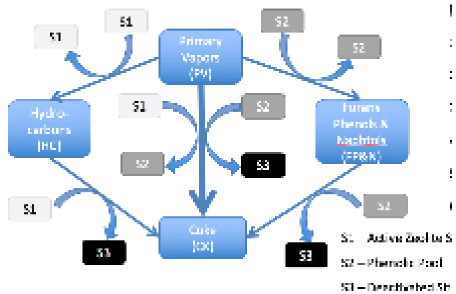
A first-principles relation based on critical material attributes makes scaling relations applicable beyond NREL reactors.

Collaborating partners

5- Future Work: New Capability to Facilitate Catalyst Scale-Up

Strip out the hydrodynamics from the chemistry

Catalyst Chemistry

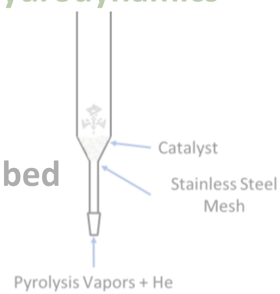


New, performance-advantaged catalysts

Time-resolved "kinetic" data

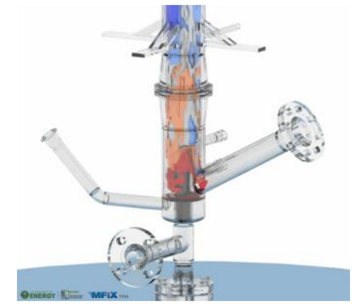
Hydrodynamics

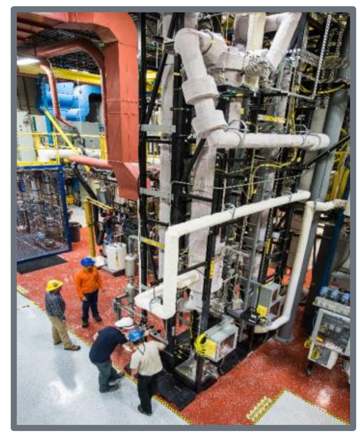
Spouted bed reactor (grams)



Combine chemistry with new reactor/particle physics

New reactor/particle model





R-cubed riser(0.5 tons)

Verify kinetic model is applicable across multiple, relevant scales

This new capability enables the construction of scaling relations to link bench-pilot-industry.

Collaborating partners

5 – Future Work: Capability Expansion and Installations

Verification catalyst (Pt/TiO_2)		
Hydrogen	**Attrition**	**Alkali**
• Bulk H_2 gas pad ○ 85% H_2 (~1 atm) ○ ~200 slm • Logistics (~ 2 years) ○ Safety (PHA/RV) ○ Building codes ○ Building engineers ○ Control systems • Contingency ○ Tube trailer/hot cylinder swaps	• Packed bed reactor ○ 1 on (upgrading), 2 off (regen) setup • 1 year ○ Install/Comm. ○ PHA/RV ○ Control ○ Analytical • Fully modeled by CCPC ○ Parametric sweeps of operating conditions ○ Minimize scaling-loss	• Hot Gas Filter ○ Design based on DCR system • 3 months ○ Install ○ Commission ○ PHA/RV ○ Control systems ○ Analytical

5 – Future Work: Go – No Go

Description	Measurable Success Criteria	Decision Point
Evaluate the performance of the verification catalyst synthesized using large-scale methods	Confirm ability to produce sufficient catalyst for verification	**GO** Finish design and installation of equipment for verification
	Bench-scale assessment engineering-scale catalyst performance is consistent with SOT	**NO GO** Re-evaluate catalyst/ reactor design or Complete redesign/build of fixed bed system
	Assessment of TCPDU modifications to meet consistency with bench SOT	

Summary

Approach

- Dedicated team provides smooth safety and operational oversight of pilot facility
- Active management style ensures successful completion of DOE objectives

Relevance

- Primary component of DOE’s verification of technology objective
- Research into scaling relations provide bridge for the ‘valley of death’ for R&D projects
- Industry access to pilot facilities

Future work

- Installation and commissioning of new capabilities to meet the 2022 verification
- Developing scaling relations for pyrolysis and vapor phase upgrading at are generally applicable
- Go/No Go decision point to make sure catalyst can be produced at scale and consistent with lab-synthesized materials

Acknowledgements

Thermochemical Process R&D Section:

- Kristin Smith
- Tim Dunning
- Katie Gaston
- Chris Golubieski
- Ray Hansen
- Matt Oliver
- Marc Pomeroy
- Daniel Carpenter
- Rebecca Jackson

- Many collaborators

DOE BioEnergy Technology Office

Thank You!

www.nrel.gov

NATIONAL RENEWABLE ENERGY LABORATORY

Response to 2017 Reviewer comments

Reviewer Comments	Response
General positive impressions & comments	***The positive feedback is appreciated. We have continued practicing the highlighted approaches*** including: (1) continuing to employ and adapt project management approaches, (2) maintaining a common and flexible pilot plant with an experienced crew, and (3) developing and deploying innovative solutions.
Entrained flow vs fluid bed	We have taken into consideration the concern regarding fluid bed versus entrained flow reactors and the consistency thereof. Based on experimental results, the TCPDU entrained flow reactor performs comparably to the bench-scale systems (e.g. yields). Furthermore, we have an ongoing effort with the Consortium for Computational Physics and Chemistry to model both systems that can shed more light onto the differences of the two systems and what we can do to minimize those issues. From a research perspective, the entrained flow reactor offers advantages that the fluid beds cannot. Such as, independent control of the residence times. Finally, we continue to monitor the needs of potential industry collaborators. As the TCPDU is designed to be a flexible facility, we are willing to install a fluid bed system if it is deemed to meet our obligations to either BETO or potential industry partners assuming capital funds are provided for the effort.
Increased industry engagement	We have initiated a directed effort based on Energy I-corps to facilitate reaching out to industry, gaining an understanding of the challenges they face, and aligning our R&D and capabilities to meet their needs. This effort is ongoing and engagement is a primary effort going forward.

Three comment areas and associated responses on highlighted on this slide. Other comments and our responses can be found in the 2017 Project Peer Review of the U.S. Department of Energy Bioenergy Technologies Office final report available at www.energy.gov/eere/bioenergy/downloads/2017-project-peer-review-report (pp. 279)

Risk Registry Table - 1

	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		Processed feed bridging in hopper	Med	Pelletization. FCIC working to determine critical material attributes. 100’s of kg material run prior to FY22 verification		Active
Conversion						
2		EFR performs differently than bench FBR	Low	Build scaling relationships and operational maps linking bench and pilot unit outputs	9/31/19	Active
Solids separation						
3		Hot gas filter cannot be modified to fit in TCPDU	Med	Learnings from previous TCPDU runs as well as bench-scale systems will inform modification and install.	12/31/19	Active
4		Char solids bridge in cyclones or collection	Med	FCIC working to determine critical material attributes. 100’s of kg material run prior to FY22 verification		

Risk Registry Table -2

	Risk Identified			Mitigation Strategy		Current Status
Risk ID	**Process Step**	**Risk Description**	**Severity (High/ Med/ Low)**	**Mitigation Response**	**Planned Action Date**	**Active/ Closed**
Vapor Phase Upgrading – Fixed Bed Unit						
5		Kinetic models for catalytic reactions cannot be achieved	High	Bench-scale experiments and kinetic/de-activation models verified prior to pilot-scale designs. Kinetic/de-activation model for zeolite catalysts in a riser reactor to demonstrate the method.	9/30/20	Active
6		Fixed bed catalyst cannot be sourced	Low	Utilize Engineering of Catalyst Scale-up task to produce catalyst on site. Alternatively, leverage existing JM CRADA.		
7		Pilot-scale catalyst performs differently than bench-scale catalyst	Med	Build scaling relationships and operational maps linking bench and pilot unit outputs using analysis as well as hydrotreating performance.		

Risk Registry Table - 3

	Risk Identified			Mitigation Strategy		Current Status
Risk ID	**Process Step**	**Risk Description**	**Severity (High/ Med/ Low)**	**Mitigation Response**	**Planned Action Date**	**Active/ Closed**
General						
8		Bulk H2 cannot be permanently installed to TCPDU	Med	Plans for install began in 2016. Temporary bulk H2 plan could be implemented in 2022 for verification	5/30/19	Active
9		Inconsistent Data Management	Med	The TCPDU team and CCPC/FCIC have an established relationship and record of collaborations and data sharing.	12/31/18	Closed